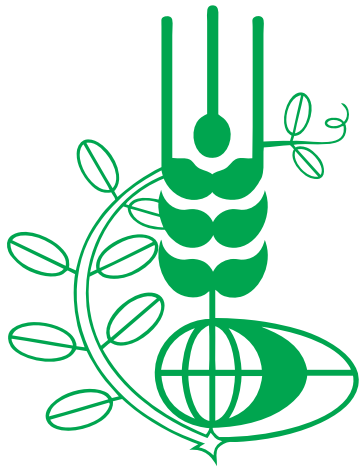
Meeting the Challenge of Yellow Rust in Cereal Crops

Proceedings of the 2nd, 3rd and 4th Regional Conferences on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region

Scientific editors
Amor Yahyaoui and Sanjaya Rajaram



ICARDA
International Center for Agricultural Research in the Dry Areas

Feedback:

ICARDA welcomes comment and feedback on this publication.
See Web site and e-mail below.

ISBN: 92-9127-273-6

Key words: yellow rust; leaf rust; stem rust; wheat; Central Asia; West Asia; North Africa;

International Center for Agricultural Research in the Dry Areas (ICARDA)
P.O. Box 5466, Aleppo, Syria.

Tel: (963-21) 2213433

Fax: (963-21) 2213490

E-mail: ICARDA@cgiar.org

Web site: www.icarda.org

Foreword

Wheat is grown on roughly 230 million hectare worldwide, with 650 million tonne of grain produced each year. It is the main food staple in many countries, particularly in Central Asia, West Asia and North Africa (the CWANA region), which has the world's highest per capita wheat consumption. Wheat is grown on 50 million hectare across CWANA, but average productivity in the region is only 1.5 t/ha, half the global average.

Wheat has its origin in West Asia, most likely in the Fertile Crescent, where productivity can be very high. However, the region also suffers from heavy periodic incidence of diseases and insect pests that cause heavy crop losses. The most important wheat diseases in CWANA are rusts, mildew, foliar blights and bunts. Among the rusts, yellow (stripe) rust is the most serious in CWANA, and perhaps globally. The world's wheat supplies are under threat from fast-mutating new strains of stripe [yellow] rust. The new strains (pathotypes) attack hitherto resistant varieties. They are also spreading to new areas as they have adapted to higher temperatures.

Millions of tonnes of wheat have been lost due to pandemics of stripe rust across CWANA countries. In the 2009–10 season, an epidemic of stripe rust swept across West and Central Asia. Syria lost nearly half of its wheat harvest in 2010. The growing threat to food security, affecting countries in CWANA that are already partially dependent on food imports, is being met with new research initiatives, led by international agencies such as ICARDA, CIMMYT and FAO in collaboration with National Agricultural Research Systems (NARS).

The first steps in combating stripe rust will be to document the geographical extent and scale of losses; share research findings and breeding material; and develop regional, multi-country, multi-institution partnerships for disease surveillance, monitoring and control.

In the last 10 years, ICARDA and its partner NARS have organized 4 international stripe rust conferences, held in Iran, Pakistan, Uzbekistan and Turkey. Hundreds of stripe rust scientists presented their findings, and shared ideas and experiences to help develop effective, broad-based strategies to reduce disease losses, predict future outbreaks, and restrict the spread of new stripe rust pathotypes. This publication summarizes the findings of the last three conferences. It includes scientific papers and abstracts covering various aspects of stripe rust monitoring, management, resistance breeding, chemical control and epidemiology.

These publications present a comprehensive view of stripe rust management and control. They are expected to be of value to rust researchers, as well as agricultural development planners, policy-makers and farmers in CWANA countries and perhaps globally.

Mahmoud Solh
Director General, ICARDA

Preface

The Central and West Asia and North Africa (CWANA) countries grow wheat on over 50 million hectare that are constantly at high risk of yellow rust attack. Several countries rely primarily on wheat production for their food security and livelihood. Together, these account for over 30% of the global wheat production area. Wheat is the staple food crop, providing on average some 40% of per capita calories, and is an important commodity in the diets of the people of the CWANA. The epidemic of the late 1980s resulted in cost of several millions in terms of crop loss and fungicide costs. Another epidemic occurred in CWANA in the 1990s. The most recent epidemic, in 2009/10, was mostly associated with the breakdown of resistance of the *Yr27* gene and has had devastating effects on wheat production in CWANA. The breakdown of *Yr27* was reported in 2004 by several authors in these proceedings and other publications.

A regional yellow rust conference for Central Asia and North Africa (YRC) was launched by ICARDA and SPII, Iran, in 2001. That [First] Regional Yellow Rust Conference for Central and West Asia and North Africa was held at Karaj, Iran, from 8 to 14 May 2001. The objective of the YRC was to focus on regional issues associated with yellow rust, to exchange scientific information and to plan collaborative activities. The researchers welcomed the organization of such a targeted conference and agreed to hold one every 3 years within the CWANA region. The proceeding of the first YRC was published under the title: *Meeting the Challenge of Yellow Rust in Cereal Crops.* The proceeding of the following three conferences—held in Pakistan, Uzbekistan and Turkey—are assembled here based on the information provided by conference participants.

Yellow Rust continues to be the most widespread and important bread wheat disease in CWANA countries. The known resistance genes are becoming ineffective against new, evolving races that are rapidly spreading across the region. Despite the commitment and ongoing breeding programmes to achieve resistance to yellow rust, severe epidemics with substantial losses have been reported in Australia, China, India and USA in the last decade.

The commercially grown wheat varieties are highly susceptible to new pathotypes of yellow rust. Detection of pathogen variation using a series of host differentials has been valuable in providing important insights into the evolution of pathotypes in response to selection pressure imposed by the host resistance genes. Breeding for resistance, and the parallel requirement to monitor pathogen populations, will continue to form the long-term strategy for yellow rust control.

The long-term solutions to yellow rust epidemics in CWANA, and perhaps globally, reside in concerted strategies and sustained funding of integrated projects on: (1) surveillance and rapid response; (2) crop breeding based on durable resistance and gene diversity; (3) scaling-up of resistant varieties and dynamic seed production programmes; (4) sharing of information, such as through these proceedings; and (5) capacity building.

Dr Amor Yahyaoui **Dr Sanjaya Rajaram**

Joint Scientific Editors

About this publication

This volume contains the Proceedings of three regional conferences addressing rust diseases, principally yellow [stripe] rust of wheat, but also addressing leaf and stem rusts of wheat and rusts on barley. The geographical focus is the swathe of countries stretching from India in the east, across Central and West Asia, the Caucasus, the Horn of Africa and North Africa to Morocco in the west.

The three conferences are:

Second Regional Conference on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region, held in Islamabad, Pakistan, 22–26 March 2004. See pages 1–144.

Third Regional Conference on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region, held in Tashkent, Uzbekistan, 8–11 June 2006. See pages 145–238.

Fourth Regional Yellow Rust Conference for the Central and West Asia and North Africa (CWANA) Region, held in Antalya, Turkey, 10–12 October 2009. See pages 239–412.

Acknowledgments

The Second Regional Yellow Rust conference for the CWANA region was jointly organized by Pakistan Agricultural Research Council (PARC), ICARDA and CIMMYT. Major funding for this conference was provided by DANIDA (Denmark) and ACIAR (Australia), with important contributions from ICARDA, CIMMYT and the Government of Pakistan. We thank the organizers, and the Institutions who provided needed funding to bring more than 100 scientists from 12 countries to attend this conference in Islamabad (16–22 March 2004). Appreciation goes to colleagues who helped edit papers of this conference, particularly Dr Ahmad Iftikhar and Dr Anjum Munir from NARC (Pakistan), Dr Habib Ketata from ICARDA and Dr Mogens Hovemoller from DIAS (Denmark).

The Third RYC was organized by the Uzbek-Ministry of Agriculture, ICARDA and CIMMYT, with great assistance from PFU. The conference was sponsored by Arab Fund (AFSED) and ACIAR (Australia), with important contributions from ICARDA and CIMMYT. The Conference was organized a year earlier than originally planned in response to the threat from Ug99 and the establishment of BGRI. The conference was held in Tashkent (Uzbekistan) from 8 to 11 June 2006, and was attended by over 70 participants from 17 countries.

The Fourth RYC was held in Antalya (Turkey) from 10 to 12 October 2009, organized jointly by the Turkish Ministry of Agriculture and Rural Affairs (MARA); the International Center for Agricultural Research in the Dry Areas (ICARDA); the International Maize and Wheat Improvement Center (CIMMYT); and the Food and Agriculture Organization of the United Nations (FAO). Over 100 participants from 25 countries attended. The conference was sponsored by FAO, with contributions from ICARDA, CIMMYT and MARA. The work done by Professor Brahim Ezzahiri, IAV, Morocco, in editing the abstracts and many papers submitted to this conference is greatly appreciated.

Great appreciation is extended to all those who served in the local, regional and international organizing committees. Their support, contribution and advice on the conference programmes was positive and very helpful

The scientific editors thank all those who made an effort and sent their full papers. Great appreciation goes to the International and Local Organizing Committees and the hosting countries of the three conferences, as well as to ICARDA and CIMMYT management for their support and encouragement.

Particular thanks go to Thor Lawrence for collating and conforming the proceedings linguistically, and preparing the texts for publication.

Amor Yahyaoui and Sanjaya Rajaram

2nd Regional Yellow Rust Conference
Islamabad, Pakistan, 22–26 March 2004

Local Organizing Committee	International Organizing Committee
Dr Iftikhar Ahmad, Director, NARC (Chair)	Dr Badar ud Din Soomro, Chair, PARC (Chair)
Dr Nafees S. Kissana	Dr Naeem I. Hashmi
Dr Ghulam Mohammad	Dr Richard Cross, GP-Director, ICARDA
Dr Mohammad Aqilhan	Dr Habib Ketata, ICARDA, Islamic Republic of Iran
Mr Shamadad Khanzada	Dr Abdul Majeed, ICARDA, Pakistan
Dr Anjum Munir	Dr Mogen Hovmoller, DIAS, Denmark

Dr Amor Yahyaoui, GP-ICARDA (Conference Scientific Secretary)

3rd Regional Yellow Rust Conference
Tashkent, Uzbekistan, 8–11 June 2006

Organizing Committee

Dr Sanjaya Rajaram, Director, ICARDA/CIMMYT Wheat Improvement Program (Chair)

Dr D. Amir Amanov, Advisor, President Aparat, Uzbekistan (Co-Chair)

Dr Raj Paroda, PFU & ICARDA Regional Representative

Dr Hans Braun, Director, CIMMYT Wheat Program

Dr Alex Morgounov, CIMMYT Turkey

Dr Mohammad R.J. Kamali, SPII, Islamic Republic of Iran

Dr Ahmad Iftikhar, PARC, Pakistan

Dr Mogens Hovmoller, DIAS, Denmark

Dr Colin Wellings, Plant Breeding Institute (PBI), Sydney, Australia

Dr Amor Yahyaoui, IPM Coordinator, ICARDA
(Conference Scientific Secretary)

4th Regional Yellow Rust Conference
Antalya, Turkey 10–12 October 2010

Local Organizing Committee

Dr Masum Burak. DG, TAGEM (Chair)

Dr Mesut Keser, ICARDA Turkey (Co-Chair)

Dr Akin, Beyhan, CIMMYT Turkey

Prof. Mahinur Akkaya, METU

Dr Vehbi Eser, Field Crops Department

Mr Zafer Mert, CRIFC

Dr Necmettin Bolat, Anatolian ARI, Eskisehir, Turkey

Dr Emin Donmez, CRIFC

Mr Mehmet Emin Sahin, Plant Protection

International Organizing Committee

Dr Maarten van Ginkel, ADG-R, ICARDA (Chair)

Dr Masum Burak, TAGEM (Co-Chair)

Dr Alex Morgounov, IWWIP, CIMMYT Turkey

Dr Kumarse Nazari, BIGM, ICARDA

Dr Mogen Hovmøller, GRC-ÅRHUS, Denmark

Dr Martius, Christopher, PFU, Tashkent, Uzbekistan

Dr Colin Wellings, Plant Breeding Institute (PBI), Sydney, Australia

Dr Ravi Singh, CIMMYT Mexico;

Dr Wafa Khoury, AGPP, FAO, Italy;

Dr Hafiz Mumidjanov, Tajik State Univ., Tajikistan

Dr Amor Yahyaoui, ICWIP (Conference Scientific Secretary)

Meeting the Challenge of Yellow Rust in Cereal Crops

Proceedings of the Second Regional Conference on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region

Islamabad, Pakistan
22–26 March 2004

Jointly organized by
PARC (Pakistan Agricultural Research Council)

and

ICARDA (International Center for Agricultural Research in the Dry Areas)

Contents

Abstracts

List of Participants

Azerbaijan

Dr Ehtibar Ibrahimov, Plant Protection and Immunity Laboratory, Research Institute of Crop Husbandry

Denmark

Dr Mogens S. Hovmøller, Department of Plant Protection, Danish Institute of Agricultural Sciences, Slagelse

ICARDA

Dr S. Rajaram, BIGM, Aleppo, ICARDA

Dr Richard Cross, Germplasm Program, ICARDA

Dr Osman Abdalla, Germplasm Program, ICARDA

Dr Mousa Mosaad, Coordinator ICARDA/Turkey activities,

Dr Amor Yahyaoui, Germplasm Programme, ICARDA

Mr Munzer Naimi, Germplasm Programme, ICARDA

Islamic Republic of Iran

Dr Reza Haghparast, Dryland Agricultural Research Institute, Kermanshah

Dr Mohammed Torabi, Seed and Plant Improvement Institute (SPII), Karaj

Dr Farzad Afshari, Seed and Plant Improvement Institute (SPII), Karaj

Dr Ali Malihipour, Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute (SPII), Karaj

Kazakhstan

Dr Alex Morgounov, International Maize and Wheat Improvement Center (CIMMYT), Almaty

Kyrgyzstan

Dr Jamin Akimaliev, Kyrgyz Agricultural Research Institute, Bishkek

Dr Mira Djunusova, Kyrgyz Agricultural Research Institute, Bishkek

Mexico

Dr Garry Rosewarne, International Maize and Wheat Improvement Center (CIMMYT)

Nepal

Dr Etienne Duveiller, CIMMYT (International Maize and Wheat Improvement Center), South Asia Regional Office, Kathmandu

Dr C.B. Karki, Pathology Division, Nepal Agricultural Research Council, Lalitpur

Pakistan

Dr Badaruddin Soomro, PARC, Islamabad

Dr Naeem Iqbal Hashmi, Crop Sciences, Pakistan Agricultural Research Council

Dr Mohammad Ashraf, National Agricultural Research Centre, Islamabad

Dr Iftikhar Ahmad, National Agricultural Research Centre, Islamabad

Dr Abdul Majid, ICARDA Pakistan, Rawalpindi,

Dr Anjum Munir, Crop Diseases Research Programme, National Agricultural Research Centre, Islamabad

Mr Altaf Hussain Tariq, Agricultural Research Institute, Bahawalpur

Dr Muhammad Aqil Khan, Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad

Mr Attaudin, Directorate of Agricultural Research (FATA), ARI, Peshawar

Dr Nazar Muhammad Cheema, Barani Agricultural Research Institute, Chakwal

Mr Manzoor Hussain, Regional Agricultural Research Institute, Bahawalpur

Mr Muhammad Riaz Khalil, Agricultural Research Institute, D.I. Khan

Mr Shafi Mohammad Khatti, Wheat Research Institute, Sakrnad

Mr M.A.S Kirmani, Consultant Agriculture, Universal Agro-Chemicals, Karachi

Dr Mumtaz Hussain, Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad

Mr S.H. Nankani, Wheat Research Institute, Sakrand

Dr Ghulam Mahboob Subhani, Maize and Millet Research Institute, Sahiwal

Dr Akram Khan, Dera Zia Khan, Manawala, Distt, Sheikhupura

Syed Nadeem Afzal, Punjab Govt Service, Agriculture Department, Lahore

Mr Munawar Hussain, Ex. PSO/CRSP

Dr Abid Mahmood, Barani Agricultural Research Institute, Chakwal

Mr Amir Afzal, Wheat Research Substation, Murree

Mr Ghulam Hussain, Regional Agricultural Research Institute, Bahawalpur

Dr Muhammad Arshad Gill, Regional Agricultural Research Institute, Bahawalpur

Mr Azhar Rashid, Nuclear Institute of Agricultural PAEC, Tando Jam

Mr Munawar Raza Kazmi, National IPM Programme, NARC, Islamabad

Mr Roshan Zada, National IPM Programme, NARC, Islamabad

Mr Jam Muhammad Khalid, IPM Facilitator, National IPM Programme, NARC, Islamabad

Mr Ali Raza Jamali, Fodder IFHC, NARC

Mr Ehsanul Haque, CDRP, Murree

Mr Ali Asghar Kiani, University of Arid Agriculture, Rawalpindi

Dr Shahid Khan, University of Arid Agriculture, Rawalpindi

Muhammad Usman Raja, University of Arid Agriculture, Rawalpindi

Mr Faisal Masood, UAAR, Islamabad

Dr Muhammad Munir, Dept of PBG, University of Arid Agricultural Rawalpindi

Mr Muhammad Shuaib, University of Arid Agricultural, Rawalpindi

Mr Muhammad Naveed Aslam, UAAR

Dr Irfan Ul Haque, University of Arid Agriculture Dept of Plant pathology, Rawalpindi

Dr Farhat Fatima Jameel, Pakistan Phytopathological Society, Nuclear Institute of Agricultural Biology, Faisalabad

Professor Dr Sultan Mahmood Khan, Pakistan Phytopathological Society, Department of Plant Pathology, University of Agriculture, Faisalabad

Ch. Bashir Ahmad, Barani Agricultural Training Institute, Dahgal

Mr Shamadad Khanzada, PAEC, NIA, Tando Jam

Dr Aly Khan, Crop Diseases Research Institute (CDRI), PARC, University of Karachi, Karachi

Dr Imtiaz Hussain, Institute of Field and Horticultural Crops, NARC, Islamabad

Mr Syed Zahid Mustafa, NARC Wheat Programme, Islamabad

Dr Muhammad Yaqub Mujahid, NARC/PARC Wheat Programme

Mr Muhammad Qasim, Summer Wheat Nursery, Kaghan

Mr Ahmad Ali Hakro, CDRI, PARC, Karachi

Dr Abdul Aziz Khakwani, Research Wing NWFP Agricultural University, Peshawar

Mr Nazir Ahmad, Cereal Crops Research Institute, Pirsabak Nowshera (NWFP)

Dr Tila Mohammad, Nuclear Institute for Food and Agric (NIFA), Peshawar

Mr Ghulam Hussain Ujjan, Wheat Research Institute Sindh, Sakrand District, Nawab Shah

Mr Muhammad Rafiq, Regional Agricultural Research Institute, Bahawalpur

Mr Mushtaq Ahamd Nadeem, Agronomic Research Institute, Ayub

Mr Javed Anwar, Wheat Research Institute, AARI, Faisalabad

Mr Shauque Subhani, Dept. of Agriculture, Azad Jammu Kashmir, Muzzaffrabad

Dr Naeem Ahmad, Wheat Research Institute AARI, Faisalabad

Mr Amanullah Khand, Wheat Research Institute Sakrand (Sindh)

Mr Muhammad Boota, Federal Seed Certification and Registration Department, Hyderabad

Muhammad Saleem Sheikh, Agriculture Research Institute, Sariab Quetta

Mr Malik Muhammad Iqbal, Agriculture Research Institute, Sariab, Quetta

Dr Karim Dino Jamli, Pakistan Atomic Energy Commission, Nuclear Institute of Agriculture (NIA), Tando Jam

Dr Muhammad Anwar, Grain Quality Testing Laboratory, GSRI PARC Karachi University Campus

Dr Nafee Sadiq Kisana, PARC/NARC Wheat programme, Islamabad

Dr Muhammad Jamal, Agricultural Research Station, Ahmadwala, Karak, NWFP

Mr Lal Khan Khokhar, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Dr Yasmin Ahmad, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Dr Mohammad Afzal Akhtar, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Dr Shamim Iftikhar, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mrs Khurshid Burney, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Dr Shahid Hameed, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Shahzzad Asad, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Hussain Shah, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Javed Iqbal Mirza, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Atiq ur Rehman Rattu, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Muhammad Zakria, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Amir Sultan, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Aziz ud Din, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Atif Jamal, CDRP, Murree

Dr Tahira Yasmin, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mrs Fauqia Fahmeed, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mrs Fauzia Sohail, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Faisal Sohail Fateh, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Ghulam Mustafa Sahi, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Mr Mohammad Fayyaz, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Tajikistan

Dr Brend Pett, GTZ/CIMMYT Project in Tajikistan, Tajik Research Institute of Farming, Sharora

Dr Hafiz Muminjanov, GTZ/CIMMYT Project in Tajikistan, Tajik Research Institute of Farming, Sharora

Turkey

Dr Arne Hede, Winter Wheat Programme, CIMMYT, Ankara

Dr Fazil Dusunceli, Central Research Institute for Field Crops, Ankara

Dr Lutfi Cetin, Central Research Institute for Field Crops, Ankara

Uzbekistan

Dr H.H. Kushiev, Gulistan State University of the Republic of Uzbekistan

Dr Bitore Djumakhanov, ICARDA, Tashkent

Yellow rust of wheat in Nepal: an overview

C.B. Karki,[1] S. Sharma[2] and E. Duveiller[3]

1. Plant Pathology Division, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal
2. Plant Pathology Division, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal
3. CIMMYT, South Asia, Kathmandu, Nepal

Introduction

Yellow rust caused by *Puccinia striiformis* West. f.sp. *tritici* Eriks. and Henn. has been known to occur since 1964 (Khadka and Shah, 1967), and is the most damaging wheat disease in Nepal, where wheat is sown on 650 000 ha, with an average yield of 2 t/ha. Most wheat is spring bread wheat, although facultative or winter types are grown in some high hill areas. Since modern genotypes were introduced, 26 cultivars have been recommended: 12 of them for the hills and the others for the *terai* (plains). This paper summarizes the yellow rust situation in Nepal and presents highlights on epidemiology, pathotype, grain yield loss and host resistance.

Distribution, incidence and severity

Yellow rust is uniformly distributed in the mid-hills belt. In annual surveys, it is principally observed on local varieties at 600–1500 masl, particularly in the central and far western hills. Improved wheat varieties, especially RR 21, started showing susceptibility in the central and eastern regions after the mid-1980s. Cv. Annapurna 1 showed susceptibility in Kabre and in Kathmandu valley during the same period (Karki and Sharma, 1990). Epidemics were observed in parts of western hills in the mid-1990s (Karki, 1998). Severity increased in river basin areas of the central region during the late 1990s, and greater yellow rust severity was recorded even in the mid-western inner terai (Dang) below 300 masl.

In resistance screening trials conducted in the field at disease hot-spot locations or in growth chambers, many improved varieties and advanced lines appear resistant, in contrast to local susceptible genotypes (Karki, 1980). In 1986–1988, infection was observed in improved wheat varieties such as RR 21, Annapurna 1, Annapurna 2, BL 1022, Lerma Rojo 64, Kalyansona and

Nepal 297 (Karki, 1989). Severity was high on RR 21 and moderate on Annapurna 1, but Annapurna 4, Kanti and Pasang Lhamu had no infection (Table 1). In 1998, many varieties showed greater severity compared with results obtained a decade earlier, and genotypes possessing the *Yr9* gene became susceptible. Varieties Nepal 297 and BL 1473 recommended for the terai and that were introduced in the hills, were now showing susceptible reactions in parts of Kathmandu valley.

Table 1. Yellow rust severity and reactions on some wheat cultivars at Kabre

Wheat cultivar	Yellow rust severity and reaction		
	1979/80	1987/88	1997/98
Annapurna 1	0	40MS-S	80S
Annapurna 2	0	5MR	40MR-MS
Annapurna 4	0	5MR	60MS-S
BL 1022	0	40MS	90S
BL 1473	–	0	0
Kalyansona	10MS	80S	70S
Kanti	0	0	80S
Lerma 52	5MR	20MS	30MS-S
Lerma Rojo 64	0	40MS-S	60MS-S
Nepal 297	0	10MS	30MS
NL 769	–	0	20MR-MS
NL 792	–	0	80S
NL 810	–	0	0
Pasang Lhamu	–	0	Tr-R
Pavon 76	0	50MS-S	40MR-MS
RR 21	0	70MS-S	80MS-S
WK 831	–	0	30MS-S

Epidemiology

High yield, bold amber grain and disease resistance made variety RR 21 very popular among farmers, who adopted it extensively, both in the terai and hills. It was even grown during the off-season (July–November) in some parts of eastern and central hills (Dolakha and Sindhupalchok), but due to a change in pathogen virulence, RR 21 became susceptible in the mid-1980s. Cool and humid weather, susceptible wheat varieties and viable inoculum are necessary for any epidemic to occur. Because of different cultivation practices, varying altitudes and diverse climates, fields growing wheat can be found all the year round. Thus, if a susceptible variety is grown, yellow rust inoculum is likely to remain available throughout the year. Yellow rust epidemics in the central or eastern hill zone during the 1980s might have resulted from early infection by

inoculum originating from infected off-season (June–November) wheat. Off-season wheat in the high hills, a potential green bridge for survival of yellow rust, presumably serves as source of inoculum to infect normal season (November–April/May) wheat in lower hills. Kabre in the eastern hills was found to have all favourable conditions for yellow rust epidemics in the mid-1980s and was identified as a hot-spot screening site.

The cause of yellow rust epidemics in western hills of Nepal is not well known. However, favourable weather and the occurrence of *Yr9* virulence combined with the extensive and continuing cultivation of susceptible cultivars BL 1022 and BL 1066 possessing *Yr9* may be among the major factors causing the epidemics in the 1990s in these areas. Similarly, cultivation of susceptible varieties RR 21 and BL 1022, inoculum originating from the high hills and favourable weather condition were probably causing the high yellow rust incidence in the mid-western inner-terai (Dang) in the late 1990s.

Grain yield loss

As yellow rust severity on improved commercial varieties increased, field experiments were conducted at Kabre to estimate grain yield losses. Spraying RR 21 with Bayleton (triadimefon) showed grain yield losses as high as 30% when yellow rust appeared at the flowering stage, and reached a severity of 80S (Upreti and Karki, 1999). At the same site, no grain was produced on susceptible wheat cv. Morocco when infection started before the booting stage. When infection appeared at the heading stage, 52% grain yield loss was recorded on cv. Morocco in the same year at Khumaltar. In the mid-hill region, farmers reported grain yield losses up to 50% on local wheat.

Gene postulation

Resistance gene postulation started in 1994 with support from the Directorate of Wheat Research (DWR) Regional Station, Shimla, in India. Using more than 200 wheat genotypes, including wild emmer derivatives, Karki (1994) detected only two resistance genes *Yr2* and *Yr9*. Annapurna 2, BL 1473, Lerma Rojo 64, Nepal 297 and RR 21 were known to possess *Yr2*, while Annapurna 1, Annapurna 4, BL 1022, Kanti, Pasang Lhamu and advanced lines BL 1530, BL 1655, BL 1794, BL 1804, NL 769, NL 781 [Attila], NL 792 and WK 810 were postulated to have *Yr9*. Results have been confirmed in other studies by Sharma *et al*. (1995), Mahato (1996) and Sharma (1997). Since most genotypes were selected and developed in Nepal from CIMMYT bread wheat materials, many of them have 1B/1R translocation, which is known to be associated with yellow rust resistance gene *Yr9*.

Pathotypes

Race analysis of yellow rust samples from Nepal started in 1979 with the help of IPO in Wageningen, and continued with support from DWR (Shimla) after 1993, following Johnson *et al*. (1972) in the Netherlands and Nagarajan *et al*. (1986) in India. As many as 16 pathotypes (0E0, 0E16, 2E0, 4E0, 6E0, 4E16, 7E0, 7E150, 7E158, 15E0, 15E150, 15E158, 66E18, 68E16, 70E0 and 70E16) were identified at IPO (Karki, 1980; Louwers, van Silfhout and Stubbs, 1992). In 1979/80, 4E16 was dominant; 7E150 frequency increased in 1986–1992. No pathotype could attack differential lines *Triticum spelta* var. *album* (*Yr5*), Clement or Riebesel (*Yr9*), and Moro (*Yr10*) until the mid-1990s. Pathotypes 46S103 (P), 47S102 (K) and 47S103 (T) were identified during 1993–1997 using the Indian differential sets (Nayar *et al.*, 1992; Karki, 1994, 1998; Mahato, 1996; Sharma, 1997). Pathotype 46S119 virulent against *Yr9* was detected among many samples during 1996–1998 (Sharma, 1997; Karki, 1998).

Virulence change and reactions on near-isogenic lines

After RR 21 became susceptible, infection was observed on Annapurna 1 (Veery #5) in Kabre and Kathmandu in the late 1980s. After 1997, Annapurna 1 and several other wheat cultivars possessing the *Yr9* gene showed susceptibility to yellow rust at many locations. Similarly, significant changes were observed in the western hills, where recommended cultivars Annapurna 4 and Kanti became severely infected, in addition to varieties BL 1022 and BL 1066 (Sharma, 1997; Karki, 1998). Limited studies showed that the virulence spectrum of yellow rust gradually increased over years. Only *Yr6* and *Yr8* were vulnerable in 1979/80, while resistance genes *Yr1, Yr2, Yr6, Yr7* and *Yr8* were infected in 1986/87. Yellow rust started attacking *Yr3* and *Yr4* in the early 1990s (Louwers, van Silfhout and Stubbs, 1992), and since 1997 cv. Riebesel, possessing *Yr9,* was found infected due to presence of pathotype 46S119 (Sharma, 1997).

Near-isogenic lines (NILs) developed in the cv. Avocet background in Australia were tested under field conditions in Nepal. Data from Lumle (western hills) during the 2001–2003 wheat seasons are presented in Table 2. Resistance genes *Yr5, Yr10* and *Yr15* that were not infected earlier showed mixed results, with some plants presenting susceptible reactions. Genes *Yr24, Yr26* and *YrSP* that were resistant are gradually becoming susceptible. All other genes were no longer effective in Lumle, and check varieties Annapurna 1, BL 1022 and RR 21 were susceptible. Severity and reaction increased in 2003 compared with 2001 and 2002.

Control

Efforts were made to develop resistant lines based on seedling reaction in a plastic house, and by screening at hot-spot locations or inducing epiphytotics in the field. Since lines with *Yr9* are no longer resistant to the prevailing pathotype 46S119, and gene *Yr2* frequently found in Nepalese cultivars is no longer effective, new sources of resistance are needed. Many wheat genotypes recently developed in CIMMYT are known to possess *Yr18,* which may be of a durable nature (Johnson, 1988; Singh, 1992). Since many wheat genotypes in Nepal have been selected from CIMMYT material, several lines are expected to possess *Yr18.*

Table 2. Yellow rust severity and reaction on near-isogenic lines and check varieties at Lumle during 2001–2003

Line or variety	Severity and reaction		
	2001	2002	2003
Yr1/6*Avocet (S)	0, 20MS	5MS-S	90S
Yr2/6*Avocet (S)	—	—	15MR
Yr5/6*Avocet (S)	0, 20MR-MS	0, 5R	20MS
Yr6/6*Avocet (S)	20MS-S	60S	60MS-S
Yr7/6*Avocet (S)	30MS	60S	70S
Yr8/6*Avocet (S)	0, 20MR	10MR-MS	100S
Yr9/6*Avocet (S)	0, 60MS	10MS, 80S	10MS
Yr10/6*Avocet (S)	0, 10MS	0, 40MS	0, 80S
Yr11/3*Avocet (S)	30MS	40S	60MS-S
Yr12/3*Avocet (S)	Tr-MR	30MS	30MS
Yr15/6*Avocet (S)	0	0, 20MS	80S
Yr17/6*Avocet (S)	5MS	30MS-S	70S
Yr18/3*Avocet (S)	0, 20MS	10MS	10MS
Yr24/3*Avocet (S)	0	10R	10MR
Yr26/3*Avocet (S)	0	5R	10MR
YrSP/6*Avocet (S)	0	0	5MS
YrSk/3*Avocet (S)	5MS	20S	100S
Avocet (R)	10MS	60S	90S
Annapurna 1	40MS	40MS-S	60MS-S
BL 1022	60MS-S	70S	80S
RR 21	30MS	40MS	60MS-S
Morocco	60S	60S	80S

Although 1 or 2 sprays of triadimefon (as Bayleton 25%) or oxycarboxin (as Plantvax-20) are effective using even low doses (275–500 g a.i./ha), the high cost and unavailability of fungicide make this option not possible for farmers. Early sowings (before November 15) escape yellow rust infection, but in many irrigated lands where wheat is grown after rice, sowing is delayed. Yellow rust is favoured by nitrogen. Application of phosphorus and potash, however, lessen the infection. Thus, using a recommended fertilizer dose helps control the rust. Lastly, since it provides rust inoculum to the normal season wheat in lower hills and valleys, cultivation of off-season wheat should be discouraged.

Conclusion

Yellow rust is a threat to wheat cultivation in Nepal, particularly in the mid-hills. Due to the topography, information on the distribution of rusts is lacking. Well equipped greenhouses are needed in Nepal to conduct seedling tests and allow timely production of inoculum for satisfactory field screening. Effective and durable resistance genes need to be incorporated. Regular survey and monitoring, detailed epidemiological studies and extensive pathotype analysis of rust samples need to be continued in close collaboration with scientists of neighbouring countries to sustain an effective management strategy.

Acknowledgements

Dr C.B. Karki is indebted to Mr R.P. Sapkota, Dr R.P. Sah and Dr S.P. Pandey (NARC) for nominating him to attend the conference, and to CIMMYT-Nepal for sponsoring the travel. The authors are grateful to Mr S. Pradhan, CIMMYT-Nepal, for his technical assistance.

References

Johnson, R. 1988. Durable resistance to yellow (stripe) rust in wheat and its implications in plant breeding. pp. 63–75, *in*: N.W. Simmonds and S. Rajaram (editors). *Breeding strategies for resistance to the rusts of wheat*. CIMMYT, Mexico.

Johnson, R., Stubbs, R.W., Fuchs, E., Chamberlaine, N.H. 1972. Nomenclature for physiological races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society*, 58: 475–480.

Karki, C.B. 1980. Evaluation of Nepalese wheat and barley varieties in the seedling stage on their resistance to yellow rust. Report submitted to the Research Institute for Plant Protection (IPO), Wageningen, the Netherlands. 21 p.

Karki, C.B. 1989. Wheat yellow rust and monitoring virulence of its pathogen, *Puccinia striiformis* f.sp. *tritici*, in Nepal. Regional Seminar on Microbial Research. Royal Nepal Academy of Science and Technology, Kathmandu.

Karki, C.B. 1994. Genetics of rust resistance of some Nepalese wheat and barely cultivars. A research study carried out at the DWR Regional Station, Flowerdale, Shimla, India. 41 p.

Karki, C.B. 1998. Wheat disease report 1997–98. Winter Crops Research Workshop, Siddhartha Nagar, (Bhairahawa) Nepal.

Karki, C.B. & Sharma, S. 1990. Wheat disease report 1989–90. pp. 189–206, *in:* Proceedings of the 13th National Winter Crops Seminar, NWRP, Siddhartha Nagar.

Khadka, B.B. & Shah, S.M. 1967. Preliminary list of plant diseases recorded in Nepal. *Nepal Journal of Agriculture,* 2: 47–56.

Louwers, J.M., van Silfhout, C.H. & Stubbs, R.W. 1992. Race analysis of yellow rust in wheat in developing countries. Report 1990–92. *IPO-DLO Report,* 92-11. 23 p.

Mahato, B.N. 1996. Genetics of rust resistance of selected wheat lines and mapping of pathotype flora of leaf rust in Nepal. DWR Regional Station, Flowerdale, Shimla, India. 53 p.

Nagarajan, S., Nayar, S.K., Bhadur, P. & Kumar, J. 1986. Wheat pathology and wheat improvement. Indian Agricultural Research Institute, Flowerdale, Shimla, India.

Nayar, S.K., Prashar, M., Kumar, J. & Bhardwaj, S.C. 1992. Prevalence of wheat rust pathogens and identification of rust resistance genes. 31st All-India Wheat Research Workers' Workshop, IARI, New Delhi, India.

Sharma, S. 1997. Virulence monitoring and detection of leaf and yellow rust resistance genes in Nepalese wheat varieties. DWR Regional Station, Flowerdale, Shimla, India, 25 p.

Sharma, S., Louwers, J.M., Karki, C.B. & Snijders, C.H.A. 1995. Postulation of resistance genes to yellow rust in wild emmer wheat derivatives and advanced wheat lines from Nepal. *Euphytica,* 81: 271–277.

Singh, R.P. 1992. Association between gene *Lr34* for leaf rust resistance and leaf tip necrosis in wheat. *Crop Science,* 32: 874–878.

Upreti, R.P. & Karki, C.B. 1999. Effects of fungicides on yellow rust, grain yield and thousand kernel weight of wheat. *Nepal Agricultural Research Journal,* 3: 107–109.

Monitoring of the wheat yellow rust pathogen in Iran

F. Afshari,[1] M. Torabi,[1] K. Nazari,[1] A. Malihipour,[1] M. Agnoum,[2] S. Rejaei,[3] M. Dehgan,[4] S. Safavei,[5] M. Nasrolahi,[6] T. Dadrezaei,[7] R. Hoshyar,[8] M. Hassanpour-Hosni,[9] S. Kemangar,[10] M.S. Ahmedian-Moghaddam,[11] A. Forotan,[11] M. Chaeichei,[12] H. Soltani,[12] F. Jebalbarez,[13] H. Akbari-Mogaddam,[14] M. Galandar,[15] M. Damadzadeh,[16] Kh. Norolahi,[17] K. Keshavarz[18] and H.A. Maibodi[19]

1. Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran
2. Khorasan Agricultural Research Centre, Islamic Republic of Iran
3. Fars Agricultural Research Centre, Islamic Republic of Iran
4. Golestan Agricultural Research Centre, Islamic Republic of Iran
5. Ardabil Agricultural Research Centre, Islamic Republic of Iran
6. Lorestan Agricultural Research Centre, Islamic Republic of Iran
7. Khozastan Agricultural Research Centre, Islamic Republic of Iran
8. E. Azarbaijan Agricultural Research Centre, Islamic Republic of Iran
9. DARI Agricultural Research Centre, Islamic Republic of Iran
10. Kordestan Agricultural Research Centre, Islamic Republic of Iran
11. Mazanderan Agricultural Research Centre, Islamic Republic of Iran
12. Hamadan Agricultural Research Centre, Islamic Republic of Iran
13. Kerman Agricultural Research Centre, Islamic Republic of Iran
14. Zabol Agricultural Research Centre, Islamic Republic of Iran
15. Markazi Agricultural Research Centre, Islamic Republic of Iran
16. Isfehan Agricultural Research Centre, Islamic Republic of Iran
17. Ilam Agricultural Research Centre, Islamic Republic of Iran
18. Yasoj Agricultural Research Centre, Islamic Republic of Iran
19. Yazd Agricultural Research Centre, Islamic Republic of Iran

Abstract

Yellow (stripe) rust disease caused by fungus *Puccinia striiformis* f.sp. *tritici* is the major problem in wheat production in most parts of Iran. Monitoring of the pathogen virulence factors and their changes provides basic information for the development of an early warning system. This experiment was carried out in 20 locations throughout Iran. For this purpose, 30 lines of a standard set of yellow rust and 14 near-isogenic lines developed by Dr Wellings from Australia were sown in 2-m rows for each line in cropping seasons 2001/2 and 2002/3. According to the results, virulence on Heines Kolben (*Yr2*), Kalyansona (*Yr2*), Lee (*Yr7*), Avocet R (*YrA*), Federation*4/Kavkaz (*Yr9*), *Yr6*/6*Avocet "S", *Yr7*/6*Avocet "S", *Yr9*/6*Avocet "S", *Yr17*/6*Avocet "S", TP1295 (*Yr25*) and *YrSU* was common during those two seasons. The frequency of virulence on plants with *Yr2, Yr6, Yr7, Yr9* or *YrA* was up to 70%.

No virulence was observed on plants with *Yr1, Yr3, Yr4, Yr5, Yr8, Yr10, Yr15, Yr18, YrSD, YrND, YrCV, YrSP* or *YrSK(27)* genes. Virulence surveys of pathogen populations have provided valuable information during last 10 years and have been used in our breeding programmes.

Introduction

Yellow (stripe) rust disease is the major problem for wheat production in most parts of Iran. Wheat yellow rust epidemics in certain regions of Iran caused crop losses over several seasons in the 1990s, with the detection of virulence for *Yr9* in 1993. The Falat cultivar (Veery 5)—a high yielding wheat cultivar with *Yr7* and *Yr9*—became susceptible with the appearance of a new pathotype, and the crop loss due to that was estimated at 1.5 million tonne (Torabi *et al.*, 1995). There are three main factors involved in epidemic development. Firstly, an environmental effect such as a mild winter is an ideal opportunity for rust development. One of reasons for the yellow rust epidemic in Mogan, Iran, in 1993 was the extended moderate (10–20°C) wet spring weather in the region (Afshari, unpublished). A second factor is cultivation of susceptible cultivars over a large area. The third factor is a virulent pathogen. The most common mechanism driving evolution in the yellow rust pathogen is mutation and migration. Virulence for *Yr27*, which was widely deployed in cultivars selected from CIMMYT materials, such as Attila 50 (Chamran), apparently spread rapidly through the West Asia and North Africa (WANA) region and arrived in Iran in 2003 (Afshari, Torabi and Malihipour, 2004). Monitoring of the pathogen virulence factors and their changes provides basic information for the development of an early warning system. To monitor yellow rust virulence and virulence changes, this study was carried out at 30 locations throughout Iran.

Materials and Methods

This study used 30 lines of a standard set of yellow rust differentials and 14 near-isogenic lines developed by Dr Wellings from Sydney University, which were sown in 2-m rows for each line in cropping seasons 2001/2 and 2002/3 (Table 1). At the flag leaf stage, when the infection and severity under natural infection on the susceptible controls was high, field assessments were done on disease severity, according to the modified Cobb scale (Peterson, Campbell and Hannah, 1948) and disease reaction based on Roelfs (1978).

Table 1. Yellow rust differentials, cultivars and their responses in the four main regions in two cropping season 2001/2 and 2002/3 in Iran

Differential or Cultivar	*Yr* gene	North	West	Central	East
Chinese 166	*Yr1*	R	R	R	R
Lee	*Yr7*	S	S	S	R
Heines Kolben	*Yr2*	S	S	S	R
Vilmorin 23	*Yr3*	R	R	R	R
Moro	*Yr10*	R	R	R	R
Strubs Dikkopf	*YrSD*	R	R	R	R
Suwon 92/Omar	*YrSU*	R	R	S	R
Clement	*Yr2, Yr9*+	R	R	R	R
Hybrid 46	*Yr4*	R	R	R	R
Reichersberg 42	*Yr7*+	R	R	R	R
Heines Peko	*Yr2, Yr6*+	R	R	R	R
Nord Desprez	*YrND*	R	R	R	R
Compair	*Yr8*+	R	R	R	R
Carstens V	*YrCV*	R	R	R	R
Spalding Prolific	*YrSP*	R	R	R	R
Heines VII	*Yr2*+	R	R	R	R
Triticum spelta var. *album*	*Yr5*	R	R	R	R
Anza	*YrA*+	R	R	S	R
Jupateco "73R"	*Yr18*	R	R	R	R
Jupateco "73S"		S	S	S	S
Avocet "R"	*YrA*	S	S	S	S
Avocet "S"		S	S	S	S
Kalyansona	*Yr2*	S	R	S	R
Federation *4/Kavkaz	*Yr9*	S	S	S	R
Federation		S	S	S	S
Trident (= Spear*4/VPM1)		S	R	R	R
TP 981		S	R	S	R
TP 1295	*Yr25*	S	S	S	S
Meering + *Yr24*	*Yr24*	R	R	R	R
Meering		S	R	S	R
Yr1/6*Avocet "S"	*Yr1*	R	R	R	R
Yr5/6*Avocet "S"	*Yr5*	R	R	R	R
Yr6/6*Avocet "S"	*Yr6*	S	S	S	S
Yr7/6*Avocet "S"	*Yr7*	S	S	S	S
Yr8/6*Avocet "S"	*Yr8*	R	R	R	R
Yr9/6*Avocet "S"	*Yr9*	S	S	S	S
Yr10/6*Avocet "S"	*Yr10*	R	R	R	R
Yr15/6*Avocet "S"	*Yr15*	R	R	R	R
Yr17/6*Avocet "S"	*Yr17*	R	R	S	R
Yr18/6*Avocet "S"	*Yr18*	R	R	R	R
YrSP/6*Avocet "S"	*YrSP*	R	R	R	R
YrSK/6*Avocet "S"	*Yr27*	R	R	R	R
Avocet "R"	*YrA*	S	S	S	S
Avocet "S"		S	S	S	S

KEY: R = Resistant; S = Susceptible.

Results and discussion

In the two years of study, yellow rust developed in most nurseries. The results are summarized for four main regions (West, North, East and Central) of Iran, and presented in Table 1. According to the results, virulence on Heines Kolben (with gene *Yr2*), Kalyansona (*Yr2*), Lee (*Yr7*), Avocet R (*YrA*), Federation*4/Kavkaz (*Yr9*), *Yr6*/6*Avocet "S", *Yr7*/6*Avocet "S", *Yr9*/6*Avocet "S", *Yr17*/6*Avocet "S" and TP 1295(*Yr25*) and *YrSU* was common during those two years (Table 1).

The frequencies of virulence on plants with *Yr2, Yr6, Yr7, Yr9* and *YrA* were up to 70%. Virulence for *Yr1* was common in Central Asia and China, rare in most parts of the Middle East and absent in Iran (Afshari, unpublished). No virulence was observed on plant with *Yr1, Yr3, Yr4, Yr5, Yr8, Yr10, Yr15, Yr18, Yr24, YrND, YrCV, YrSP* or *YrSK(27)* genes in our trap nurseries. Ma and Singh (1996) noted that *Yr18* might not provide adequate protection when deployed alone in a susceptible background. According to them, the preferred option for achieving durable stripe rust control is to have combinations of adult plant resistance (APR) genes giving protection approaching the levels of the most effective seedling resistance genes.

The varieties with the *Yr18* gene have remained resistant in Iran and the gene is being used in the breeding programme in combination with other resistance sources to obtain acceptable levels of resistance in new cultivars. Virulence for *Yr27* (Selkirk gene) was not reported from trap nurseries, but virulence for this gene appeared in farmer's fields and was confirmed by seedling tests in the greenhouse (Afshari, Torabi and Malihipour, 2004). Moreover, the population of this pathotype is still limited. Virulence surveys of pathogen populations have provided valuable information during last 10 years and have been used in our breeding programmes.

References

Afshari, F., Torabi, M. & Malihipour, A. 2004. Appearance of a new race of *Puccinia striiformis* f.sp. *tritici*. *Seed and Plant Journal of Agricultural Res.* [Karaj, Iran]. *In press.*

Ma, H. & Singh, R.P. 1996. Contribution of adult plant resistance gene *Yr18* in protecting wheat from yellow rust. *Plant Disease,* 81: 66–69.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research,* 26c(5): 496–500.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States, 1918–1976. *USDA Miscellaneous Publication*, No. 1363. 85 p.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildews Bulletin,* 23: 9–12.

Virulence to yellow rust resistance gene *Yr27*: a new threat to stable wheat production in Asia

R.P. Singh,[1] E. Duveiller and J. Huerta-Espino[3]

1. International Maize and Wheat Improvement Center (CIMMYT), Mexico
2. CIMMYT South Asia, P.O. Box 5186, Kathmandu, Nepal
3. INIFAP-CEVAMEX, Chapingo, Mexico

Introduction

Yellow [stripe] rust, caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*) is an important disease of wheat in Asia, where use of genetic resistance is the most common control strategy. Genetic resistance to yellow rust can involve major (race-specific) or minor (race-non-specific) genes. In the recent past, a *Yr9*-virulent *Pst* race that evolved in eastern African highlands during the mid-1980s had migrated to South Asia by the mid-1990s, via Middle East and West Asia, causing severe epidemics on various cultivars that were formerly protected by the resistance gene *Yr9*. Several resistant cultivars released in the region following the abovementioned epidemics were protected by the resistance gene *Yr27*. These included two most important cultivars—Inqilab 91 and PBW 343 (= Attila)—grown on over 11 million ha of the stripe rust-prone areas of Pakistan and India. Other selections out of Attila released as Shirudi and Chamran in Iran, and selections of Kauz released as Bakhtwar in Pakistan and WH 542 in India, and under different names in several other countries, were also protected by *Yr27*. These cultivars are now under threat as virulence for gene *Yr27* has been now observed and confirmed in India, Pakistan, Tajikistan, Kyrgyzstan and possibly Iran. *Yr27*-virulence has so far not been seen in eastern Africa, Turkey, Syria or Georgia, but it is expected that soon it will be widespread in the region.

In the present paper we aim to provide information on gene *Yr27* and explain the methodology used in incorporating durable stripe rust and leaf rust resistance in cultivars PBW 343 and Inqilab 91.

Stripe rust resistance gene *Yr27*

McDonald *et al.* (2004) recently designated a gene *Yr27* that was previously known as *YrSk* or *YrBjy*. This gene is located on the short arm of chromosome 2BS in a region where several other rust resistance genes are present. These include *Lr13* and *Lr23* for resistance to leaf rust and *Yr31* for resistance to stripe rust. Recombination between all these genes occurs, although for some cases the frequency is low. Gene *Yr27* is present in several wheats, especially those of CIMMYT origin. These include selections of Attila, Kauz, Opata, Nacozari, Buk Buk and Crow, or lines derived from their crosses. According to McDonald *et al.* (2004), the origin of this gene can be traced to cultivar McMurachy, which was used in breeding for resistance to stem rust in Canada. The source of this gene in CIMMYT germplasm could be Selkirk. The recently identified resistance gene *Yr31* (Singh *et al.*, 2003) present in CIMMYT wheat line Pastor is recombined with *Lr27* at a frequency of about 15%.

Variation in virulence for *Yr27* in *Pst* populations

Mexican races show three infection types on seedlings in greenhouse tests. Using the 0-9 scale of McNeal *et al.* (1971), these are low (infection types 2 to 3), intermediate (infection type 4 to 6, depending on the genetic background) or high (8 to 9) depending the isolates used. This could indicate that Mexican races are either homozygous avirulent, heterozygous or homozygous virulent. With avirulent Australian races, *Yr27* confers a very characteristic and uniform low infection type, and wheats with the gene are readily recognized in host screening. The testers carrying *Yr27* are highly resistant when tested in the field in Mexico with homozygous avirulent or heterozygous races, but show high susceptibility with the homozygous virulent race.

Gene *Yr27* is not used as a differential in most countries where *Pst* races are currently being characterized. However, based on historical field data from CIMMYT's international nurseries, the presence of virulence can be indicated based on the response of wheat lines Buk Buk and Opata 85. The *Yr9*-virulent race that migrated from eastern Africa to South Asia in the 1990s lacked virulence for *Yr27*, although data from Pakistan indicate that virulence for *Yr27* was present earlier. After the 1995 and 1996 epidemics on *Yr9*-carrying cultivars Pak 81 and Pirsibak 85, the *Yr9* virulent race became predominant. However, 2004 data now indicates that probably the old *Yr27* virulent race is again becoming predominant, as main cultivar Inqilab 91 (known to carry *Yr27*) is showing moderate susceptibility and Pak 81 has become resistant again. In contrast, the Indian cultivar PBW 343, which carries *Yr9* and *Yr27* in combination, has also shown susceptibility since 2001, indicating that the *Yr27*-virulent race in India must have evolved from the *Yr9*-virulent race. Although race analysis from Iran in the past has indicated combined virulences for *Yr9*

and *Yr27,* the seedling data may not be correct, as in field trials cv. Kauz had shown a high level of resistance. Kauz also carries *Yr9* and *Yr27* in combination. Multiplication of a breeding line derived from a cross of Kauz and Opata 85, and hence carrying *Yr27*, was suspended in 2002 due to its susceptibility, indicating that virulence for *Yr27* should be present in Iran but not in combination with *Yr9*. Kauz has remained resistant in West and Central Asia; however, during 2003 we observed stripe rust on a Kauz plot in the International Disease Trap Nursery planted in Kyrgyzstan, indicating that the combination of *Yr9* and *Yr27* is not effective in the area. A different selection of Attila that does not carry *Yr9* has shown moderate susceptibility in Tajikistan, indicating virulence for *Yr27.* Combined virulences for the *Yr9* and *Yr27* genes have been present in Mexico since 1996, and also occur in Ecuador.

Incorporation of durable resistance to stripe and leaf rusts in PBW 343 and Inqilab 92

Durable resistance to stripe rust and leaf rust are based on the interaction of minor, slow-rusting resistance genes that have small to intermediate, but additive, effects. If we look at the disease progressions for susceptible and slow-rusting cultivars (Figure 1), we find that as more minor genes are accumulated in a line the progress of rust becomes slower. Accumulating 4 to 5 such minor genes leads to near-immunity in most environments (Singh, Huerta-Espino and Rajaram, 2000). Following the observation that two mega-cultivars—PBW 343 and Inqilab 91—are moderately susceptible in Mexico, in 1999 we initiated incorporating durable resistance genes into these two important cultivars using the single-backcross selected-bulk breeding approach described below.

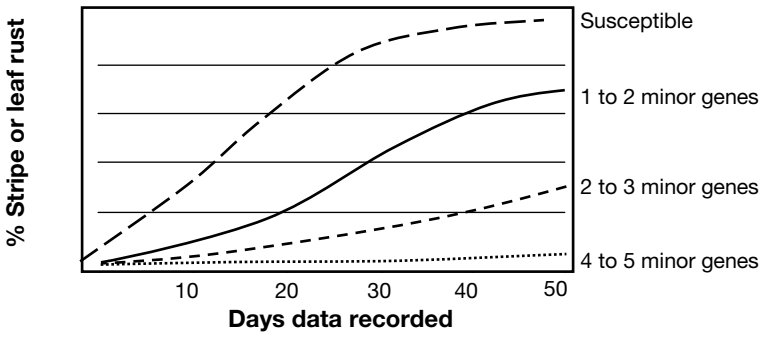


Figure 1. Relationship between the progress of stripe or leaf rust and the number of minor genes present in a wheat cultivar.

Questions often arise as to why try to transfer slow-rusting resistance genes into a popular cultivar in a planned fashion, instead of identifying a totally new cultivar. Reasons to do so are: (1) cultivars such as Inqilab 91 and PBW 343 must have unique combinations of numerous genes to achieve their wide adaptability and acceptability by millions of farmers; (2) it is comparatively easy to add a few more genes in such cultivars; (3) a planned transfer ensures selection for slow-rusting genes-based resistance; and (4) the strategy is highly economical, as only a few crosses need to be made. The traditional backcrossing scheme where several backcrosses are made is a highly conservative scheme and is designed for transferring single genes at a time. It has been realized that despite several backcrosses, it is difficult to recover the yield potential of the adapted cultivar, often due to a small population size used during backcrossing.

The use of a single-backcross strategy not only increases the possibility of maintaining and re-selecting desirable genes of the recurrent parent, but also promotes simultaneous selection of multiple genes or characters. This strategy also permits selection of additional useful genes or characters present in donor parents. We recommend that the susceptible or moderately susceptible adapted cultivar is crossed with 6 to 10 donor wheats, and the resulting F_1 lines are then backcrossed once with the adapted cultivar to obtain between 400 and 500 seeds per cross combination. This is equivalent to emasculating and pollinating 20 spikes. It is important to produce a large number of BC_1 seeds to obtain enough plants that will have between 3 and 4 minor genes in the BC_1 generation. The slow-rusting genes are not recessive and give intermediate resistance when present in a heterozygous condition, and such BC_1 plants can be selected by comparing their response with the response of the F_1 plants under high rust pressure created by artificial epidemics. We use a selected bulk selection scheme, where plants with good agronomic features and desired level of resistance are selected in the field, but only one spike from each selected plant is harvested as bulk. This scheme thus permits the selection of many plants in each generation without any constraints due to the cost and field area needed to grow them. Selecting many plants increases the possibility of identifying transgressive segregates in higher generations as homozygosity increases. Because selected plants are maintained as populations, cost of harvesting, threshing and planting is low.

In the F_2, F_3 and F_4 generations a large number of plants must be grown, and plants with good agronomic characteristics and low to moderate resistance can be selected and then harvested as bulk. By the F_5 generation enough homozygosity is achieved, so plants with a high resistance level and good agronomic features must be selected and harvested individually. Selection for grain characteristics can be done on individually harvested plants, and plants with good grains are then promoted to the F_6 generation and grown as small plots to evaluate resistance and agronomic homogeneity. The best lines are then yield tested in the F_7 generation.

Yield evaluations of the PBW 343- and Inqilab 91-derived lines were conducted during the 2002/03 crop season at Ciudad Obregon, Mexico, and, based on the yield data, the 10 best derivatives of each of the two cultivars were selected for yield evaluations at multiple sites in India, Pakistan, Afghanistan, Iran and Nepal. The idea of this trial was to distribute these lines as fast as possible and obtain information on grain yield and rust resistance as soon as possible from locations in Asia. We initiated the crossing in 1999 and just five years later yield trials were planted in the region. In Mexico these lines had shown high levels of resistance to both stripe rust and leaf rust and 4–12% higher yield potential compared with the plots of the parent cultivars that were protected from leaf rust through fungicide applications. At present we are waiting for the multi-site yield results to identify the best lines for further yield testing and release. If superior lines are identified they can provide farmers an option to grow durably resistant versions of their favourite cultivar.

References

McDonald, D.B., McIntosh, R.A., Wellings, C.R., Singh, R.P. & Nelson, J.C. 2004. Cytogenetical Studies in Wheat XIX. Location and linkage studies on gene *Yr27* for resistance to stripe (yellow) rust. *Euphytica,* 136: 239–248.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

Singh, R.P., William, H.M., Huerta-Espino, J. & Crosby, M. 2003. Identification and mapping of gene *Yr31* for resistance to stripe rust in *Triticum aestivum* cultivar Pastor. pp. 411–413 (vol. 1), *in:* N.E. Pogna, M. Romano, E.A. Pogna and G. Galterio (editors). *Proceedings of the 10th International Wheat Genetics Symposium*, 1-6 September 2003, Paestum, Italy. Published by S.I.M.I., Rome, Italy.

Singh R.P., Huerta-Espino, J. & Rajaram S. 2000. Achieving near-immunity to leaf and stripe rusts in wheat by combining slow-rusting resistance genes. *Acta Phytopathologica et Entomologica Hungarica,* 35: 131–139.

Screening of CIMMYT bread wheat germplasm and post-release monitoring of Bakhtawar 92 against yellow rust (*Puccinia striiformis* f.sp. *tritici*) in Pakistan

S.J.A. Shah,[1] T. Mohmmad,[1] I. Ali,[1] F. Azam,[1] S. Hussain,[2] A.R. Rattu[3] and J.I. Mirza[3]

1. Nuclear Institute for Food and Agriculture (NIFA), Tarnab, Peshawar, Pakistan
2. Department of Plant Pathology, NWFP Agricultural University, Peshawar, Pakistan
3. Crop Diseases Research Programme (CDRP), National Agriculture Research Centre (NARC), Islamabad, Pakistan

Introduction

Yellow or stripe rust, caused by *Puccinia striiformis* Westend. f.sp. *tritici*, is potentially a destructive pathogen of wheat and one of the important factors limiting grain yield in wheat worldwide (Sonmez, Keskin and Gocmen, 2002). In Pakistan, wheat is an economically important crop worth Rupees (Rs) 150 billion annually in Pakistan, and a one percent loss in production is Rs 1.5 billion (Kisana, Mujahid and Mustafa, 2003). Yellow rust occurs regularly and has been responsible for various epidemics in the country during the past fifty years, with national losses in 1978 and 1995 alone accounting for US$ 116 million (Hassan, 1968; Kidwai, 1979; Roelfs and Bushnell, 1985; Saari, Hashmi and Kisana, 1995). Development of wheat cultivars is carried out by public sector organizations in Pakistan, where the cost of developing a single cultivar is around Rs 2.7 million (Bhutta and Hussain, 2003). It therefore becomes essential to monitor the durability of deployed resistance after its release for early warning of the need to replace the cultivar and avoid economic losses due to disease.

Yellow rust resistance in wheat has been a major goal of numerous breeding programmes (Cetin, Dusunceli and Albustan, 1998; Dusunceli *et al*., 1998; Khan, Yaqub and Nasir, 1998; Hussain *et al*., 1999; Pasquini *et al*., 1998). Genetic

variation for yellow rust resistance exists among wheat cultivars (Anpilogova and Levashova, 1995; Pasquini *et al*., 1998). Several studies (Cetin, Dusunceli and Albustan, 1998; Dusunceli *et al*., 1998; Khan *et al*., 1998; Hussain *et al*., 1999; Pasquini *et al*., 1998) have been conducted to determine reaction of wheat genotypes, which have been variously classified as resistant, moderately resistant, moderately susceptible or and susceptible to yellow rust (Pasquini *et al*., 1998). Khan *et al*. (1998) also reported that wheat lines or cultivars tend to rust faster under favourable environmental conditions. As the appearance of new races of yellow rust poses a continuing threat, there is an urgent need to identify new sources of yellow rust resistance from the wheat gene pool.

Materials and methods

Plant material and sowing

Bakhtawar 92 was tested in the Trap Nursery during 1999–2000 and was incorporated in the National Wheat Disease Screening Nursery (NWDSN) in 2001/02 and 2002/03. The Trap Nursery comprised 110 entries, whereas NWDSN consisted of 468 and 432 entries, respectively. The Trap Nursery was sown at 15 locations, whereas NWDSN was planted at 11 sites throughout Pakistan. In each nursery, entries were planted in single 1-m-long rows and 30 cm apart. Two rows of varieties Local White, Morocco and Sonora, which are susceptible to wheat rust, were planted around the nursery.

Additional field experiments were conducted under irrigated conditions at NIFA from 1996 to 2000 and included two nurseries: the International Bread Wheat Screening Nursery (IBWSN) and Semi-Arid Wheat Screening Nursery (SAWSN), which originated from CIMMYT (Mexico). In the five seasons 1996–2000, SAWSN consisted of 291, 283, 205, 174 and 166 entries each year, respectively. The IBWSN consisted of 493, 445, 265 and 276 genotypes each year, except 1997–98 when it was not tested. During each cropping cycle both nurseries were separately planted in strips of small adjacent plots with 2 rows per plot of 2.5 m length separated by 0.3 m. A susceptible wheat cultivar (Local White) was sown around each nursery as spreader, and also served as an adult plant susceptible check.

Development of yellow rust epiphytotics

Artificial inoculation with a mixture of field-collected bulk inoculum of known prevalent races of the pathogen was carried out in February–March each year. Initial inoculation of spreaders involved inoculating 3 to 5 tillers in a row, with a hypodermic syringe containing aqueous urediospore suspension to which 1–2 drops of Tween-20 were added in order to break surface tension. Subsequently, all material was spray inoculated 2–3 times at fortnightly intervals using a turbo-air sprayer to provide an aqueous spore suspension conducive to heavy rust development.

Disease assessment and scoring of host resistance

Observations on response and disease severity were recorded at all locations. Disease severity was recorded as percentage infection of plants according to the modified Cobb's Scale (Peterson, Campbell and Hannah, 1948), where 0 = no visible infection; R = Resistant (necrotic areas with or without small pustules); MR = Moderately Resistant (small pustules surrounded by necrotic areas); MS = Moderately Susceptible (medium-sized pustules, no necrosis, but some chlorosis possible); and S = Susceptible (large pustules, no necrosis or chlorosis). Subsequently the scale was converted to a coefficient of infection by using R = 0.2, MR = 0.4, MS = 0.8, M = 0.6, MS = 0.8 and S = 1. Lines with up to 3 Average Coefficient of Infection (ACI) were considered resistant, lines falling between 4 and 10 were rated as moderately susceptible, while those scoring more than 10 were regarded as susceptible.

Results and discussion

Status of Bakhtawar 92 resistance in Pakistan

Bakhtawar 92 has been an important bread wheat cultivar, released in 1993 for commercial cultivation in the North West Frontier Province (NWFP) by the NWFP Seed Council. Its parentage is Kauz 'S' and has the pedigree CM 67458-4Y-1M-3Y-1M-5Y-0B. During the pre-release disease-testing period (1988–1992) the performance of this cultivar against yellow rust was satisfactory for all prevalent pathogen virulences. Keeping in view its popularity and large acreage occupied, it was included in the yellow rust monitoring studies.

Table 1 shows results of the observation of the post-release monitoring for yellow rust resistance carried out for three growing seasons (1999/00, 2001/02 and 2002/03). Rust severity was high in 2002/03 but had been comparatively low during the preceding years at all three test locations. Bakhtawar 92 consistently displayed a high level of resistance or immunity (as demonstrated in the pre-release stage) over sites and seasons in comparison with the susceptible check cv. Local White.

Table 1. Post-release yellow rust resistance status of Bakhtawar 92 at three locations in Pakistan

Years	Peshawar		Nowshara		Islamabad	
	Bakhtawar 92	Local White	Bakhtawar 92	Local White	Bakhtawar 92	Local White
1999/00	0	20 S	0	40 S	Tr-MR	Tr-S
2001/02	0	10 S	0	10 S	0	20 S
2002/03	Tr-R	60 S	Tr-R	90 S	5 MR-MS	90 S

A number of Kauz-derived cvs, e.g. Bakhtawar 92 (Pakistan), WH 542 (India), Memof (Syria), Basribey 95 and Seyhan 95 (Turkey) and Atrak (Iran) were released following widespread epiphytotics on cultivars derived from Veery #5. These cultivars displayed immunity, as demonstrated by our monitoring results for Bakhtawar 92 (Table 1). The genetic basis of immunity to yellow rust of Kauz demonstrated in these countries is due to the combination of *Yr9* and *Yr27*. The combined virulences for these two genes in the yellow rust population do not exist at present in the above countries; however, they are known to occur in Mexico and slow-rusting gene *Yr18*, also present in Kauz, does not by itself confer enough protection under high disease pressure (Ma and Singh, 1996).

Characterization of CIMMYT lines for resistance in Pakistan

Identification and selection of novel sources of yellow rust resistance is a preliminary step that forms the basis of developing genetically diverse cultivars. Results regarding the diversity of yellow rust resistance of 2600 bread wheat lines tested during the past five years are presented in Table 2. Results obtained from this study showed that there were differences among lines for resistance to prevailing yellow rust race populations. A clear trend was observed with regard to resistance classes in IBWSN and SAWSN (Table 2) tested from 1995 to 2000 at NIFA. A diminishing trend in the percentage of immune entries was observed in both nurseries, while the percentage of entries was enhanced each year in the other three resistance categories. It is postulated that immune material from CIMMYT is gradually losing its effectiveness and efforts are now concentrated on moderately resistant and moderately susceptible classes of resistance in order to hamper the development of new virulent races.

Table 2. Phenotypic diversity of yellow rust resistance in 2600 lines tested in two international bread wheat nurseries grown during the 1995/96–1999/00 cropping seasons at NIFA

Cropping season	International Bread Wheat Screening Nursery (IBWSN)				Semi-Arid Wheat Screening Nursery (SAWSN)			
	F	R	MS	S	F	R	MS	S
1995/96	213	159	47	74	131	106	27	27
1996/97	78	190	46	131	49	145	38	51
1997/98	–	–	–	–	30	95	33	47
1998/99	10	119	39	97	1	46	25	102
1999/00	4	144	60	68	18	106	29	13
Total	305	612	192	370	229	499	152	245

NOTES: F = Free.

About 70 lines from the resistant genetic resources of CIMMYT (Table 2) were tested at multiple locations each year (Table 3) for durability of yellow

rust resistance. Yellow rust was comparatively less prevalent during 2001/02, as mentioned earlier, but was enough for reliable scoring, and all the entries tested during that year demonstrated resistance, while only 26% of the entries were found to exhibit resistance during 2002/03.

Slow-rusting behaviour in the desirable genotypes and further testing of this material should lead to development of resistant cultivars that could be deployed to avoid boom-and-bust cycles.

Table 3. Multi-location testing of lines selected from IBWSN and SAWSN for yellow rust resistance in Pakistan

Season	No of test entries	% resistant
2001/02	67	100
2002/03	69	26

NOTES: Up to 3 ACI was considered as resistant. ACI of susceptible check (Local White) during 2001/02 was 15 while during 2002/03 it was 70 for cv. Morocco. Test locations in 2001/02 were Peshawar, Nowshara, Islamabad, Bahawalpur and Faisalabad. Test locations in 2002/03 were Peshawar, Nowshara and Islamabad.

References

Anpilogova, L.K. & Levashova, G.I. 1995. Resistance of winter wheat to harmful diseases. *Agrokhimiya,* 4: 85–89.

Bhutta, A.R. & Hussain, A. 2003. Pakistan: Emerging seed sector for investment. *Seed Info,* 24: 11–13

Cetin, L., Dusunceli, F. & Albustan, S. 1998. Bazi kislik ekmeklik vemakarnalik Bugday 1997 norserilerinde pas (*Puccinia* spp.) hastaliklarina dayanikli Genotiplerin Ankara ko, sullarinda belirlen-mesi. pp. 297–300, *in:* Turkiye VIII Fitopatoloji Kongresi Bildirileri, 21–25 Eylul, 1998. Ankara, Turkiye.

Dusunceli, F., Cetin, L., Albustan, S. & Benita, S.P.S. 1998. Baziuluslararasi bugday hastaliklari dayaniklilik kaynaklarinin Orta Anadolu 'da sari pasa (*Puccinia striiformis* f.sp. *tritici*) reaksiyon-larinin belirlenmesi. pp. 293–296, *in:* Turkiye VIII Fitopatolaji Kongresi Bildirileri, 21–25 Eylul 1998. Ankara, Turkiye.

Hassan, S.F. 1968. Cereal rusts situation in Pakistan. pp. 124–125, *in:* Proceedings of the Cereal Rusts Conference, 1968.

Hussain, M., Khan, M.A., Irsdhad, M. & Hussain, M. 1999. Screening of wheat germplasm against leaf and stripe rust epidemics for the identification of resistant sources against these diseases. *Pakistan Journal of Phytopathology,* 11(1): 93–99.

Khan, M.A., Yaqub, M. & Nasir, M.A. 1998. Slow-rusting response of wheat genotypes against *Puccinia recondita* f.sp. *tritici* in relation to environmental conditions. *Pakistan Journal of Phytopathology,* 10(2): 78–85.

Kidwai, A. 1979. Pakistan reorganizes agriculture research after harvest disaster. *Nature (London),* 227: 169.

Kisana, S.N., Mujahid, Y.M. & Mustafa, Z.S. 2003. Wheat production and productivity 2002–2003. A Technical Report to Apprise the Issues and Future Strategies. Published by Coordinated Wheat, Barley and Triticale Programme, National Agricultural Research Center, Pakistan Agricultural Research Council, Islamabad. 19 p.

Ma, H. & Singh, R.P. 1996. Contribution of adult plant resistance gene *Yr18* in protecting wheat from yellow rust. *Plant Disease,* 80: 66–69.

Pasquini, M., Sereni Casulli, F., Siniscalco, A., Mameli, L., Gallo, G., Prima, G., Spina, A., Lio Tta, C., Invernizzi, C., Padovan, S. & Minoia, C. 1998. Reaction of durum and bread wheats to some fungal diseases. *Informa Agraria,* 54(38): 63–73.

Roelfs, A.P. & Bushnell, W.R. (editors). 1985. *The Cereal Rusts.* Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Saari, E.E., Hashmi, N.I. & Kisana, N.S. 1995. Wheat and Pakistan, an update (*Yr*95 document). 3 p.

Sonmez, F., Keskin, S. & Gocmen, B. 2002. A study on the determination of the reactions of lines of Tir wheat to yellow rust (*Puccinia striiformis* f.sp. *tritici*). *Crop Protection,* 21(9): 871–874.

Yellow rust virulence patterns in Pakistan during 1998–2003, and responses of some commercial cultivars

Javed Iqbal Mirza, Iftikhar Ahmad, Atiq-ur-Rehman Rattu, Saif Khalid, M. Afzal Akhtar, Lal Khan Khokhar, Munawar Hussain, Syed Javed Hamid, M.A.S. Kirmani and Ehsan-ul-Haq

Crop Diseases Research Programme, Institute of Plant and Environmental Protection, National Agricultural Research Centre, Park Road, Islamabad, Pakistan

Introduction

Like other parts of the world, wheat cultivated in Northern Punjab, NWFP and Baluchistan is severely affected by stripe rust disease caused by *Puccinia striiformis* f.sp. *tritici* West. Mehta (1940) concluded that yellow rust is the main wheat disease of Punjab. Tahir (1978) found primary infections of yellow rust in the foothills and the adjoining parts of Punjab during early January. Early development of stripe or yellow rust is usually noted on susceptible cultivars by mid-March, which develops to greater intensities by the end of April. Cultivation of susceptible varieties can result in rust epidemics, with heavy losses. It is thus very important to monitor the pathogen in the different wheat growing areas of Pakistan. Particular virulence is found in the place where the corresponding gene for resistance is in wide use (Kirmani *et al.*, 1989). That is why in a country like Pakistan, where the genetic basis of resistance against yellow rust of wheat had always been narrow due to monoculture practices, periodic epidemics have occurred as a result of the breaking down of resistance in cultivars. Leading cultivars of the past, such as Mexipak, Pak 81, Blue Silver and Pirsabak 91, succumbed to yellow rust disease of wheat, with heavy losses.

Information on the changing virulence pattern of *Puccinia striiformis* is critical to being able to manage yellow rust disease in the area. Trap nurseries comprising near-isogenic lines are grown in different areas of Pakistan for this purpose. The present study was conducted to achieve this goal so that efficient deployment of resistant genes can be achieved to get maximum and prolonged benefit from the effective yellow rust resistance genes.

Material and methods

Wheat nurseries comprising isogenic lines along with conventional stripe rust differentials were planted under field conditions in the stripe rust zones of Pakistan, together with leading cultivars. Each line was planted in a single row 1 m long with rows spaced at 30 cm. The entire nursery was surrounded by susceptible cv. Local White as spreader, and cv. Morocco was included as a susceptible check. Stripe Rust was allowed to develop under natural conditions. Disease severity and reaction on each entry was recorded using the scale of McNeal *et al.* (1971).

Results and discussion

Data of the average disease response from locations at the Agricultural University of Peshawar (AUP), the Nuclear Institute of Food and Agriculture (NIFA), Peshawar, the Cereal Crop Research Institute (CCRI), Pirsabak, and the National Agricultural Research Centre (NARC), Islamabad, represent the virulence spectrum of the area for the cropping seasons 1998/99, 1999/2000 and 2002/03, while data from Sialkot represented virulence patterns of the northern Punjab for 1999/00. Data for 2000/01 and 2001/02 were not available due to the prevalence of dry conditions unfavourable for pathogen development. The patterns of infection on the differential hosts, near-isogenic lines and commercial cultivars carrying postulated genes of resistance against *P. striiformis* was found to be similar during the period of study.

Cvs Kalyansona (*Yr2*), Lee (*Yr7*), Seri (*Yr9*) and Federation (*Yr9+*) showed moderately susceptible to susceptible reactions at different locations in NWFP (AUP, NIFA Peshawar and CCRI Pirsabak). Rust development for these genes at locations in NWFP seems to be more than in Islamabad. Kalyansona (*Yr2*), which was 0 at NARC during the 1998/99 cropping season showed MR-MS type of reaction in 1999/00 and 90S reaction in 2002/03, indicating progressive development of virulence against *Yr2* at NARC. Line WL 711, carrying *Yr2*, was susceptible at NARC in 1998/99 and 1999/00, and at CCRI Pirsabak in 1999/00. Similarly, Mexipak was susceptible during 1999/00 and 2002/03. Vilmorin (*Yr3*), which showed MR-MS reaction at NIFA Peshawar in 1998/99 was susceptible here in 1999/00. Kirmani *et al*. (1989) reported absence of virulence against this gene. Susceptible reaction for *YrA* in 2002/03 could be anticipated at NARC as virulence for this gene prevailed in CCRI Pirsabak in 1998/99 and in NIFA Peshawar in 1999/00. Virulence for this gene was reported from the stripe rust zones of NWFP and Punjab in the past (Kirmani *et al.,* 1989). Cv. Heines Kolben (*Yr6*) showed MS-S reaction at NARC in 1998/99 and susceptible reaction at CCRI Pirsabak and Sialkot in 1999/00. Virulence for these genes was also reported in the past by Kirmani *et al.* (1989). *Yr6* is one of the most frequent genes in our commercial wheat cultivars, either

in combination or alone. Lee (*Yr7*) had a susceptible reaction at NIFA in 1998/99 and at CCRI in 1999/00, and an MS-S reaction at NARC in 2002/03. Commercial cultivars Parwaz 94 and Soghat with *Yr6* in combination with *Yr7* showed an MS-S to S type of reaction throughout the study period. Pathotype analysis of the samples from Punjab and NWFP during 1986/88 revealed the presence of race 7E150 (Kirmani, 1986) which has virulence for *Yr1, Yr2, Yr6, Yr7* and *YrA*.

MS to S type of reaction was noted on Seri (*Yr9*) throughout the study period. Cultivar Kaghan 93 showed MS-S reaction at CCRI Pirsabak, and Pasban showed S type of reaction at NARC, during 1998/99. In 1999/00, Seri showed S type of reaction at CCRI Pirsabak, while Kaghan 93 showed MS-S type of reaction, confirming the prevalence of virulence for *Yr9* at this location. *Yr9* had been an effective gene for resistance in leading cultivars like Pak 81, Kohinoor 83 and Pirsabak 85. Race 134E150 was detected in 1994 attacking *Yr9*. Jupateco R with *Yr18* gave an MR to MS type of reaction during 1998/99, and was MR-MS at CCRI Pirsabak during 1999/00. It was showing an MS-S reaction at three locations in NWFP and S reaction at NARC during 2002/03.

Virulence for *Yr15*, *Yr8* and Hybrid 46 was not found at any of the locations during the three years of study. Virulence for *Yr8* was however reported in race groups 6E16, 38E16 and 6(38)E16 identified during 1977/80 (Hussain, pers. comm.).

Oxley with *Yr6*+ APR showed terminal reaction of 10MR during 1998/99, 30MS-S during 1999/00, and 10S during 2002/03. Similarly Cook with APR was 0 during 1998/99 and 1999/00, and 20S during 2002/03. Inqilab, which had dominated wheat growing areas of Pakistan since 1998, was T-R-MR during 1998/99, T-MS-S in 1999/00 and MR-MS in 2002/2003 in NWFP and Punjab.

References

Kirmani, M.A.S. 1986. Preliminary information about genetic analysis of Pakistani wheat cultivars against stripe rust in seedling stage. IPO, The Netherlands.

Kirmani, M.A.S., Hussain, M., Aslam, M. & Hamid, S.J. 1989. Distribution of stripe rust virulences of wheat and varietal response in Pakistan. *Pakistan Journal of Botany,* 21(2): 313–317.

Mehta, K.C. 1940. Further studies on cereal rusts in India. *Imperial Council for Agricultural Research Scientific Monograph*, No. 14. pp. 1–118.

Tahir, M. 1978. Wheat research and production in Pakistan. PARC, Islamabad.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA Agricultural Research Service Bulletin,* 34-121: 1–42.

Challenge of a new race of *Puccinia striiformis* f.sp. *tritici* in Iran

F. Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

E-mail for correspondence: fafshari@hotmail.com

Introduction

Stripe [yellow] rust of wheat caused by *Puccinia striiformis* f.sp. *tritici* is an important disease in some wheat growing regions of the world. Economic appraisals of national losses ranged from $US 150 to 180 million due to the 1993 yellow rust epidemic in Iran. The use of resistant cultivars is the most effective, economical and environmentally safe method to manage the disease. Extensive research on stripe rust resistance in wheat has occurred over many years and has been successful in providing farmers with rust-resistant cultivars. The occurrence of pathogenic variability in rust fungi led to considerable confusion and disagreement among early researchers of rust diseases. For example, Rudorf (1929; cited in Wellings, 1986) noted that some cultivars resistant in the USA were susceptible in Germany. This was due presumably to variation in pathogenic attributes between geographical regions.

Two types of disease resistance are widely recognized. These are seedling resistance and adult plant resistance (APR). Seedling resistance is recognized and characterized on seedlings in the greenhouse, but is usually effective throughout the life cycle of the plant. APR can be defined as resistance that develops during the post-seedling stages; the seedlings are susceptible under standard greenhouse test conditions. APR is more difficult to assess and study compared with seedling resistance. Studies of APR are usually not undertaken in the greenhouse for economic reasons, which limits population sizes, and it is well known that stripe rust response is more environmentally influenced than resistance to other cereal rusts (Knott, 1989) and thus interpretation of greenhouse APR responses is difficult.

In a breeding programme for rust resistance, it is necessary to identify sources of resistance and the genes that confer resistance. When resistance is conferred by a number of genes, a single mutation in the pathogen is not able to break down resistance in a short time; such a resistance is considered durable.

In 1995, wheat yield loss due to the appearance of new pathotype of stripe rust was estimated at 1 million tonne in Iran (Torabi *et al.*, 1995). The widespread cultivation by farmers of acceptable cultivars such as Falat, known for its adaptation to abiotic stresses in irrigated wheat areas, was perhaps the major reason for stripe rust outbreaks in Iran in 1993 and 1995. Later, cv. Chamran (Attila 50 CM 85836-50Y-0M-0Y-3M-0Y), released in the late 1990s for the warm to moderate temperature zone, was sown on more than 500 000 ha in Iran. It became susceptible in 2003, indicating further change in the pathotype flora. The study reported here was carried out in the greenhouse and under field conditions to confirm the presence of a new pathotype.

Materials and methods

Stripe rust-infected samples of cv. Chamran (Attila 50) were brought from the field to the rust pathology laboratory of SPII at Karaj for further investigation. After increasing spores from samples, inoculations were done on a standard set of stripe rust differential lines at the seedling stage to determine the race. The seedlings were inoculated with a mixture of uredospores and talcum powder (1:4) and placed on trays and covered with plastic hoods. Trays were placed in an incubation room for 24 h at 10°C and 100% RH in the dark, and later moved to a greenhouse with a temperature of 18 to 19°C. Infection symptoms were recorded 16–19 days after inoculation using the scale described by McNeal *et al*. (1971). Infection types equal to or greater than 7 were considered as virulent, and those less than 7 as avirulent (Johnson *et al.*, 1972).

Results and discussion

Chamran was resistant until 2003. It may carry *Yr27* and at least one minor gene, and had 0–20MR responses in the adult plant stage in the different parts of Iran until 2003. In 2003, the first report of susceptibility (90S) of this cultivar was reported in several fields in Kermanshah and Fars provinces of Iran. This cultivar was found susceptible when tested in Yemen in a yellow rust trap nursery in 2002 (A. Yahyaoui, pers. comm.).

The present study identified race 166E134A+ and it is reported for the first time from Iran (Table 1). At the time of writing, the population of this pathotype is limited. It is suggested that cultivation of Chamran may be considered in the southern part of Iran, such as Khozestan province, where there is less chance of the appearance of stripe rust. It is very important to continuously monitor yellow rust in national and international trap nurseries that include most cultivars cultivated in the WANA region.

Table 1. Response of the yellow rust differential set to a new isolate of *Puccinia striiformis* f.sp. *tritici* in Iran

No.	Differential Cultivar	*Yr* gene	Seedling response
		World set	
1	Chinese 166	*Yr1*	0
2	Lee	*Yr7*	7+
3	Heines Kolben	*Yr2*	8
4	Vilmorin 23	*Yr3*	4+CN
5	Moro	*Yr10*	0
6	Strubs Dikkopf	*YrSD*	8
7	Suwon 92/Omar	*YrSU*	0
8	Clement	*Yr2,Yr9* +	7+
		European set	
9	Hybrid 46	*Yr4*	CN
10	Reichersberg 42	*Yr7*+	8
11	Heines Peko	*Yr2*,*Yr6* +	8
12	Nord Desprez	YrND	6CN
13	Compare	*Yr8*	CN
14	Carstens V	*YrCV*	2+CN
15	Spalding Prolific	*YrSP*	0
16	Heines VII	*Yr2*+	8
		Supplemental set	
17	*Triticum spelta* var. *album*	*Yr5*	0
18	Anza	*YrA*+	8
19	Avocet "R"	*YrA*	9
20	Avocet "S"		9
21	Kalyansona	*Yr2*	9
22	Federation *4/Kavkaz	*Yr9*	8
23	TP981		9
24	TP1295	*Yr25*	8
25	Meering + *Yr24*	*Yr24*	8
26	Chamran (Attila 50)		8
27	Bolani (Susceptible check)		9
Pathotype Identified			166E134A+

References

Johnson, R., Stubbs, R.W., Fuchs, E. & Chamberlain, N.H. 1972. Nomenclature for physiologic races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Knott, D.R. 1989. *The Wheat Rusts. Breeding for Resistance.* Monographs on Theoretical and Applied Genetics, vol. 12. Springer Verlag, Berlin, Heidelberg, Germany. 201 p.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildews Bulletin,* 23: 9–12.

Wellings, C.R. 1986. Host:Pathogen studies of wheat stripe rust in Australia. PhD Thesis. University of Sydney, Australia. 237 p.

Occurrence and importance of yellow rust in Tajikistan

B. Pett, H. Muminjanov, A. Morgounov and M. Otambekova

GTZ/CIMMYT Project, Dushanbe, Tajikistan

Introduction

In Tajikistan, wheat pathology has largely been neglected till now. There has been a lack of knowledge on the occurrence, symptomatology and importance of wheat diseases in Tajikistan, and only very scarce information on cereal rusts. The GTZ/CIMMYT Project *Regional Network on Wheat Variety Promotion and Seed Multiplication* aims to carry out intensive research on wheat diseases and pests, and to provide tools for local breeders and farmers to evaluate their varieties and breeding lines for resistance or tolerance to rusts and other wheat diseases.

In a first step, the work has focused on collecting data on the occurrence of yellow and other wheat rusts, and their importance in Tajikistan. This also provided first information on the resistance level of some wheat varieties to yellow rust.

Material and methods

Localities considered in this study are:

- Isfara (north Tajikistan, 560 masl, dry climate, irrigation)
- Gissar (central Tajikistan, 920 masl, irrigation)
- Dangara (south-east Tajikistan, 760 masl, dry, irrigation)
- Sovietskiy (south-east Tajikistan, 950 masl, rainfed area)

Data were recorded in June–July 2003 on the infection level on leaf and stem as percentage leaf or stem area covered in the field.

Results and discussion

The wheat disease monitoring has shown that stripe or yellow rust is the most damaging disease on wheat in Tajikistan, followed by brown (leaf) rust. Stem rust seems to be of less importance (Figure 1). Of all infected samples examined, 65% were of yellow rust, 17.8% of brown rust and only 5.2% of stem

rust. Of all the wheat fields investigated, 22.9% were found to be affected by yellow rust, followed by brown rust (6.2%) and stem rust (only 1.8%) (Table 1).

Table 1. Incidence of diseases and pests in four localities of Tajikistan in 2003 (without consideration of saprophytic and weakly pathogenic fungi)

Locality	Mean disease incidence (%)				
	Yellow rust	Brown rust	Stem rust	*Septoria* spp.	Other diseases
Isfara	10.2	0	0	0.4	0.34
Gissar	36.4	5.2	2.2	2.8	1.9
Sovietskiy	23.8	16.5	2.2	0.6	3.1
Dangara	20.0	2.9	4.6	0	1.4

The rust species showed a similar pattern of incidence at all localities (climatic zones) investigated; however, there were considerable quantitative differences between the localities. In the case of yellow rust, the highest level of incidence could be seen in Central Tajikistan (Gissar region), followed by the Sovietskiy research station in south-east Tajikistan.

Brown rust was most prevalent (16.7%) at Sovietskiy, followed by Gisser and Dangara, while it was not found in Isfara (northern Tajikistan). Stem rust incidence was highest (4.6%) in Dangara (south-east Tajikistan), followed by Gissar and Sovietsky. The differences in occurrence of the various rusts at the different localities could be explained partly in terms of difference in level of resistance among the wheat cultivars grown, and partly because of different climatic conditions at these localities. Possibly, these differences could be attributed to the formation and duration of night dew, which plays an important role in the epidemiology of rust species. At the same time, climatic differences can also modify varietal reactions.

The cultivars investigated have shown a wide spectrum of resistance and susceptibility to yellow rust. Of the 77 cultivars evaluated, 43% showed a medium to high level of susceptibility, whereas 57% were observed to be resistant or at least having a low level of susceptibility. The local wheat cultivars Navrus and Sharora were highly susceptible to yellow rust in all the localities.

The environment (location) has significant influence on disease severity, as some cultivars showed a high degree of susceptibility in one locality, while in other localities they expressed medium or high levels of resistance.

Among the lines tested, those showing some level of resistance to yellow rust infection in all project sites were Attila, CHAM/1D13, Kinaci, Vorona/HD2402, GRK/ESDA/LIRA, Somoni and Alex. For the previous 5 years, cv. Jagger 9 had been considered to have high resistance to yellow rust, but was now affected in some localities.

To better explain the differences in varietal behaviour due possibly to climatic conditions, meteorological data should be recorded in future. Also, there is need to investigate the epidemiological aspects of rust diseases.

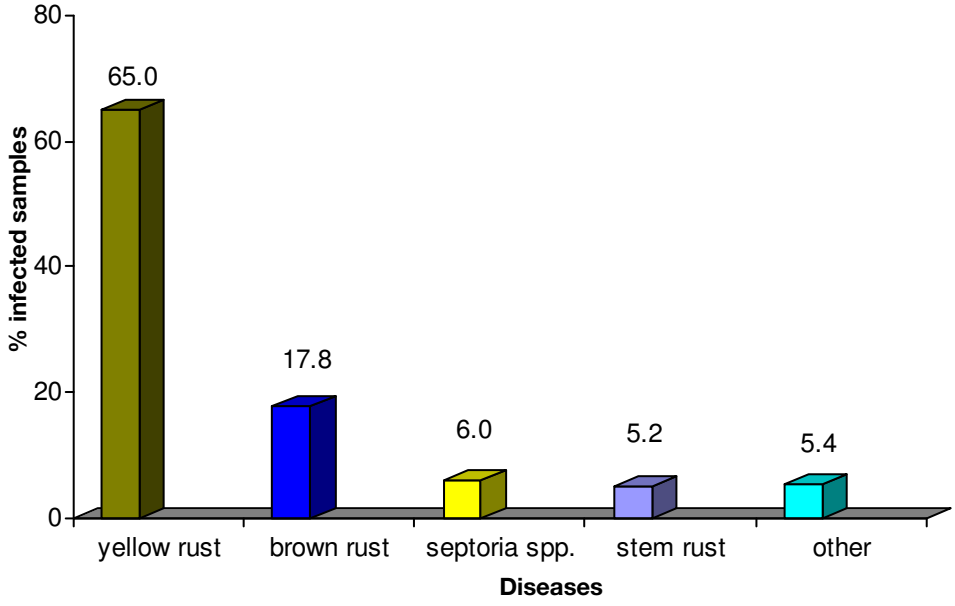


Figure 1. Occurrence of important wheat diseases in Tajikistan in 2003

Conclusions

Studies of rust and other diseases should be continued and intensified in Tajikistan. Epidemiological investigations and varietal trials should be conducted by studying the genotype × environment (G×E) interaction. For that, project sites should be equipped with small meteorological stations.

Epidemiology of wheat yellow rust (*Puccinia striiformis* f.sp. *tritici)* in Iran

M. Torabi

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Introduction

Wheat yellow (stripe) rust is the major disease of wheat in Iran. Several epidemics of this disease have occurred during last 30 years, the most recent being in 1993 and 1995 (Torabi, 1980; Torabi *et al.*, 1995). The yield losses caused by the disease were estimated to have been about 1.5 and 1 million tonne in 1993 and 1995, respectively (Torabi *et al.,* 1995). Several high yielding wheat cultivars, such as Azadi, Quds and Falat, released in Iran before 1993, became susceptible to yellow rust. Cultivation of cultivar Falat (*Yr9* resistance) and the emergence of pathotypes of yellow rust with virulence for the *Yr9* gene were the most important factors for epidemics of yellow rust during 1991–1995 in many parts of the wheat growing areas of Iran (Torabi *et al.,* 1995).

In many wheat growing areas of Iran, summer conditions are typically dry and hot, so survival of yellow rust during the summer period is important for the epidemiology of the disease. At the same time, in climatically moderate and cold regions, where temperature is mild during summer, yellow rust can survive on volunteer wheat and wild grasses in the absence of a wheat crop in fields. The survival of the fungus during winter in these regions needed investigation. The present study was carried out to investigate different factors affecting the epidemics of yellow rust in different parts of Iran.

Materials and methods

The study covered 11 provinces—Ardebil, Moghan, Fars, Golestan, Hamedan, Khuzestan, West Azarbaijan, Mazandaran, Kermanshah, Sistan and Baluchistan—for four years (1995–98).

Study on disease progress

Five fields in five different locations in each province were chosen for studying the effects of different climatic factors, including temperature, relative humidity and rainfall, on disease incidence and epidemiology.

Weather data were taken from the nearest meteorological stations. Disease records were assessed weekly by infection type and disease severity. Disease progress curves were drawn for each field from coefficients of infections that were calculated from disease assessment data.

Oversummering of the pathogen

To study the survival of the yellow rust pathogen during summer months, in the absence of a wheat crop, disease was assessed: (1) on volunteer plants of wheat in harvested fields; (2) in late-harvested fields in cooler areas and highlands; and (3) on wild grass species in the vicinity of wheat fields and in the highlands. Grasses with yellow rust infections were collected frequently, and samples tested under greenhouse conditions for pathogenicity on wheat and on seedlings of a range of grass species (Table 2).

Overwintering

To study the time of primary infection of seedlings in newly sown fields, during the autumn and winter months, several leaf or seedling samples with flecks, suspected to be caused by yellow rust, were taken to the greenhouse. The seedlings were maintained in favourable environmental conditions for yellow rust development.

Results and discussion

Disease progress

Appearance of primary infections in each location was highly correlated with the mean daily temperature in March and April (Table 1). In cases where mean temperature reached 12–15°C for five consecutive days, disease symptoms usually appeared a few days later. Disease development in the field was highly correlated to rainfall duration and amount, temperature and relative humidity during the growing season (Figures 1 and 2).

Table 1. Appearance of primary infections of yellow rust on wheat cultivars in different locations and years in Iran

Location	1994/95		1995/96		1996/97		1997/98	
	Date	Cultivar	Date	Cultivar	Date	Cultivar	Date	Cultivar
Ardebil	5 May	P.K.	27 Apr.	P.K.	18 May	P.K.	4 May	P.K.
Moghan	1 Mar.	Falat	14 Mar.	Falat	9 Mar.	Falat	20 Mar.	Falat
Gorgan	22 Mar.	Falat	17 Mar.	Falat	7 Mar.	Falat	–	–
Hamedan	29 Apr.	Sardari	–	–	7 Mar.	Navid	–	–
Fars (Zarghan)	9 Apr.	Falat	13 Apr.	Falat	20 April	Falat	–	–
Mashhad	5 Apr.	Tabasi	–	–	28 Apr.	Bolani	–	–
Ahvaz	28 Feb.	Bolani	2 Mar.	Bolani	21 Mar.	Chenab	14 Mar.	Falat
Miandoab	15 Apr.	Sardari	11 May	Sardari	20 Apr.	Navid	22 Apr.	–

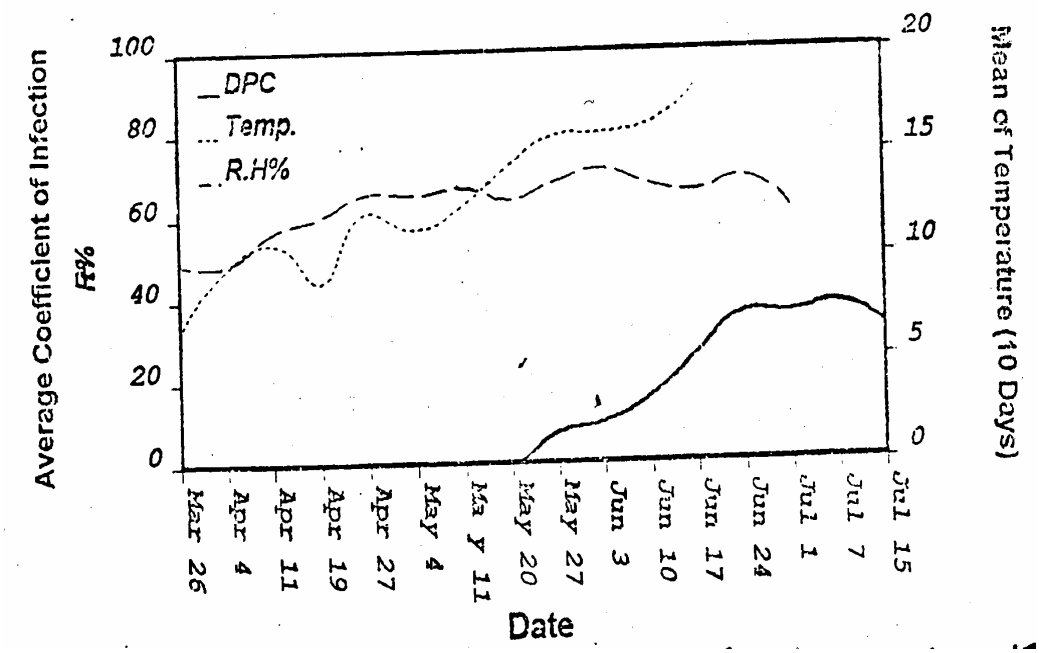


Figure 1. Disease progress curve (DPC) of yellow rust in relation to climatic factors in Ardebil region

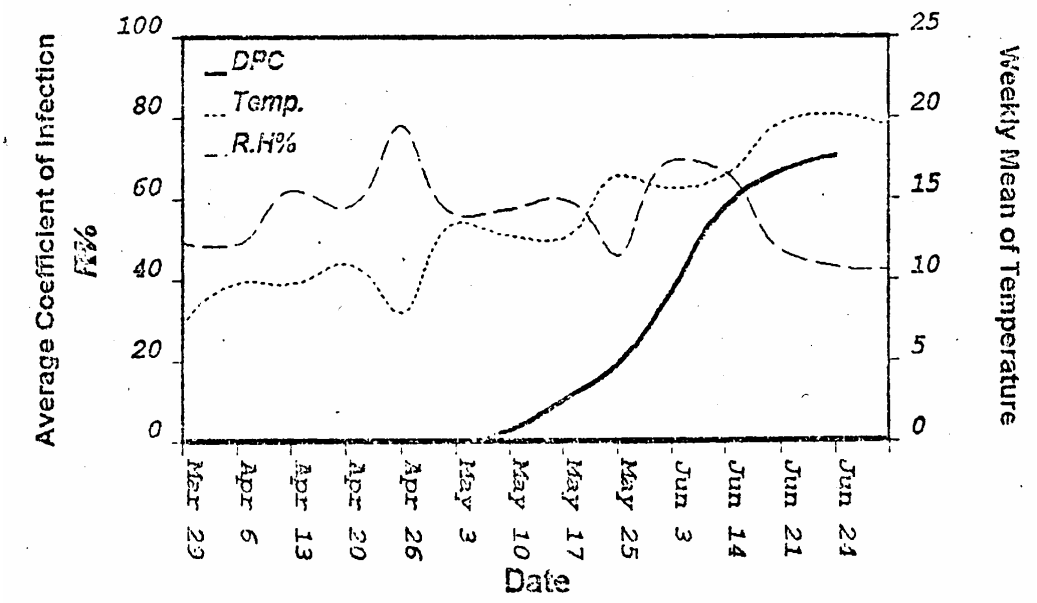


Figure 2. Disease progress curve (DPC) of yellow rust in relation to climatic factors in Hamedan region

Disease progress stopped, in general, when mean temperature reached about 20°C for five consecutive days.

Primary infection and disease development during the growing season (March–June) were not only strongly correlated with weather parameters in the growing season, but also with the amount of viable pathogen inoculum surviving on volunteer wheat and grass hosts during summer, and latent infections of seedlings in the new crop during autumn and winter months.

Mild temperature during summer (June–September) had positive effects on survival of the inoculum and time of primary infection in the emerging crop.

Over-summering

Yellow rust pustules were found on volunteer wheat in fields after harvest in some areas. In cold regions, where the new crop is sown at the end of September, it is very likely that infection on volunteer wheat has an important role in transmission of infection to the new crop.

Twenty-three grass species carrying pustules of yellow rust were collected from different provinces. Yellow rust from thirteen of those proved to be pathogenic on wheat (Table 2). Infections of yellow rust on wild grasses were active up to September in some areas, suggesting that spores can easily be transmitted from these to the new wheat crop.

Over-wintering

Latent infections of yellow rust were detected on seedling leaves during autumn and winter months (October–January). In 1996, in Mazandaran, where temperature was favourable for rust development in autumn, heavy infection of yellow rust was observed in November on the first and second leaves of seedlings of Falat. A similar situation was observed in west Azarbaijan in the same year.

In many other provinces, primary latent infection occurred during November to January on newly sown wheat when temperatures rose to about 15°C.

In general, the four-year study showed that in years with mild temperature and suitable rainfall during spring and summer, a huge amount of spores are produced in fields. Some of these spores survive by infecting volunteer wheat and wild grass species in late-harvested fields and on wheat in the highlands. Spores move from over-summering sites to newly grown crops, and primary infections occur in primary leaves in fields, before snow fall. Infections may remain latent until favourable conditions are established. Development of disease in the primary growing season depends on the weather conditions in spring (February–May). Similar results have been reported by Nagarajan and Joshi (1985) in India, Roelfs (1985) in North America, Luig (1985) in Australia, and Zadoks and Bowman (1985) in Europe.

Occurrence of an epidemic does not always follow a specific rule, as several factors, including geographical location, air stream, wind direction, host cultivars and pathogen pathotype, are as important as the climatic conditions.

Table 2. Pathogenicity on wheat of yellow rust from wild grass species in Iran

Species	Location	Pathogenicity on Wheat
Hordeum spontaneum	West Azarbaijan, Kermanshah, Fars	+
H. glaucum	Fars, Kermanshah, Zanjan, Khorasan, Gorgan, Mazandaran	+
H. bulbosum	Fars	-
H. murinum	Karaj, Mazandaran, Gorgan, Fars	-
H. geniculatum	Fars	-
Hordeum sp.	Kermanshah, Fars, Mazandaran, Isfahan, West Azarbaijan	+
Aegilops crassa	Kermanshah, Fars, Khorasan, Moghan	+
Ae. crassa var. *crassa*	West Azarbaijan	+
Ae. cylindrica	Karaj, West Azarbaijan, Gorgan, Mazandaran	+
Ae. triuncialis	Khorasan, Mazandaran	+
Ae. (*Triticum*) *tauschii*	Kermanshah, Fars, Khorasan, West Azarbaijan, Karaj	+
Ae. kotschyi	West Azarbaijan, Moghan, Ardebil	-
Ae. squarrosa	Karaj	+
Agropyron repens	Fars	+
Biossiera squarrosa	Fars	-
Bromus tectorum	Fars, Gorgan	+
B. scoparius	Fars	+
Elymus hispidus var. *podporae*	Fars	-
Eremopyrum bonaepartis	Fars, Khorasan, Mazandaran	-
Bromus danthoniae	Fars	-
Heteranthelium piliferum	Fars	-
Poa trivialis	West Azarbaijan	-
Phalaris minor	West Azarbaijan	+

Notes: + = prescence; — = absence.

References

Luig, N.H. 1985. Epidemiology in Australia and New Zealand. pp. 301–328, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Nagarajan, S. & Joshi, L.M. 1985. Epidemiology in the Indian subcontinent. pp. 371–402, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Roelfs, A.P. 1985. Epidemiology in North America. pp. 403–434, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Torabi, M. 1980. Factors affecting an epidemic of yellow rust on wheat in the north-western and western regions of Iran. Proceedings of the Fifth European and Mediterranean Cereal Rusts Conference. 28 May–4 June, Bari and Rome, Italy.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildew Bulletin*, 23: 9–12.

Zadoks, J.C. & Bouwman, J.J. 1985. Epidemiology in Europe. pp. 329–369, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Identification of wheat yellow (stripe) rust pathotypes in Iran

F. Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

E-mail for correspondence: fafshari@hotmail.com

Abstract

Stripe rust in wheat caused by the fungus *Puccinia striiformis* f.sp. *tritici* is an important disease in Iran. In order to determine the stripe rust races and use the information in a breeding programme it is necessary to determine races and virulence factors of the pathogen flora. In this study, 15 isolates of the stripe rust pathogen were collected from different parts of Iran. Spores of each isolate, after multiplication, were inoculated on an international standard differential set in the greenhouse. According to the results, virulence on plant with genes *Yr2, Yr6, Yr7, Yr8, Yr9, Yr24, YrND* and *YrA* was detected. The majority of isolates with high frequency had virulence on plants with *Yr2, Yr6, Yr7, Yr9, YrA* and *Yr24* genes. No virulence was detected on plants with *Yr1, Yr3, Yr4, Yr5, Yr10, YrSP, YrCV, YrSU* and *YrSK*.

Introduction

Common wheat (*Triticum aestivum* L.) is probably the most important of all cultivated plants with respect to the nutrition of mankind because of its value as an energy-rich food source.

Wheat is a host for many groups of parasitic fungi, bacteria, viruses and insects. Major threats to wheat production on a worldwide basis come from one or more of the three rust diseases. Yellow rust (stripe rust) caused by *Puccinia striiformis* West. f.sp. *tritici* Eriks. and Henn. (*Pst*) is the most important rust disease in Iran. The annual value of losses due to stripe rust in Australia was estimated to be $AUS 139 million (Brennan and Murray, 1988). In 1994, an estimated 15% (1.5 million tonne) yield loss was caused by yellow rust in the national wheat crop in Iran (Torabi *et al.*, 1995). The occurrence of pathogenic variability in rust fungi led to considerable confusion and disagreement among early researchers of rust diseases. For example, Rudorf (1929; cited in Wellings, 1986) noted that some cultivars resistant in the USA were susceptible in Germany. This was due presumably to variation in pathotypes between geographical regions.

The wheat stripe rust pathogen oversummers on volunteer wheat and possibly certain species of *Aegilops, Agropyron, Bromus* and *Elymus* in Europe (Stubbs, 1985). Stripe rust uredospores can be wind-borne in a viable state for at least 800 km (Zadoks, 1961). O'Brien *et al*. (1980) reported the introduction of wheat stripe rust to Australia, which was probably aided by man. In 1980, the pathotype first found in Australia appeared in New Zealand, presumably having been air-borne from Australia, a distance of approximately 2000 km (Beresford, 1982). In Iran, yellow rust epidemics were recorded during the 1993/94 and 1994/95 seasons (Torabi *et al*., 1995), with crop losses estimated at 1.5 and 1 million tonne, respectively. In Yemen and Ethiopia, early yellow rust epidemics have been recorded since 1988 (Mamluk, EL-Naimi and Hakim, 1996). Torabi *et al.* (2001) noted that the majority of Iranian yellow rust pathotypes had virulence on plant with genes *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23* and *YrA.* Surveys of *Pst* pathotypes and the genetic variation within the pathotypes are important and valuable information for the breeding programme. This study reports on the prevailing pathotypes of the wheat yellow rust pathogen in Iran.

Materials and methods

For this study, 15 isolates of stripe rust agent were collected from different parts of Iran, including Gazvein, Mogan, Dezful, Islam Abad, Hamadan, Sari, Maneh, Mashhad, Borojerd, Darab, Gachsaran and Ahvaz, Yazd, with one isolate from Kyrgyzstan. Spores of each isolate, after increasing, were inoculated on an international standard differential set of yellow rust lines in the greenhouse. A set of the World (8 genotypes) and European (8 genotypes) wheat yellow rust differentials, as proposed by Johnson *et al.* (1972), was used in the study, in addition to 10 supplementary varieties that included Federation*4/Kavkas (*Yr9*), Anza (*YrA*), Avocet R (*YrA*), Kalyansona (*Yr2*), *Triticum spelta* var. *album* (*Yr5*), TP981 (*Yr25*), Meering 24 (*Yr24*), Bolani (susceptible check), Avocet S and TP 1295.

For inoculation, uredospores were mixed with talcum powder (1:4). After each inoculation, spray equipment was thoroughly washed in water and dried in an oven at 60°C to avoid contamination when successively inoculating with different pathotypes. Inoculation conditions consisted of a tray with a base tray containing 2 cm of tap water. After inoculation, the seedlings were placed in the trays and covered with plastic hoods. Trays were placed in an incubation room at 10°C where the differential temperatures between the water and room temperature resulted in dew formation. Seedlings were held for 24 h at 10°C and 100% RH in the dark. Following incubation, plants were moved to a greenhouse. The temperature was maintained at 18 to 19°C for yellow rust. Infection types were recorded 16–19 days after inoculation, depending upon the disease and temperature. The objective was to record reactions when the

differences between the controls were at their maximum. Infection types were recorded using the 0–9 scale described by McNeal *et al*. (1971).

Results and discussion

Genetic variation in the yellow rust pathogen is continuously evolving in Iran. In the 2002/03 crop season, pathotypes from different parts of Iran were determined under greenhouse conditions (Table 1). The yellow rust population in the region consists of a number of pathotypes that differ in their pathogenicity toward the host plants. Some pathotypes, such as 6E0A+ (Sari) and 6E2A+ (Isalm Abad) can attack 2 and 3 resistance genes in the host plant. In contrast, some pathotypes, such as 134E130A+ (Yazd) and 166E6A+ (Gachsaran), have virulence on 10 identified genes in the host plants (Figure 1).

Table 1. Accession numbers and origins of yellow rust pathotypes (races) identified during the 2002/03 cropping season in Iran

No.	Acc. No.	Location	Race
1	81-101	Gazvin	6E130A+
2	81-67	Yazd	134E130A+
3	81-104	Mogan	6E150A+
4	82-3	Dezful	6E2A+
5	81-63	Mogan	6E150A+
6	81-110	Islam Abad	6E2A+
7	81-78	Hamadan	6E22A+
8	81-6	Sari	6E0A+
9	81-33	Maneh	4E8A+
10	81-31	Mashhad	130E2A+
11	81-22	Bojnord	130E4A+
12	81-14	Darab	6E4A+
13	81-30	Gachsaran	166E6A+
14	81-2	Ahvza	6E142A+
15	81-81	Gergizastan	6E142A+

According to the results, virulence on plants with genes *Yr2, Yr6, Yr7, Yr8, Yr9, Yr24, YrND* and *YrA* was detected. The majority of isolates with high frequency had virulence on plants with *Yr2, Yr6, Yr7, Yr9, YrA* and *Yr24* genes. No virulence was detected on plants with *Yr1, Yr3, Yr4, Yr5, Yr10, YrSP, YrCV, YrSU* and *YrSK(27)*. Torabi *et al.* (2001) reported that virulence was not detected for plants with genes *Yr1, Yr4, Yr5* and *Yr10*, and virulence on plants with genes *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23* and *YrA* was common in Iran. Of these, pathotypes possessing the combination of virulence for plants with *Yr7* and *Yr9* were particularly implicated in the epidemics on cv. Falat in Iran. Hakim *et al*. (2002) reported that the Iranian yellow rust pathotypes do not differ in their pathogenicity from those found in Syria and Lebanon.

The monitoring of yellow rust pathotypes and their change over time can be an important consideration for the breeding programme in Iran. The pathogen population should therefore be monitored regularly to determine whether new virulence genotypes have been introduced and developed in the different parts of Iran.

Figure1. Distribution of wheat yellow rust pathotypes during the 2002/03 cropping season in Iran

References

Beresford, R.M. 1982. Stripe Rust (*Puccinia striiformis*), a new disease of wheat in New Zealand. *Cereal Rusts Bulletin,* 10: 35–41.

Brennan, J.P. & G.M. Murray. 1988. Australian wheat diseases: assessing their economic importance. *Agricultural Science New Series* 1: 26–35.

Hakim, M.S., Yahyaoui, A., El-Naimi, M. & Maas, I. 2002. Wheat yellow rust pathotypes in Western Asia. pp. 55–61, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Johnson, R., Stubbs, R.W., Fuchs, E. & Chamberlain, N.H. 1972. Nomenclature for physiologic races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Mamluk, O.F., EL-Naimi, M. & Hakim, M.S. 1996. Host preference in *Puccinia striiformis* f.sp. *tritici*. pp. 86–88, *in:* Proceedings of the 9th European and Mediterranean Cereal Rusts and Powdery Mildews Conference. 2–6 September 1996, Lunteren, The Netherlands.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

O'Brien, L., Brown, J.S., Young, R.M. & Pascoe, T. 1980. Occurrence and distribution of wheat stripe rust in Victoria and susceptibility of commercial wheat cultivars. *Australasian Plant Pathology Society. Newsletter,* 9: 14.

Stubbs, R.W. 1985. Stripe Rust. pp. 61–101, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildew Bulletin*, 23: 9–12.

Torabi, M., Nazari, K., Afshari, F., Mardoukhi, V. & Malihipour, A. 2001. Seven-year pathotype survey of *Puccinia striiformis* f.sp. *tritici* in Iran. p. 69, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). First Regional Yellow Rust Conference for Central and West Asia and North Africa. 8–14 May, Karaj, Iran.

Wellings, C.R. 1986. Host:Pathogen studies of wheat stripe rust in Australia. PhD Thesis. University of Sydney, Australia. 237 p.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over Plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

Agriculture-guided evolution of pathotypes of *Puccinia striiformis* Westend f.sp. *tritici* in Pakistan

Munawar Hussain,[1] M.A.S. Kirmani[1] and Ehsanul Haque[2]

1. Crop Diseases Research Programme, National Agricultural Research Centre, Islamabad, Pakistan
2. Crop Diseases Research Programme, Sunny Bank, Murree, Pakistan

Introduction

Among the diseases of wheat (*Triticum aestivum*) prevalent in Pakistan, yellow rust (stripe rust) is becoming increasingly important in the cooler northern foothill areas of the Punjab, North West Frontier Province (NWFP), Azad Jammu and Kashmir, uplands of Baluchistan and Kohistan, and to a lesser extent in central Punjab and southern NWFP. It is practically absent from Sindh.

Our present knowledge of yellow rust in the Indian sub-continent is mainly based on the research work carried out by Mehta and co-workers. Mehta (1940) reported isolating races 19, 31 and A of yellow rust during 1930–1937 from the areas now forming Pakistan. Little work on identification of physiological races prevalent in Pakistan has since been done, except for a few samples collected from Murree that were analysed in 1965, which yielded races 20 and 31 (M. Hussain, unpublished). Vasudeva *et al.* (1952) identified yellow rust races 19, A and G from East Punjab in 1950. Later, races 20, 19, 38, A, 14, 31,13, 57 and G were isolated from east Punjab during 1965–1969 (Joshi *et al.*, 1977). Thus the yellow rust races collected by Vasudeva *et al.* (1952) and Joshi *et al.* (1977) prevalent in parts of India contiguous with Pakistan are likely to be present here due to free exchange of inoculum between the two countries. This assumption is further supported by the similarities of wheat rust races between India and Pakistan (Hassan and Hussain, 1975; Hassan, Kirmani and Hussain, 1965; Hussain, Aslam and Kirmani, 1989; Kirmani, 1980; Kirmani *et al.*, 1989; Stubbs and Van Silfhout, 1977; Stubbs *et al.*, 1974).

This paper presents the results of pathotyping and virulence evolution of pathogenic races of yellow rust during 1969–1995.

Materials and methods

Due to lack of controlled environment facilities and growth rooms, these studies were partly conducted at the Research Institute for Plant Protection (IPO), Wageningen, The Netherlands, which was the world centre for yellow rust pathotyping up to 1990 (Kirmani, 1980, 1986).

The rust samples were characterized using the World and European sets of differential wheat varieties, as proposed by Johnson *et al.* (1972).

The differential varieties were grown under controlled conditions in a climate room at ≈15°C with a 16-hour light period (Intensity ≈22 000 lux). After about 9–10 days, when the seedlings were at the one-leaf stage (≈10 cm), they were inoculated using spray inoculators in the isolating chamber having a circular base to obtain uniform spread of spores on the varieties. The inoculated plants were incubated at 9°C and 100% relative humidity (RH) for 24 h. The plants were later transferred to the climate room, with a light period of 16 h and illuminated at ≈26 000 lux. The temperature was maintained at 18°C day and 15°C night, with 75% RH. Observations were recorded 17 days after inoculation using the 0–9 scale proposed by McNeal *et al.* (1971). Infection types (IT) 1–6 were scored as avirulent, while IT 7–9 were classified as virulent.

Results and discussion

The yellow rust races 13, 14, 19, 20, 31, 38, 57, A and G identified from India and Pakistan from 1930 to 1969 (Table 1) by using the differentials of Gassner and Straib (1932) were virulent on *Yr1, Yr2, Yr6, Yr7* and uncatalogued resistance genes present in Webster, Suwon 92 and Holzapfels Fruh (Stubbs, 1985). Amongst these races, 20 and 31 were most virulent, and races 14 and 57 least virulent.

From the data it appears that *P. striiformis* samples analysed from Pakistan carried virulence for *Yr2, Yr6, Yr7, Yr Webster* and *YrSU*. The virulence of Webster has some similarities with cv. Selkirk and some Mexican wheats like Ciano 79, Crow, Buck Buck and Opata 85 displaying a distinctive seedling reaction. (Welling, 1992). The relative prevalence of races remained almost static till the late 1960s. It could be due to a large acreage under susceptible tall varieties and landraces, which may not have exerted selection pressure on the pathogen.

The pathotype survey conducted partly in Pakistan and using the facilities of IPO, Wageningen, revealed the presence of 46 race groups during the 1969–1995 period. Of these, pathotypes 6E16, 6(38)E16, 7E150, 38E16, 66E0 and 134E150 were most prevalent and virulent (Kirmani 1980, 1986; Louwers, Van Silfhout and Stubbs, 1992; Stubbs, 1973, 1975, 1984; Stubbs and Silfhout, 1977; Stubbs *et al.*, 1974). Virulence for *Yr1, Yr2, Yr3, Yr4, Yr6, Yr7, Yr8, Yr9, Yr10,*

Yr SD, Yr SU and *YrA* was observed. Thus virulences were recorded on almost all differential hosts included in the World and European sets. They were avirulent only on Carsten V and Spalding Prolific.

Table 1. Yellow rust races identified in India and Pakistan during 1930–1969 and their seedling reaction on some differential varieties

Yellow rust race	Differential wheat varieties					
	Webster Fruh	Holzapfels	Kolben Heines	Chinese 166	Suwon 92 ×Omar	Lee
13	V	•	•	V	V	–
14	•	•	•	•	V	–
19	•	•	V	•	V	–
20	V	V	V	•	V	V
31	V	V	V	V	V	V
38	V	V	•	•	V	V
57	•	•	•	•	V	–
A	V	•	V	•	V	–
G	•	•	V	•	V	–

KEY: V = virulence; • = avirulence; – = absence of data. SOURCES: Gassner and Straib, 1932, and Johnson *et al.*, 1972.

The list of test differentials along with resistance gene loci and the year of first detection of virulence is presented in Table 2. The data suggest that the wheat breeders have little or no choice when breeding varieties with race-specific resistance. It is logical and timely to evaluate adult plant resistance genes at hot-spot locations against the natural populations of yellow rust.

Most of the virulences were first detected in India, followed by Pakistan. Virulence on *YrA* was detected in India during 1973 and in Pakistan in 1977. Similarly, Vilmorin and Hybrid 46 virulences were reported from India in 1982 and 1989 respectively. In Pakistan, these virulences were encountered in 1983 and 1990 respectively. The only exception was virulence of *Yr9*. It was reported from Iran in 1992, Pakistan in 1994 and India in 1996 (Saari, 1996). The early detection of virulence on *Yr9* in Pakistan may be attributed to large-scale cultivation of wheat cultivars possessing *Yr9* resistance. Changes in virulence of yellow rust in the neighbouring countries emphasize the need for more regional cooperation and exchange of information.

The evolution of yellow rust virulence is presented in Table 3. It illustrates step-by-step increase of virulence in races either due to mutation or introduction, although somatic recombination could not be excluded. However studies were not carried out to verify this hypothesis. It also demonstrates the unintentional inputs of modern agriculture in the evolution of yellow rust.

Table 2. Test differentials, resistance gene loci and year of first detection of virulence in Pakistani populations of *Puccinia striiformis*, 1969–1995

Test Differential	Resistance gene locus	Year of detection of virulence
Suwon 92×Omar	–	1969
Chinese 166	*Yr1*	1969
Lee	*Yr7*	1969
Compair	*Yr8*	1970
Heines Kolben	*Yr6* + *Yr2*	1973
Avocet	*YrA*	1977
Strubes Dickopf	–	1977
Moro	*Yr10*	1979
Vilmorin	*Yr3*+	1983
Heines VII	*Yr2*	1983
Heines Peko	*Yr6* + *Yr2*	1983
Reichersberg 42	*Yr7*	1983
Hybrid 46	*Yr4*+	1990
Nord Desprez	*Yr3*+	1990
Clement	*Yr9* + *Yr2*	1994
Carsten V	–	–
Spalding Prolific	–	–

Table 3. Step-wise evolution in the virulence spectrum of yellow rust pathotypes and their response to wheat cultivars

Period	Predominant pathotypes	Virulence factors	Resistant cultivars	Susceptible cultivars
1969–70	64E0, 66E0, 67E0, 66E(16)	*Yr1, Yr7, Yr8,YrSU*	Mexipak, Mangla 68, Khushal 69, Barani 70 Chenab 70	C 271, C 273, C 591, Local White
1973–76	6E16, 7E16, 66E0, 66E16, 70E16, 71E16	*Yr1, Yr6+2, Yr7, Yr8*	Blue Silver, Lyall 73, Nuri, Pari, Sandal, Torim, SA 42, SA 75	Mexipak, Mangla, Khushal, Barani 70, Chenab 70, Yecora
1977–80	6E16, 6(38)E16, 38E16	*Yr6+2, Yr7 Yr8, St. Dick YrA*		Arz, BWP 79, Chenab 79, Blue Silver, Lyallpur 73 Nuri, Pari, Sandal, Torim, Yecora, Sonalika, WL 711
1981–93	2(70)E16, 6E0, 6E16, 7E150, 7(15)E150, 70E0(16), 70E16, 66E17, 68E0	*Yr1, Yr2, Yr3 Yr4, Yr6+2, Yr7, Yr8, YrSU, YrA*	PAK 81, Pirsbak 85, PB 85,Sarhad 82, FLD 85, Sutlej, Rawal, Rohtas, Pasban, Kohinoor, Pirsbk 91, Khyber 87, Kaghan 93	PB 81, LU 26, Pavon, BWP 79, Chenab 79, Lyall 73, Blue Silver, Sonalika, Barani 83, FLD 83, Indus 79
1994–95	134E150	*Yr2, Yr6+2 Yr7, Yr8 Yr9, YrA*		PAK 81, Pirsbk 85, Pirsbk 91, PB 85, FLD 85, Sutlej, Rawal Rohtas, Pasban, Khyber 87, Kohinoor, Kaghan 93

The data presented in Table 3 show that during 1969–70 pathotypes 64E0, 66E0, 67E0 and 66E(16) were predominant. These pathotypes carry virulence on genes *Yr1, Yr7, Yr8* and *YrSU.* The local tall varieties like C 271, C 273, C 591 and Local White were susceptible to these pathotypes, but the extensively cultivated semi–dwarf varieties Mexipak, Mangla 68, Khushal 69, Barani 70 and Chenab 70 were resistant. The reduction in the acreage of rust-susceptible varieties coupled with large-scale cultivation of resistant cultivars from wheat breeders subjected the pathogen to selection pressure. As a result, cvs Mexipak, Chenab 70, Barani 70, Khushal and Mangla succumbed to an aggressive form of pathotype 66E0 and 70E16 during 1973. These pathotypes remained most prevalent during 1973–76. The wheat cvs SA 42, Blue Silver and SA 75 possessing *YrA*, and cvs Pari 73, Sandal, Yecora and Lyallpur 73 possessing *YrA* and *Yr6*, remained resistant to these pathotypes as the pathogen did not have matching virulence. During 1977–80, more cvs having *YrA,* such as Arz, Sonalika, Chenab 79 and Jauhar 78, were released for cultivation. As a result of the large acreage of wheat having *YrA,* the pathotypes acquired matching virulence for *YrA.* Due to selection, the frequency of races changed and races 6E16, 6(38)E16 and 38E16 appeared. These pathotypes were able to infect *Yr6+2, Yr7, Yr8, YrSD* and *YrA.* The cultivars Arz, Blue Silver, Sonalika, Bahawalpur 79, Chenab 79 and Nuri, all possessing *YrA,* and cultivars possessing *YrA* or *Yr6,* or both, such as LU 26, Lyallpur 73, Pari, Sandal, and Yecora, became susceptible (Hussain *et al.,* 1988; Kirmani, 1986; Pervaiz and Johnson, 1986). These pathotypes were mostly responsible for the yellow rust epidemic of 1978.

During 1980–93, a number of wheats with 1B/1R translocation carrying host gene *Yr9* singly or in combination with *Yr7* were released. The pathogen population prevalent during this period, such as 2(70)E16, 7E150, 7(15)E150 and 66E17, were avirulent on *Yr9*. By the late 1980s and early 1990s these genotypically similar cultivars occupied the major area in the yellow rust-prone area of Pakistan. Sporadic progressive increase in virulence was observed on some of the cultivars. Finally there was a yellow rust epidemic in 1995 that caused an estimated Rs 270 million loss. The 1997 and 1998 epidemics caused a loss of Rs 2 billion. The pathotype 134E150 was responsible for these epidemics. Wheat cultivars Pak 81, Kohinoor, Faisalabad 85, Pirsabak 85, Pirsabak 91, Punjab 85, Sutlej, Khyber 87, Rawal, Rohtas, Pasban, Bakhtawar 93 and Kaghan 93 were amongst those found susceptible.

It is evident from these studies that during the course of evolution of yellow rust influenced by humans, races with low virulence (64E0) have developed into pathotypes with higher virulence (Table 4).

The data suggest that the distribution of the factors of virulence of yellow rust is closely related to the factors of resistance of the cultivated host varieties, and the evolution of yellow rust develops in the same direction as the human-guided evolution of host varieties.

Table 4. Example of increased virulence of yellow rust of wheat in Pakistan, 1969–1995

Pathotype	Virulence number	Factors designation
64E0	1	64
6E0	2	2, 64
6E16	3	2, 4, E16
38E16	4	2, 4. 32, E16
71E16	5	1, 2, 4, 64, E16
7E150	7	1, 2, 4, E2, 4, 16, 128
134E150	7	2, 4, 128, E2, 4, 16, 128

NOTES: 'Factors designation' values refer to the decanery values of the differential wheat varieties (Johnson *et al.,* 1972).

Conclusion

A practical approach to reducing the susceptibility of cultivars to changes in virulence is to diversify by growing a number of cultivars with different sources of resistance. This slows the progress of epidemics because it is unlikely that the pathogen would acquire virulence for all the resistances simultaneously.

References

Gassner, G. & Straib, W. 1932. Dei Bestimmung der biologi schem Rassen des Weizengelbrostes (*Puccinia glumarun* f.sp. *tritici* (Schmidt Erikss-Und. Henn). *Arb. der biol. Reich. Fur Land und Forst.*, Berlin, 20: 141–163.

Hassan, S.F. & Hussain, M. 1975. Occurrence of race 117 of *Puccinia graminis* var. *tritici* in Pakistan. *Agriculture Pakistan,* 26: 261–264.

Hussain, M., Aslam, M. & Kirmani, M.A.S. 1989. Occurrence of a new pathotype of leaf rust of wheat and its impact on wheat production in Pakistan. *Cereal Rust and Powdery Mildew Bulletin,* 17: 16–19.

Hassan, S.F., Kirmani, M.A.S. & Hussain, M. 1965. Physiologic races of stem rust of wheat in Pakistan during 1961–64. *West Pakistan Journal of Agricultural Research,* 3: 17–20.

Hussain, M., Hakro, A.A., Aslam, M. & Gordon-Werner, E. 1988. Postulated genes for rust resistance in Pakistani wheats. pp. 33–35, *in:* Proc. of the 7th European & Mediterranean Cereal Rusts Conference, Vienna, Austria.

Johnson, R., Stubbs, R.W., Fuchs, E., Chamberlaine, N.H. 1972. Nomenclature for physiological races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Joshi, L.M., Singh, S., Goel, L.B., Ahmed, S.T., Joshi, P.C., Madan Mohan, Sharma, S.K. & Sharma, R.C. 1977. Prevalence and distribution of physiologic races of wheat and barley rusts in India. *Indian Phytopathology,* 30: 299–305.

Kirmani, M.A.S. 1980. Comparative evaluation of wheat varieties from Pakistan against stripe rust in seedling stage. IPO, The Netherlands.

Kirmani, M.A.S. 1986. Preliminary information about the genetic analysis of Pakistani wheat cultivars against stripe rust in seedling stage. IPO, The Netherlands.

Kirmani, M.A.S., Hussain, M., Aslam, M. & Hamid, S.J. 1989. Distribution of stripe rust virulences of wheat and varietal response in Pakistan. *Pakistan Journal of Botany,* 21(2): 313–317.

Louwers, J.M., Van Silfhout C.H. & Stubbs R.W. 1992. Race analysis of yellow rust in wheat in developing countries. Report 1990–92. Research Institute for Plant Protection (IPO), Wageningen, The Netherlands.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin,* 34-121: 1–42.

Mehta, K.C. 1940. Further studies on cereal rusts in India. *Imperial Council for Agricultural Research Scientific Monograph*, No. 14. 118 p

Pervaiz, M.S. & Johnson, R. 1986. Genes for resistance to yellow rust in seedlings of wheat cultivars from Pakistan tested with British isolates of *Puccinia striiformis. Zeitschrift für Pflanzenzüchtung*, 97: 289–296.

Saari, E.E. 1996. The *Yr9* virulence factor in *Puccinia striiformis* and South Asia: co-evolution or migration from a distant place? p. 142, *in:* Proc. of the 9th European and Mediterranean Cereal Rusts and Powdery Mildews Conference. Lunteren, The Netherlands.

Stubbs, R.W. 1973. International survey of factors of virulence. Stripe rust samples identified at Wageningen in 1973. IPO, The Netherlands.

Stubbs, R.W. 1975. International survey of factors of virulence. Stripe rust samples identified at Wageningen in 1975. IPO, The Netherlands.

Stubbs, R.W. 1984. Report. Research Institute for Plant Protection (IPO), Wageningen, The Netherlands.

Stubbs, R.W. 1985. Stripe rust. pp. 61–101, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Stubbs, R.W. & Van Silfhout, C.H. 1977. International survey of factors of virulence. Rust samples identified in Wageningen in 1976 and 1977. Report. IPO, The Netherlands.

Stubbs, R.W., Fuchs, E., Vecht, H. & Basset, E.J. 1974. The international survey of factors of *Puccinia striiformis* Westend in 1969, 1970 and 1971.

Vasudeva, R.S., Lele, V.C. & Joshi. L.M. 1952. Occurrence of physiologic races of wheat rusts in India during 1949–50. *Indian Phytopathology,* 5(2): 63–65.

Wellings, C.R. 1992. Resistance to stripe (yellow) rust in selected spring wheats. *Vortrage fur Pflanzentuchtung*, 24: 273–275.

Development of molecular markers for slow-rusting resistance to yellow rust

G.M. Rosewarne,[1] R.P. Singh,[1] M. William[1] and J. Huerta-Espino[2]

1. International Maize and Wheat Improvement Centre (CIMMYT), Mexico
2 Campo Experimental Valle de Mexico-INIFAP, Chapingo, Edo. de Mexico, Mexico

Introduction

Resistance to yellow rust has often been achieved through the use of race-specific genes that elicit a hypersensitive response and programmed cell death in infected leaf tissue. Although this type of resistance often provides immunity against rust pathogens, resistance is relatively short-lived, with the emergence in a few years of new pathotypes overcoming the race-specific form of resistance. This can result in epidemics when cultivars with single resistance genes are deployed over large areas. Non-race-specific resistance, although not conferring immunity, has, in many cases, been shown to be durable (Johnson, 1988). These types of genes have small, incremental, effects in slowing infection (increased latent period, smaller and fewer pustules, etc.) and are often called slow-rusting genes. To achieve adequate protection, multiple non-race-specific genes need to be incorporated into a single genotype (Singh, Huerta-Espino and Rajaram, 2000). As these types of genes often have minor, additive effects against the pathogen, it can be difficult to determine how many non-race-specific genes a variety carries. Furthermore, wheat varieties that contain effective race-specific resistances cannot be assayed in the field for underlying non-race-specific genes. These problems can be overcome through the development of molecular markers for the non-race-specific genes. Molecular markers will provide an understanding of the level of diversity of these genes in wheat and facilitate the incorporation of multiple genes into wheat breeding programmes.

Materials and methods

A population was developed from a cross between the yellow rust-susceptible line Avocet "S" and a line of Attila that shows a moderate level of non-race-specific resistance to both leaf and yellow rusts. The 148 F_2 plant-derived F_5 Single Seed Descent (SSD) lines were evaluated in the field for both types of

rust infection at the CIMMYT station in Toluca, near Mexico City, for yellow rust, and the Obregon station in Sonora State, Mexico, for leaf rust. Approximately 80 seeds of each line were sown in 75 cm wide paired-row plots, 1 m in length, with 20 cm inter-row spacing and a 50 cm pathway between plots. Rust epidemics were initiated about 4 weeks and 8 weeks after planting (yellow rust and leaf rust respectively) by inoculating a susceptible spreader row of cv. Morocco planted on one side of the plots in the pathway. To start the epidemic, Morocco was sprayed with a suspension of rust urediniospores in lightweight mineral oil (Soltrol 170, from Phillips 66 Co., Bartesville, OK, USA). The percentage infection of rust was evaluated in three growing seasons (growing seasons 2000, 2002 and 2003 for yellow rust and 2000, 2002 and 2004 for leaf rust) in non-replicated field trials. Infection was measured when the susceptible parent showed between 80 and 100% infection on the flag leaf.

All lines were grown in the greenhouse in 10 cm pots (10 seeds per pot) for 5 weeks for DNA extraction using a CTAB (alkyltrimethyl-ammonium bromide) based extraction system (Hoisington, Khairallah and Gonzalez-de-Leon, 1994). Initial molecular studies focused on lines that had phenotypes similar to the parents. These were termed Homozygous Parental Type Resistant (HPTR) (12 lines for leaf rust and 10 lines for yellow rust) and Homozygous Parental Type Susceptible (HPTS) (10 lines being susceptible to both pathogens). An Amplified Fragment Length Polymorphism (AFLP) technique was used to identify polymorphisms between the different pools of DNA (Hoisington, Khairallah and Gonzalez-de-Leon, 1994). Briefly, DNA was digested with the restriction enzymes *Pst1* and *Mse1*, adaptors ligated to the DNA and pre-amplified with a polymerase chain reaction (PCR) protocol. Equal quantities of pre-amplified DNA from the HPTR and HPTS lines were pooled for a Bulked Segregant Analysis (BSA), resulting in three pools of DNA, namely HPTR (leaf rust), HPTR (yellow rust) and HPTS (both rusts). AFLP analysis was done using a total of 192 primer combinations. Primer combinations that gave polymorphisms between the pooled DNA samples were then used on the individual DNA samples that made up the bulks. Primer combinations that identified polymorphisms consistently were screened across the entire population.

Results and discussion

Field results

The level of rust infection was consistent over the three years in which the measurements were taken. In the case of yellow rust, the susceptible parent, Avocet "S", had an average infection level of 93% leaf area infected, and the resistant parent, Attila, had 12% of the leaf area infected. The Pearson Correlation Coefficient was used to determine the level of correlation between

years. Yellow rust infection was highly correlated between all years, with r being 0.57 for years 1 and 2, 0.86 for years 1 and 3 and 0.66 for years 2 and 3 (all significant at $P<0.01$). This is a strong indication of the consistency of the data, with differences between the levels of infection among lines being genetically determined. Similar correlations were obtained between the different years for leaf rust (data not shown). Furthermore, there was a high level of correlation between the average leaf rust and average yellow rust results ($r = 0.76$, $P<0.01$). This suggests that either closely linked or identical genetic determinants give rise to resistance against the two pathogens. The data for individual lines were pooled and the average percentage leaf area covered by yellow rust in lines was plotted (Figure 1). The population had a continuous distribution with regards to yellow rust infection. The number of genes conferring resistance was estimated by comparing the observed frequencies of lines that resembled each of the parents, with frequencies that would be expected in an F_5 generation if 2, 3 or 4 genes conferred resistance in one of the parents. To calculate the most likely number of genes conferring resistance, lines were classified into 3 categories: HPTR lines (up to 20% leaf area covered by yellow rust), HPTS lines (81–100% leaf area covered), and others (intermediate levels of leaf area covered). The frequency of observed lines in each category, along with expected values for 2, 3 and 4 genes, is summarized in Table 1. The χ^2 values represent an acceptance of the hypothesis that 3 genes confer resistance and a rejection that either 2 or 4 genes confer resistance ($P<0.01$). Lines that were consistently similar to the parental types were chosen for molecular analysis.

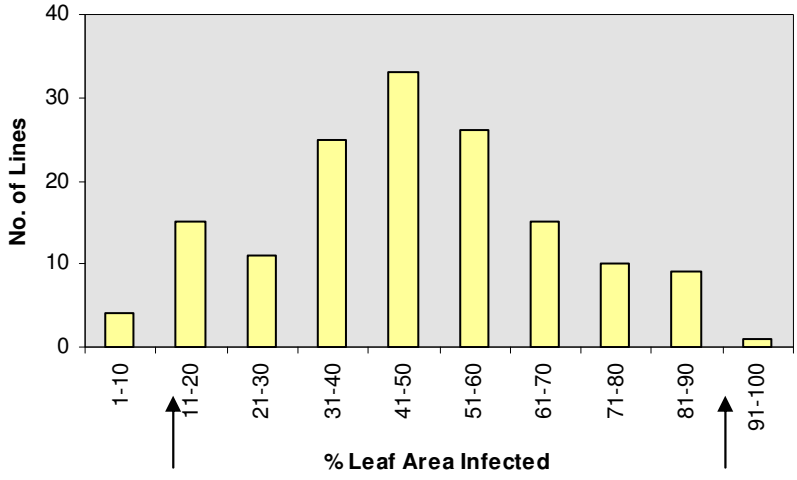


Figure 1. Percentag of leaf area infected by yellow rust on individual lines from the Avocet "S"×Attila population averaged over 3 years of field data. Arrows indicate % leaf area infected on “S" (right arrow) and Attila (left arrow).

Table 1. Estimation of the number of additive, non-race-specific genes for yellow rust through the identification of HPTR, HPTS and intermediate lines in the Avocet "S"×Attila F_5 population of 148 lines

	Frequency of responses			
	HPTR	**HPTS**	**Other**	**χ2**
Observed frequency	18	10	120	
Expected frequency, 2 genes	28.33	28.33	91.34	24.6**
Expected frequency, 3 genes	12.39	12.39	123.22	3.1
Expected frequency, 4 genes	5.42	5.42	137.16	35.5**

NOTES: ** indicates significant χ^2 value at P=0.01. HPTR = Homozygous Parental Type Resistant; HPTS = Homozygous Parental Type Susceptible

AFLP analysis

DNA samples were pooled to make bulks for the rapid screening of different primer combinations in an AFLP analysis. In total, 192 primer combinations were used and 22 potential polymorphisms were identified for further investigations. The potential polymorphisms were analysed on the individual lines that made up the bulks. Five polymorphisms showed high levels of association, in either coupling or repulsion, with resistance (Table 2). Of these polymorphisms, two had been previously identified as being associated with the non-race-specific rust resistance gene complex *Lr46/Yr29* (William *et al.*, 2002). Furthermore, analysis of the initial 32 homozygous parental type lines indicate that the new markers are likely to be more closely associated with resistance than the existing *Lr46/Yr29* markers. It was not known whether the 3 new polymorphisms were associated with *Lr46/Yr29* or a different slow-rusting gene. The levels of recombination between one of the known *Lr46/Yr29* markers and the three new markers were therefore measured on the entire population of 148 lines. The results show that the three new markers segregated in 79% or 82% of lines with the known *Lr46/Yr29* markers (Table 3), suggesting the new markers are associated with the *Lr46/Yr29* locus. Furthermore, in this population, the new markers accounted for a larger reduction in disease severity of both leaf rust and yellow rust than did the known *Lr46/Yr29* marker (Table 3). This supports the notion that the new markers are more closely associated with *Lr46/Yr29* than previously identified markers.

Table 2. AFLP polymorphisms associated with resistant lines (in coupling or repulsion)

Primer combination	Polymorphism in LR resistant lines	Polymorphism in YR resistant lines	Polymorphism in susceptible lines	% association with LR resistance	% association with YR resistance
TCC/GTT	12/12	10/10	0/10	100	100
TCG/GCA	12/12	10/10	0/10	100	100
AAG/CGA*	2/11	0/10	11/11	91	100
AAG/CTA*	10/11	10/10	1/10	90	95
ACA/CGA	2/11	0/10	11/11	91	100

NOTES: * denotes previously associated with *Lr46/Yr29.* LR = leaf rust; YR = yellow rust.

Table 3. Summary of analysis of markers across entire Avocet "S"×Attila population to determine the level of association between markers and the amount each marker contributes to a reduction in disease severity of both leaf rust and yellow rust

	AAG/CTA (*Lr46*)	TCC/GTT	TCG/GCA	ACA/CGA	% reduction LR severity	% reduction YR severity
AAG/CTA (*Lr46*)	100	79	82	82	36	20
TCC/GTT	–	100	98	86	51	29
TCG/GCA	–	–	100	86	48	26
ACA/CGA	–	–	–	100	46	27

NOTES: LR = leaf rust; YR = yellow rust.

References

Hoisington D., Khairallah M. & Gonzalez-de-Leon D. 1994. *Laboratory Protocols: CIMMYT Applied Molecular Genetics Laboratory*. 2nd Ed. CIMMYT, Mexico, D.F., Mexico.

Johnson, R. 1988. Durable resistance to yellow (stripe) rust in wheat and its implications in plant breeding. pp. 63-75, *in:* N.W. Simmonds and S. Rajaram (editors). *Breeding Strategies for Resistance to the Rusts of Wheat*. CIMMYT, Mexico, D.F., Mexico.

Singh, R.P., Huerta-Espino, J. & Rajaram S. 2000. Achieving near-immunity to leaf and stripe rusts in wheat by combining slow-rusting resistance genes. *Acta Phytopathologica et Entomologica Hungarica,* 35: 133–139.

William, M., Singh, R.P., Huerta-Espino, J., Ortiz Islas, S. & Hoisington, D. 2002. Molecular marker mapping of leaf rust resistance gene *Lr46* and its association with stripe rust resistance gene *Yr29* in wheat. *Genetics and Resistance*, 93: 153–159.

Resistance to stripe rust disease of wheat in *Aegilops speltoides* × durum, and their parents

Javed Iqbal Mirza,[1] Abdul Mujeeb Kazi,[2] Iftikhar Ahmad[1] and Atiq-ur-Rehman Rattu[1]

1. Crop Diseases Research Programme, Institute of Plant and Environmental Protection, NARC, Islamabad, Pakistan
2. International Maize and Wheat Improvement Centre (CIMMYT), Mexico

Abstract

Twenty-one *Aegilops speltoides* × durum lines, 5 durum parents and 32 *Ae. speltoides* accessions, including 14 parents, were screened against the prevailing races of stripe rust. Six of the *Ae. speltoides* × durum lines were found immune, 4 resistant and 2 moderately resistant. Four out of 5 durum parents were resistant to the stripe rust races used. Three of the *Ae. speltoides* accessions screened were immune, 9 resistant and 4 moderately resistant to the inoculums of stripe [yellow] rust used. Analysis of the data indicates that the resistance in some of the lines is inherited from durum parents, while in others from *Ae. speltoides.* In a few cases, resistance seems to be derived from both parents.

Introduction

Stripe [yellow] rust of wheat, caused by *Puccinia striiformis,* is an important cereal rust disease in wheat growing regions of the world, especially in areas with cool and wet environmental conditions (Roelfs, Singh and Saari, 1992). Many epidemics have been reported in diverse areas, including China (Saari and Prescott, 1985), continental Europe, Australia, Ethiopia (Johnson, 1992), USA (Line, 1976; Roelfs, 1978), and in the Indo-Pakistan subcontinent (Tahir, 1978; Kidwai, 1979). Although chemical application and cultural practices have been adopted effectively in controlling an outbreak of this disease (Line, 1982), genetic resistance is the most economical and environmentally safe approach. Related wild progenitor and non-progenitor species of wheat represent a large reservoir of useful variability that can be exploited for wheat improvement. Wide hybridization has contributed significantly to germplasm enhancement of bread wheat. Many agronomically important traits, including resistance to diseases, pests and abiotic stresses have been transferred from related species

and genera into wheat (Knott and Dvorak, 1976; Sharma and Gill, 1983) and exploited commercially.

Germplasm of various *Triticum* species has been screened for resistance to stripe rust. Resistance sources have been identified in *Triticum monococcum* and *T. timopheevii* (Mikhova, 1988), *T. dicoccoides* (The, Nevo and McIntosh, 1993) and a number of *Aegilops* species (Damania and Pecetti, 1990).

In this study, diversity for stripe rust resistance in *T. turgidum*, *Ae. speltoides* and derivatives of *T. turgidum* × *Ae. speltoides* crosses were evaluated for use in future to manage stripe rust disease of wheat.

Material and methods

A set of 21 *Ae. speltoides* × durum lines, 5 durum parents and 32 *Ae. speltoides* accessions, including 14 parents, were planted in 15-cm diameter pots under glasshouse conditions at CDRP Murree substation. Four- to six-week-old plants were inoculated with urediospore suspensions of bulk inoculum suspended in mineral oil and petroleum ether (50:50). The bulk inoculum had virulence for genes *Yr1, Yr3, YrSD, Yr5, Yr4, Yr7, Yr6+, YrCV* and *YrSP*. Inoculated plants were placed in open air for two hours to evaporate the oil. Plants were then transferred to a dew chamber set at 15–18°C in a growth room with a 16 h light and 8 h dark period for 24 h. Plants were then transferred to a greenhouse held at 10–15°C. Three weeks after inoculation the infection types were recorded on the plants when the susceptible check was showing maximum infection on a 0–9 scale (McNeal *et al.*, 1971).

Results and discussion

Among five durum parents screened, four lines, namely CROC1, CPI/GEDIZ/GOO/JO/CRA, D67.2/P66.270 and CETA, were resistant to the stripe rust inoculum used, while Arlin 1 was susceptible. Three of the *Ae. speltoides* accessions screened were immune, nine resistant and four moderately resistant to the inoculums of stripe rust used (Table 1).

Among crosses, accessions #1 and #3 seem to have derived resistance from their durum parent CPI/GEDIZ/GOO/JO/CRA, and accessions #8 and #9 inherit their resistance from CROC, as *Ae. speltoides* lines 124, 129, 134 and 137 lack resistance against the inoculum used (Table 2). Accessions #11 and #12 have inherited their resistance from *Ae. speltoides* (126) as one of their parents is susceptible durum accession D67.2/P66.270. Resistance in accessions #19 and #20 is inherited from resistant *Ae. speltoides* (144) and *Ae. speltoides* (146) respectively, as Arlin 1 is susceptible. The source of resistance for accession #21 is not clear as *Ae. speltoides* (144) was not available for screening; resistance

may be from the *Aegilops* parent as Arlin is susceptible. Resistance of accession #23 seems to be inherited from both parents.

Table 1. Reaction of *Ae. speltoides* and durum accessions to stripe rust pathogen

Acc. #	Accession	Reaction	Acc. #	Accession	Reaction
26	*Triticum turgidum* CROC 1	1	38	*Ae. speltoides* (131)	2
27	*Triticum turgidum* Arlin 1	8	39	*Ae. speltoides* (132)	2
28	*Triticum turgidum* CPI/GEDIZ/3/GOO//JO/CRA	1	40	*Ae. speltoides* (133)	7
29	*Triticum turgidum* D67.2/P66.270	1	34	*Ae. speltoides* (126)	3
30	*Triticum turgidum* CETA	1	43	*Ae. speltoides* (136)	2
31	*Ae. speltoides* (123)	0	44	*Ae. speltoides* (137)	2
32	*Ae. speltoides* (124)	6	45	*Ae. speltoides* (138)	7
33	*Ae. speltoides* (125)	3	46	*Ae. speltoides* (139)	4
41	*Ae. speltoides* (134)	8	47	*Ae. speltoides* (140)	6
42	*Ae. speltoides* (135)	9	48	*Ae. speltoides* (141)	7
52	*Ae. speltoides* (145)	8	49	*Ae. speltoides* (142)	7
35	*Ae. speltoides* (127)	8	53	*Ae. speltoides* (146)	6
36	*Ae. speltoides* (129)	8	54	*Ae. speltoides* (147)	2
55	*Ae. speltoides* (148)	9	57	*Ae. speltoides* (150)	1
56	*Ae. speltoides* (149)	9	58	*Ae. speltoides* (151)	7
60	*Ae. speltoides* (153)	8	65	*Ae. speltoides* (158)	0
61	*Ae. speltoides* (154)	9	66	*Ae. speltoides* (159)	2
68	*Ae. speltoides* (162)	8	67	*Ae. speltoides* (160)	0
37	*Ae. speltoides* (130)	1			

Table 2. Reaction of the lines derived from *Ae. speltoides* × durum crosses

Accession #	*Ae. speltoides* × durum cross	Reaction
1	CPI/GEDIZ/3/GOO//JO/CRA/4/AE.SPELTOIDES(124)	2
2	CETA/*Ae. speltoides* (124)	8
3	CPI/GEDIZ/3/GOO//JO/CRA/4/AE.SPELTOIDES(129)	3
5	ARLIN 1/*Ae. speltoides* (134)	8
6	CETA/*Ae. speltoides* (135)	8
7	CETA/*Ae. speltoides* (139)	8
8	CROC1/*Ae. speltoides* (134)	0
9	CROC1/*Ae. speltoides* (137)	0
10	CROC1/*Ae. speltoides* (149)	9
11	Arlin 1/*Ae. speltoides* (126)	0
12	D67.2/p66.270//*Ae. speltoides* (126)	0
13	ARLIN 1/*Ae. speltoides* (128)	9
14	ARLIN 1/*Ae. speltoides* (131)	8
15	D67.2/p66.270//*Ae. speltoides* (131)	8
16	ARLIN 1/*Ae. speltoides* (138)	0
18	ARLIN 1/*Ae. speltoides* (134)	7
19	ARLIN 1/*Ae. speltoides* (144)	2
20	ARLIN 1/*Ae. speltoides* (146)	45
21	CETA/*Ae. speltoides* (146)	0
23	CPI/GEDIZ/3/GOO//JO/CRA/4/AE.SPELTOIDES(147)	1
24	ARLIN 1/*Ae. speltoides* (150)	9

References

Damania, A.B. & Pecetti, L. 1990. Variability in collections of *Aegilops* species and evolution for yellow rust resistance at two locations in North Syria. *Journal of Genetics and Breeding*, 44: 97–102.

Line, R.F. 1976. Factors contributing to an epidemic of stripe rust on wheat in Sacramento Valley of California in 1974. *Plant Disease Reporter*, 60: 312–316.

Line, R.F. 1982. Chemical control of stripe rust and leaf rust of wheat in the Pacific North West. *Phytopathology*, 72: 338(Abst.).

Johnson, R. 1992. Reflection of a plant pathologist on breeding for disease resistance with emphasis on yellow rust and Eye Spot of wheat. *Plant Pathology*, 41: 239–254.

Kidwai, A. 1979. Pakistan re-organizes agricultural research after harvest disaster. *Nature*, 277: 169.

Knott, D.R. & Dvorak, J. 1976. Alien germplasm as source of resistance to disease. *Zeitschrift fur Pflanzenzucht*, 92: 15–21.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

Mikhova, S. 1988. Sources of resistance to yellow rust (*Puccinia striiformis* West.) in the genus *Triticum.* [In Russian with English abstract]. *Rasreniev dni-Nauki,* 25: 3–8.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States, 1918–1976. *USDA Miscellaneous Publication*, No. 1363. 85 p.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. *Rust Diseases of Wheat: Concepts and Methods of Disease Management.* CIMMYT, Mexico D.F., Mexico. 81 p.

Saari, E.E. & Prescott, J.M. 1985. World distribution in relation to economic losses. pp. 280–281, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Sharma, H.C. & Gill, B.S. 1983. Current status of wide hybridization in wheat. *Euphytica,* 32: 17–31.

Tahir, M. (editor). 1978. Wheat research and production in Pakistan. PARC, Islamabad, Pakistan.

The, T.T., Nevo, E. & McIntosh, R.A. 1993. Response of Israeli wild emmers to selected Australian pathotypes of *Puccinia* species. *Euphytica* 71: 75–81.

Inheritance of yellow rust resistance in advanced lines and commercial wheat varieties

A.M. Kokhmetova,[1] A.I. Morgunov,[2] R.A. Urazaliev,[3] M.A. Yessimbekova[3] and A.S. Absattarova[3]

1. Institute of Plant Physiology, Genetics and Bioengineering, Kazakhstan
2. CIMMYT
3. SFC of Agronomy and Soil Management, Almaty, Kazakhstan

Introduction

Yellow rust (*Puccinia striiformis* f.sp. *tritici*) is one of the most important diseases in the cereal world. In order to develop a breeding strategy to control stripe [yellow] rust in Kazakhstan it is necessary to have better knowledge of the genetic basis of resistance in potential donor varieties. In the Central Asia region, wheat yellow rust over the past few years has been among the major factors adversely affecting wheat yield and quality, causing considerable economic damage. During the epidemic of 2001/03, most widely grown high yielding cultivars had severe stripe rust. The area affected by yellow rust in Kazakhstan and Uzbekistan was estimated to be as high as 1.5 million ha.

Use of genetic host resistance is an effective, economical and environmentally safe method of controlling stripe rust (Johnson and Bimb, 1997; Kumar *et al.,* 1999). The most effective type of resistance is durable resistance based on additive effects of slow-rusting genes (Singh, Huerta-Espino and William, 2002). There are about 35 identified genes conditioning resistance to *Puccinia striiformis*. Only 7 of them are effective in Kazakhstan. The results of previous studies showed that a number of entries (cvs Almaly, Adir, Arap and Sultan) are possible sources of resistance against the local pathogen population of yellow rust. For effective use of sources of resistance as donors it is necessary to clarify the genetic base of the material.

Materials and methods

A total of 150 wheat genotypes were included in field tests, a number of which were derived from a Central and West Asia Yellow Rust Trap Nursery, from a CAC Regional Winter Wheat Exchange Nursery, and from nurseries of local breeding programmes.

Disease severity (percentage of rust infection on the plant) and plant response (infection type) were recorded following McIntosh, Wellings and Park (1995). Five infection types are described, as follows:

0 – immune (no uredia or other symptoms of disease infection);

R – resistant (uredia minute, supported by distinct necrotic areas);

MR – moderately resistant (uredia small to medium, in green islands surrounded by chlorotic or necrotic tissue);

MS – moderately susceptible (uredia medium in size, no necrosis but chlorotic areas may be present); and

S – susceptible (uredia large, no necrosis, but chlorosis may be evident).

Cultivar Morocco and local cultivar Steklovidnaya 24 were used as susceptible checks for multiplication of the pathogen in the greenhouse and as the spreaders in the field tests. Inocula used in field tests were a mixture of identified isolates maintained on susceptible varieties. Thus the wheat genotypes were screened against stripe rust races predominant in the region.

Genetic analysis based on the reaction data of F_1 and F_2 plants and F_3 families to infection was used for identifying the genes for resistance. The selected wheat cultivars have been crossed with susceptible cultivars to determine the number of resistance genes, and other test cultivars to determine allelism of genes and their identity. The seedlings and adult plants of the parents and F_1 and F_2 progeny have been tested for resistance to the population of races prevailing in Kazakhstan.

The aim of our research is to study inheritance of yellow rust resistance in commercial varieties and advanced winter wheat lines grown in the region.

The field tests have shown that in south and south-east Kazakhstan cv. Almaly demonstrated the highest resistance to yellow rust (0-R). In the high to moderate resistance (R-MR) category were cvs Adir, Naz, Yuzhnaya 12, Arap, Sultan and advanced lines from ICARDA and CIMMYT – BWKLDN-95, BWKLDN-9 and MK-3744 (Table 1).

The data from testing international differentials and isogenic lines has shown that *Yr2*+(Heines VII), *Yr4*+(Hybrid 46), *Yr10*/6*Avocet S, *Yr15*/6*Avocet S, *Yr18*/6*Avocet S, *Yr24*/6*Avocet S and *Yr26*/6*Avocet S are effective in our region (Kokhmetova *et al.*, 2003). Therefore we suggest that resistant genotypes present the abovementioned effective genes. Virulence for genes *Yr1*, *Yr6*, *Yr7*, *Yr9*, *Yr11* and *Yr12* occurred in Kazakhstan.

Table 1. Severity and field response of differentials, near-isogenic lines and advanced wheat lines to *Puccinia striiformis* f.sp. *tritici* in field tests in 2003

Cultivar, entry	*Yr*-gene	Severity and field response	Cultivar, entry	*Yr*-gene	Severity and field response
Heines VII	*Yr2*+	R	*Yr24* /6*Avocet	*Yr24*	5R
Hybrid 46	*Yr4*+	R	*Yr26*/6*Avocet	*Yr26*	5MR
Yr1/6*Avocet	*Yr1*	60S	Avocet S	–	80S
Yr5/6*Avocet	*Yr5*	5R	Almaly	?	10R
Yr6/6*Avocet	*Yr6*	40S	Адир	?	20MR
Yr7/6*Avocet	*Yr7*	80S	Naz	?	5R
Yr8/6*Avocet	*Yr8*	30S	Taza	?	R
Yr9/6*Avocet	*Yr9*	20S	Arap	?	10R
Yr10/6*Avocet	*Yr10*	R	Sultan	?	5R-5MR
Yr11/6*Avocet	*Yr11*	30S	Umanka	?	10MR
Yr12/6*Avocet	*Yr12*	90S	Karlygash	?	10R-10MR
Yr15/6*Avocet	*Yr15*	R	BWKLDN 95	?	0-15MR
Yr17/6*Avocet	*Yr17*	R	BWKLDN 9	?	15R
Yr18/6*Avocet	*Yr18*	20MR-MS	MK 3744	?	10R

NOTES: ? = Unknown, probably new gene(s) for resistance

The most important stage in breeding for improvement of wheat against yellow rust is the study of inheritance of resistance. The study was designed to identify the genes determining specific and non-specific resistance against the yellow rust pathogen by analysing different wheat segregating populations. Allelism tests involved crosses between resistant parents and near-isogenic lines and sources with known genes for resistance: *Yr2*+(Heines VII), *Yr4*+(Hybrid 46), *Yr10*/6*Avocet S, *Yr15*/6*Avocet S, *Yr18*/6*Avocet S, *Yr24*/6*Avocet S and *Yr26*/6*Avocet S. The ratio of resistant to susceptible F_2 plants was used to determine the mode of inheritance and the number of resistant genes segregating in the cross (Table 2).

In segregating F_2 hybrids of Almaly/*Yr2*+(Heines), susceptible plants were noted. This indicates that *Yr*-genes of Almaly are non-allele, i.e. non-identical to *Yr2* and *Yr18* genes. Segregation ratios were 249:7, suggesting genetic control by two complementary and two independent genes. One of the independent genes could be *Yr2*+(Heines VII) and others, apparently, are the genes of Almaly.

Table 2. Genetic analysis of resistance to *Puccinia striiformis* f.sp. *tritici* in commercial varieties

Cross	Ratio R:S		X^2	*P*	Number of genes conferring resistance
	Observed	Expected			
Алмалы × *Yr2*+(Heines VII)	188:2	249:7	2.01	0.10–0.20	2 complementary, 2 independent genes
Алмалы × *Yr10*/6*Avocet S	150:0	–	–	–	Resistance genes of Almaly and *Yr10* neither identical, nor tightly linked
Алмалы × *Yr18*/6*Avocet S	143:49	3:1	0.091	0.25–0.50	1 dominant gene
Алмалы × Avocet (S)	130:45	3:1	0.15	0.50–0.75	1 dominant gene
Адир × *Yr10*/6*Avocet S	144:0	–	–	–	Resistance genes of Adir and *Yr10* neither identical, nor tightly linked
Адир × *Yr15*/6*Avocet S	108:3	63:1	0.94	0.25–0.50	3 dominant duplicate genes
Адир × *Yr18*/6*Avocet S	110:6	61:3	0.061	0.80	2 dominant, 1 recessive genes
Адир × Avocet (S)	90:31	3:1	0.024	0.50–0.75	1 dominant gene
Адир × Umanka	174:11	15:1	0.032	0.80–0.90	2 dominant genes
Адир × MK 3744	152:0	–	–	–	Identical genes
Sultan × *Yr2*+(Heines VII)	177:0	–	–	–	Resistance genes of Sultan и *Yr2* neither identical, nor tightly linked
Karl × *Yr24*/6*Avocet S	105:38	3:1	0.19	0.50–0.75	1 dominant gene
Karl × *Yr26*/6*Avocet S	108:39	3:1	0.11	0.75	1 dominant gene

In F_2 hybrids Almaly/*Yr18* and Almaly/Avocet (S) segregation ratios were 3:1, which indicate genetic control by 1 dominant gene. The same ratios were obtained in crosses of Karlygash with *Yr24* and *Yr26*.

In F_2 of cross Adir/*Yr18* the segregation ratio corresponded to the expected three-hybrid, 61:3. Resistance of Adir is controlled by non-allele gene interaction of two dominant and one recessive gene that interact in a complementary manner.

In F_2 Adir/*Yr15* we observed a three-hybrid type of segregation with phenotype ratio 63:1. The resistance is controlled by non-allele gene interaction of three duplicate dominant genes. No segregation was observed in F_2 Adir/MK 3744. It indicated that these two samples (Adir and MK 3744) have the same or identical genes for resistance.

In F_2 of cross Adir/Umanka we observed di-hybrid segregation with phenotype ratio 15:1 with control by two dominant genes.

No segregation was observed in F_2 Almaly/*Yr10*/6*Avocet S, Адир/*Yr10*/6*Avocet S and Султан/*Yr2*+(Heines VII). It allows one to suppose that the genes for resistance of Almaly and Adir are neither identical nor tightly linked to *Yr10*. However, the reaction type of Almaly differs from the reaction type of Adir and *Yr10*/6*Avocet S. Perhaps Almaly has an additional gene-modifier that promotes increasing the effect of the major resistance gene. Data obtained also indicate that cv Sultan probably has genes that are identical or tightly linked to *Yr2*+(Heines VII).

Thus, we evaluated the number of genes and the character of gene interaction conferring resistance in the most important wheat samples. It was found that resistance of the Almaly cultivar is controlled by interaction of at least 4 genes. These genes could include *Yr2*+(Heines VII), *Yr10* and *Yr18*. It is possible that genetic control in Almaly also involves adult plant resistance (APR) genes. It should be noted that this cultivar demonstrated resistance not only to yellow rust, but also to leaf rust and wheat tan spot.

References

Johnson, R. & Bimb, H.P. 1997. Breeding resistance to yellow (stripe) rust in wheat. CIMMYT Wheat Special Report (WPSR), No. 41. 20 p.

Kokhmetova, A.M., Yessimbekova, M.A., Morgunov, A.I. & Absattarova, A.S. 2003. Inheritance of yellow rust resistance in winter wheat cultivars. pp. 133–137, *in:* A. Morgounov, A. McNab, K.G. Campbell and R. Parada (editors). *Increasing Wheat Production in Central Asia through Science and International Cooperation*. Proceedings of the First Central Asian Wheat Conference. Almaty, Kazakhstan, 10–13 June 2003. CIMMYT, Mexico. Available at http://libcatalog.cimmyt.org/download/cim/81430.pdf

Kumar, J., Singh, R.P., Nagarajan, S. & Sharma, A.K. 1999. Further evidence on the usefulness of *Lr34/Yr18* gene in developing adult plant rust resistant wheat genotypes. *Wheat Information Service,* 89: 23–29.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Singh, R.P., Huerta-Espino, J. & William, M. 2002. Additive genes for durable resistance to yellow rust in wheat: Genetics, molecular mapping and breeding at CIMMYT. pp. 4-12, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Defence mechanisms against rust, and genetic engineering

R. Haghparast, M. Aghaee, A. Dariaee and R. Mohammadi

Dryland Agricultural Research Institute, Kermanshah, Islamic Republic of Iran

Introduction

Among the diseases that attack wheat, the rusts, namely leaf or brown rust (*Puccinia recondita* Rob. ex Desm. f.sp. *tritici*), stripe or yellow rust (*P. striiformis* West. f.sp. *tritici*) and stem or black rust (*P. graminis* Pers. f.sp. *tritici* Eriks & Henn.) are the most damaging diseases. They inflict heavy losses on three cultivated species of wheat, namely bread wheat (*Triticum aestivum*), durum wheat (*T. durum*) and emmer or khapli wheat (*T. dicoccum*). It is estimated that rust diseases reduce wheat yield worldwide by 15–20%, which suggest a loss of 20–30 million tonne annually in developing countries (Hanson, Borlaug and Anderson, 1982). These pathogens are found wherever wheat is grown, but their importance from area to area depends on the climate and also on the degree of resistance of predominant cultivars (Knott, 1989). Rust pathogens of wheat are important as they have caused a number of epidemics in the past in various major environments of the world (McIntosh, Wellings and Park, 1995; Nayar and Bhardwaj, 1998). For instance, losses in grain production in severe epidemics of stripe rust in cool and humid wheat-growing regions has been recorded up to 70% (Roelfs, 1978). Although chemicals can be used to control leaf rust, genetic manipulation of host resistance represents the most cost effective and environmentally safe control measure. However, the existing disease resistance sources, even those claimed to be durable, provide no guarantee of remaining effective in the future (Assefa and Fehrmann, 2000). Due to neutralization of resistance with the evolution of new pathogenic pathotype(s), breeding for resistance using diverse resistance sources is the most effective strategy to prolong the life of new cultivars (Sharma and Singh, 2000). Recent evidence is available indicating the possibility of producing durable resistant against rusts in transgenic wheat. Production of rust resistant transgenic wheat is possible through better understanding of the molecular and biochemical mechanisms involved in defence against rust pathogens. In this review, some of these mechanisms potentially leading to progress in rust resistance in transgenic wheats are discussed.

Host-pathogen interaction

Plants are constantly exposed to threats from the environment. Because plants are confined to the place where they grow, they have developed ingenious molecular strategies to defend themselves against the biotic and abiotic stresses with which they might be confronted. The ability to sense and rapidly respond to external stimuli allows plants to resist pathogen attack (Sessa and Martin, 2000). Plant disease resistance is mostly dependent on the genetic background of both host and invading agent, and often relies on complex mechanisms of molecular recognition and cellular signal transduction. In some cases, resistance occurs when the plant recognizes the presence of the pathogen and rapidly triggers a battery of defence mechanisms, which efficiently arrest further invasion. In this type of resistance, early recognition of the pathogen at the level of single cells is essential to mount successfully efficient defence responses (Sessa and Martin, 2000).

Elicitors – the signal compounds

Plant cells are able to sense pathogen invasion by recognizing either endogenous signal molecules derived from degradation of plant cell wall components, or exogenous molecules synthesized by the invading pathogen. Endogenous and exogenous signal compounds are termed elicitors, and include proteins, glycoproteins, oligosaccharides and lipids. In several instances, the elicitors are sufficient to induce a complete set of the plant defence responses, and they presumably interact with specific plant receptors (Benhamou, 1996). Elicitors are defined as race-specific or non-race-specific, according to the range of genoptypes in which they are able to induce defence responses. Race-specific elicitors are often products of avirulence (Avr) genes encoded by pathogens, and are specifically recognized by products of plant resistance (R) genes. This recognition event between the products of a pathogen Avr gene and a plant R gene is referred to as gene-for-gene interaction, and represents the molecular basis of race- and cultivar-specific host resistance (Baker *et al.*, 1997). Non-race-specific elicitors are able to activate defence responses by mechanisms independent of plant R genes. Their recognition in the host plant is probably mediated by high-affinity receptors present in the plasma membrane (Yang, Shah and Klessig, 1997). Because plants lack a circulatory system, each plant cell must possess a preformed or inducible defence capability, thus distinguishing plant defence from the vertebrate immune system (Walbot, 1985). However, this does not mean that a plant's cell possesses all the required factors for defence by itself. The evidence for this claim is as follows. Production of isoflavonoid phytoalexins and deposition of lignin into the cell wall, both of which are involved in plant defence reactions against pathogens like stem rust, are through the phenylpropanoid pathway. In plants, phenylalanine ammonia lyase (PAL) plays a key role in this pathway, because this enzyme provides an entry point

for the biosynthesis of a large number of products derived from the phenylpropane skeleton (He-Ping, Fischer and Liao, 2001). Phenylpropanoid synthesis is activated as a response to stress, which includes elicitor treatment, pathogen infection, wounding and UV irradiation. Since changes in PAL activity are key events controlling the synthesis of phenylpropanoids, PAL has become one of the most extensively studied enzymes in plants. Infection of wheat leaves with the stem rust fungus or injection with an elicitor from this fungus causes the accumulation of lignin or lignin-like polymers (lignification). The specific inhibition of lignification by enzyme inhibitors increases disease susceptibility to stem rust fungus in wheat. He-Ping, Fischer and Liao (2001) reported that in the *Sr6* near-isogenic line in the background of cv. Prelude, the transcription of the mRNA from PAL gene (*Wpalt1*) are initiated quickly (4–8 days after infection) in copious quantity, but in susceptible cv. Prelude, without *Sr6*, the PAL gene is transcripted too late and in small quantities. Moreover, it has been shown that *Wpalt1* expression was high in roots and moderate in stem, but with no detectable expression found in leaves. It indicates that PAL production is tissue specific. Therefore, it supports the idea that some required factors for defence against pathogens are induced by infection through signal transduction and transferred from other tissues to the defending cells.

Role of plant disease resistance genes

Considerable knowledge has now been accumulated on the biochemical and genetic bases of disease resistance, while the use of resistant cultivars has become a valuable strategy to control crop disease. Within only the past few years, disease resistance genes against distinct pathogen types have been isolated. Intriguingly, the proteins encoded by resistance genes from different species against different pathogens have many features in common (Hammond-Kosack and Jones, 1997).

In race- and cultivar-specific disease resistance, rapid activation of the defence response is mediated by a specific recognition event, involving the product of an Avr gene in the pathogen and the corresponding resistance (R) gene in the plant (Flor, l971). Many plant-pathogen interactions are of this type. R genes are presumed to enable plants to detect the product(s) of the Avr gene of the pathogen, and to initiate signal transduction to activate defence.

Isolation of resistance genes has revealed five main classes of sequences of production to activate a range of defence mechanisms. Discovery of the structure of the R gene provides insight into R gene function and evolution, and should lead to novel strategies for disease control (Hammond-Kosack and Jones, 1997). In the last few years, many R genes have been isolated that confer resistance to pathogens, including viruses, bacteria, fungi and nematodes.

Several lines of evidence convincingly indicate that a kinase signalling cascade may originate from the specific recognition of the products of the plant R gene and corresponding pathogen Avr gene (Sessa and Martin, 2000).

Role of protein kinase in gene-for-gene interaction

A remarkable difference between resistant and susceptible plants is the time needed to recognize pathogen invasion and activate defence responses. The ability to quickly induce defence mechanisms is a characteristic of incompatible (resistant) plant-pathogen interactions. Resistant plants are equipped with a molecular alert system, which allows them not only to recognize pathogen intrusion, but also to amplify very efficiently the initial alarm signal and to activate self-defence. In recent years it has become evident that reversible protein phosphorylation plays a cardinal role in transducing signals leading to disease resistance in plants. Protein kinase and phosphatase in plants, as well as in animals, are implicated as key components in the signalling mechanism critical for responses to environmental stresses and attack by pathogens (Sessa and Martin, 2000).

Protein kinase and resistance to rusts

In plants, several types of receptor-like kinases have been isolated and characterized based on the sequence of their extracellular domains, and some have been demonstrated to be involved in plant development or in the reaction to environmental signals. An *RLK* gene family in wheat (*wlrk*, wheat leaf rust kinase) with a new type of extracellular domain has been described. A member of this new gene family has previously been shown to co-segregate with the leaf rust resistance gene *Lr10*. The diversity of the *wlrk* gene family was studied by cloning the extracellular domain of different members of the family. Sequence comparisons demonstrated that the extracellular domain consists of three very conserved regions interrupted by three variable regions. Linkage analysis indicated that the *wlrk* genes are specifically located on chromosome group 1 in wheat and on the corresponding chromosomes of other members of the Triticeae family. The *wlrk* genes are constitutively expressed in the aerial parts of the plant, while no expression was detected in roots. Protein immunoblots demonstrated that the WLRK protein coded by the *Lrk10* gene is an intrinsic plasma membrane protein. This is consistent with the hypothesis that WLRK proteins are receptor protein kinases localized to the cell surface. In addition, preliminary evidence is present that other disease resistance loci in wheat contain genes that are related to WLRK (Feuillet *et al.*, 1998). The product of WLRK, which is a receptor-like protein kinase, recognizes the invasion of specific leaf rust races, and starts its function as a protein kinase and cause phosphorylation of downstream kinases such as MAPK (mitogen-activated protein kinase) involved in signal transduction.

Signal transduction pathways link pathogen perception with the final execution of defence action. Signalling mechanisms that mediate plant defence response may be strongly conserved among different species of plants, and by-passing the specific recognition events by permanently activating components of key signalling pathways has the potential to enhance disease resistance in general (Xing and Jordan, 2000). In other words, if we identify one of the key

components of the signalling pathway which would be produced downstream of the recognition event between the product of a pathogen and the resistance gene, and constitutively overexpress it, we would be enabled to induce the final defence mechanism component independent of the recognition events. MAPK (mitogen-activated protein kinase) pathways have been shown to play multiple roles, including responsiveness to pathogens and abiotic stresses, as well as plant hormones. In the MAPK signal transduction cascade, MAPKK (MAP kinase kinase) is activated by upstream MAPKKK (MAP kinase kinase kinase) and in turn activates MAPK. Xing *et al.* (2003) in their transgenic studies indicated that tMEK2, a MAPKK isolated from tomato, i.e. one of the key components of the signalling pathway, enhanced disease resistance in tomato and wheat. tMEK2mut was first isolated from tomato. Following mutagenesis, a permanently activated mutant was created. tMEK2mut was introduced into tomato through *Agrobacterium*-mediated transformation. Leaves were inoculated with bacterial pathogen *Pseudomonas syringae* pv. tomato. After 4–5 days, transgenic tomato overexpressing tMEK2mut under tCUP constitutive promoter enhanced resistance to virulent *Pseudomonas syringae* pv. tomato. Fielder, a wheat cultivar susceptible to wheat leaf rust, was transformed with tMEK2mut under rice actin promoter. A resultant transgenic wheat overexpressing tMEK2mut had enhanced resistance to virulent wheat leaf rust.

Conclusion

Plants are constantly exposed to threats from the external environment. Because plants are confined to the place where they grow, they have developed ingenious molecular strategies to defend themselves against biotic and abiotic stresses. Understanding the molecular events behind the resistance mechanisms may help us in adopting strategies to develop plants with durable resistance. In recent years it has become clear that reversible protein posphorylation plays a cardinal role in transducing signals leading to disease resistance in plants. Protein kinase and phosphatase in plants, as in animals, are implicated as key components in signalling mechanisms critical for responses to environmental stresses and attacks by pathogens. The use of protein phosphorylation for signal transduction is particularly suited for defence, because it allows efficient amplification of the original signal for the activation of defence. Thus, overexpression of tMEK2mut, a kinase of mitogen-activated protein kinase in a signal transduction pathway, enhanced resistance to a bacterial pathogen in tomato (a dicotyledonous plant) and to a fungal pathogen, leaf rust, in wheat (a monocotyledon). Advantages of the strategy include: (1) interspecies transferability; (2) high potential for broad spectrum resistance; (3) reduction in the possibility that pathogens will evolve new strategies to overcome resistance in transgenic plants generated by conventional

approaches; and (4) provision of new alternatives in systems, such as wheat *Fusarium* head blight, where information about resistance genes is limited. This approach will not only contribute to the understanding of signalling systems in plants, but will eventually lead to the identification and verification of novel traits for plant improvement for disease resistance.

References

Assefa, S. & Fehrmann, H. 2000. Resistance to wheat leaf rust in Aegilops tauschii Coss. and inheritance of resistance in hexaploid wheat. Genetic Resources and Crop Evolution, 47: 135–140.

Baker, B., Zambryski, P., Staskawicz, B. & Denish-Kumar, S.P. 1997. Signalling in plant microbe interactions. *Science*, 276: 726–733.

Benhamou, N. 1996. Elicitor-induced plant defence pathways. *Trends in Plant Science,* 1: 233–240.

Feuillet, C., Reuzeau, C., Kjellbom, P. & Keller, B. 1998. Molecular characterization of a new type of receptor-like kinase (wlrk) gene family in wheat. *Plant Molecular Biology*, 37: 943–953.

Flor, H.H. 1971. Current status of the gene-for-gene concept. *Annual Review of Phytopathology*, 9: 275–296.

Hammond-Kosack, K.E. & Jones, J.D.G. 1997 . Plant disease resistance genes. *Annual Review of Plant Physiology and Plant Molecular Biology*, 48: 575–607.

Hanson, H., Borlaug, N.E. & Anderson, R.G. 1982. **Wheat in the Third World.** Westview Press, Boulder, CO, USA. 174 p.

He-Ping, L., Fischer, R. & Liao, Y.C. 2001. Molecular evidence for induction of phenylalanine ammonia-lyase during *Puccinia graminis* infection and elicitation in wheat. *Canadian Journal of Plant Pathology*, 23: 286–291.

Knott, D.R. 1989. pp. 10–35, in: *The wheat rusts, breeding for resistance.* Springer Verlag, Berlin, Germany.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Nayar, B.N. & Bhardwaj, S.C. 1998. Management of wheat rusts in India. In: R.K. Upadhyay, K.G. Mukerji and R.L. Rajak (editors). *IPM system in agriculture*. Vol. 3. *Cereals*. Aditya Books, New Delhi, India.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States, 1918–1976. *USDA Miscellaneous Publication,* No. 1363. 85 p.

Sessa, G. & Martin, G.B. 2000 . Protein kinase in plant defence response. *Advances in Botanical Research,* 32: 379–404.

Sharma, J.B. & Singh, D. 2000. Inheritance of resistance to leaf rust in a wheat-rye recombinant 'Selection 212'. *Indian Journal of Genetics,* 60: 271–280.

Walbot, V. 1985. On the life strategies of plants and animals. *Trends in Genetics*, 1: 165–169.

Xing, T. & Jordan, M. 2000. Genetic engineering of plant signal transduction mechanisms. *Plant Molecular Biology Report,* 18: 309–318.

Xing, T., Wang, X.J., Malik, K. & Miki, B.L. 2003. Guided deletion and mutagenesis analysis identified a tMEK2-responsive region in tomato lepr1b1 promoter. *Canadian Journal of Plant Pathology,* 25(2): 209–214.

Yang, Y., Shah, J. & Klessig, D.F. 1997 . Signal perception and transduction in plant defence responses. *Genes and Development,* 11: 1621–1639.

Evaluation of candidate varieties and lines against yellow rust in the National Uniform Wheat Yield Trials 2001–2004

A.R. Rattu, I. Ahmad, S.D. Khanzada, J.I. Mirza, L.K. Khokhar, E.U. Haq and M. Fayyaz

Crop Diseases Research Programme, Institute of Plant and Environmental Protection, National Agricultural Research Centre, Islamabad, Pakistan, and Nuclear Institute of Agriculture, Tandojam, Pakistan

Introduction

Yellow rust (caused by *Puccinia striiformis* West.) is the most important biotic production constraint in several of the major wheat growing regions of the world (Singh and Rajaram, 1991). Severe epidemics of the disease may result in losses of up to 70% in commercial fields (McIntosh, Wellings and Park, 1995). Severe epidemics have been recorded since the early 1800s in India (Joshi, 1976). An estimated US$ 8 million revenue loss occurred in just three districts of Baluchistan province in Pakistan (Ahmad *et al.*, 1991). Several epidemics of stripe rust on wheat crop have been reported in the past, and this disease continues to be a major threat to future wheat production in Pakistan. Wheat rust management strategies include cultivation of resistant varieties and foliar application of fungicides (Roelfs, Singh and Saari, 1992). Chemical control of stripe rust is not practised in Pakistan on a commercial basis due to low market price of wheat and the huge labour needed for spraying the whole country crop. Genetic resistance is the most economical and environmentally safe measure to reduce crop losses. Growing resistant cultivars implies no additional cost to farmers and is the most environmentally friendly control measure (Singh 2000). It provides a cost effective benefit to the growers as the majority of wheat growers in Pakistan are poor.

For the release of new wheat varieties in Pakistan there is a system through which new candidate varieties and lines are submitted by national breeders in various institutes country-wide. These lines are evaluated for two years against diseases, especially yellow rust and leaf rust, in National Uniform Wheat Yield Trials (NUWYT). The candidate varieties must perform better in yield and yield components, and show desirable reactions against prevailing diseases or virulence. On the basis of these trials or nurseries, recommendations are

provided for final decision regarding release by the Technical Sub-Committee (TSC), Variety Evaluation Committee (VEC), Provincial and National Seed Councils (P&NSC).

In Asia, after the breakdown of *Yr27* (Attila virulence), pathotypes spread that were able to attack major wheat varieties Inqilab 91 in Pakistan and PBW 343 in India. Hence, it was imperative to identify wheat varieties or genotypes possessing resistance against *Yr27* virulence for deployment and future use.

Materials and methods

NUWYT comprised 89 promising candidate lines. The nursery was grouped into two categories of rainfed and seeding date (Tables 3, 4 and 5).

The nurseries were planted for three consecutive cropping seasons (2001/02, 2002/03 and 2003/04) at three locations representative of different agro-ecological zone's hot-spots: NARC, Islamabad; CCRI, Pirsabak; and NIFA, Peshawar. Plots were surrounded by cv. Morocco as spreader to evaluate their response against the prevailing virulence spectrum of yellow rust. Artificial rust inoculations were made at adult plant stage during February and March, using bulk inoculum of prevailing virulence found attacking *Yr1, Yr2, Yr5, Yr6, Yr7, Yr6+7,Yr9, Yr10, Yr27* and *YrA* genes, collected from different locations, fields or nurseries during 2001/02 and 2002/03 and increased and maintained on Morocco and respective isogenic lines at CDRP substation, Murree.

The nurseries were monitored regularly for rust development. Final observations were recorded after full establishment of rust and at physiological maturity of international susceptible check-cum-spreader cv. Morocco. Response and severity were recorded according to Loegering (1959) and the modified Cobb's scale of Peterson, Campbell and Hannah (1948).

The Coefficient of Infection (CI) for both rusts was calculated in the manner used in CIMMYT and IRN (USDA), with modification based on the vast field experience of the Institute in rust

Table 1. Coefficient of Infection (CI) categories used in the Pakistan National Uniform Wheat Yield Trials (NUWYT)

Reaction	Observation	Response value
No Disease	0	0.0
Resistant	R	0.2
Resistant to Moderately Resistant	R-MR	0.3*
Moderately Resistant	MR	0.4
Moderately Resistant to Moderately Susceptible	MR-MS	0.6
Moderately Susceptible	MS	0.8
Moderately Susceptible to Susceptible	MS-S	0.9*
Susceptible	S	1.0

NOTES: * indicates a national additional CI category.

research, as two new categories were added (Table 1).

Coefficient of Infection was calculated by multiplying the response value with the intensity of infection in percent. Average Coefficient of Infection (ACI) was derived from the sum of CI values of each entry divided by the number of locations.

After some modifications, a rating scale for disease resistance was adopted by PARC in 1982 for use with cereal rusts (Aslam, 1982), based on the scale by Doling (1965) for selecting wheat varieties resistant to powdery mildew and later adopted for farmers by the UK Agricultural Research Council (ARC).

The highest ACI of a candidate line is set at 100 and all other lines are adjusted accordingly. This gives the Country Average Relative Percentage Attack (CARPA). The 0–9 scale previously designated as Resistance Index (RI) has been re-designated as RRI (Relative Resistance Index). From CARPA, RRI is calculated on a 0 to 9 scale, where 0 denote most susceptible and 9 highly resistant.

The RRI is calculated according to the following formula:

$$RRI = [(100 - CARPA) \times 9] / 100$$

To illustrate the formula a hypothetical example is given in Table 2.

Table 2. Relative Resistance Index (RRI) calculated for three hypothetical samples

Location variety	1	2	3	CI total	ACI	CARPA	RRI
A	30S	10MR-MS	5S				
CI	30.0	6.0	5.0	41.0	13.7	100	0
B	Tr-R	30MR-MS	10MR				
CI	0.2	18.0	4.0	22.2	7.4	54	4
C	5MS-S	10R-MR	5MR				
CI	4.5	3.0	2.0	9.5	3.2	23.3	7

The desirable index and acceptable index numbers for rusts are:

- For yellow rust, desirable index is 7 and above, but 5 is acceptable.
- For leaf rust, desirable index is 7 and above, but 5 is acceptable.

Lines which, through yield testing, show a high degree of yield stability even under high infection conditions, have their Index rating increased by +1.

Results and discussion

Final observations of yellow rust were recorded after full establishment of rust and at physiological maturity of the international susceptible check and

spreader, cv. Morocco. The data was recorded at three locations (Cereal Crop Research Institute (CCRI), Pirsabek; Nuclear Institute of Food and Agriculture (NIFA), Peshawar; and National Agricultural Research Centre (NARC), Islamabad.

Out of 89 candidate lines included in NUWYTs 2001–2004 (Tables 3, 4 and 5), ten candidate lines were found resistant and showed desirable RRI (Tables 6 and 7). Five candidate lines (DN 18, SN 122, SD 66, 93T347 and NRL 9912) gave a maximum RRI value of 9, while susceptible checks Inqilab 91 and MH 97 (Attila) for *Yr27* virulent race showed 0 RRI during 2002/03.

During 2001–2004 it was observed that yellow rust did not establish on improved genotypes and *Yr27* virulence established on MH 97 (Attila) and Inqilab 91 gave 0 RRI values in 2002/03 and 2003/04 against *Yr27* virulence, while the average RRI values of candidate lines (Tables 6 and 7) confirm their distinctness from Inqilab 91 and MH 97 (Attila). The results show that these genotypes could be used as resistance sources and released in yellow rust-prone areas for diversification of the genetic basis of resistance in wheat growing areas of Pakistan.

Table 3A. Entries included in the National Uniform Wheat Yield Trials 2001/02, Rainfed category

Entry	Parentage or pedigree	Source
	Rainfed	
V-3	URES/JUN//KAUZ, CM 96818-1-0Y-0M-0B-5Y-3Y-0M-05Y	ARI, Quetta
SN-7	VAN 'S' /3/CNDR 'S'/ANA/CNDR 'S' /MUS, ICW 81-0466-03-AP-300-2AP-300L-0AP	ARS, S. Naurang
DN-18	KAUZ*2/OPATA//KAUZ, CRG 1046-11Y-010M-0Y	ARI, D.I. Khan
PR-72	CHIL/WUH3, CM 95700-45Y-0Y-3MORES-0Y	CCRI, Pirsabak
NR-181	PASBAN/BARANI-83	NARC, Islamabad
NR-200	PASTOR/3/VEE#5//DOVE/BUC, CM SS93Y 00302S-56Y-010Y-010M-0ID	NARC, Islamabad
NRL-9822	PRINIA CM 90722-22Y-0M-0Y-3M-0Y	NIFA, Peshawar
V-98C013	BOCRO-3 CM 69599-4AP-2AP-3AP-3AP-0AP	BARI, Chakwal
V-99166	H x L 7973/2-ABAU, CMBW 91Y 03634M-3070PM-2Y-10M-10Y-15Y-0M	AARI, Faisalabad
Morocco (Check)		

Table 3B. Entries included in the National Uniform Wheat Yield Trials 2001/02, Seeding Date category

Entry	Parentage or pedigree	Source
	Seeding date	
MAW-1	TW-161 x KARCHIA (Double Haploid)	CRS, Multan
TD-1	MAI'S' x NORTENO 65 x H 68	WRI, Sakrand
SKD-1	HD 2329 (PAU. ACC 3079)	WRI, Sakrand
V-5	KAUZ*2/YACO//KAUZ CRG 873-5Y-010M-0Y	ARI, Quetta
PR-74	KT/BAGE//FN/U/3/BZA/4/TRM/5/ALDAN/6/	CCRI, Pirsabak
PR-75	IMURIS/GALVEZ FR 6031-0K-1F-0K-2F-0K-0F	CCRI, Pirsabak
V-1076	LU 26 x AE. CYLINDRICA D/PAK-81	NIAB, Faisalabad
V-7014	V-9143/BAU'S' CM 106780-3T-1T-1SK-3SK	WRI, Sakrand
V-8975	4943 x 5930	UAF, Faisalabad
SI-91195	ULC/PVN//TAN/3/BUC CM 96119-43Y-0M-0Y-4M-ORES	NIA, Tandojam
V-91BT010-84	BLS/KLT'S'/6/HK/38MA/3/4777//REI//Y/4/K/5YR/PB.76 DHP-DHL 84	Biotech. AARI, Faisalabad
V-92T009	CHENAB/HD 2204 JUN 'S'	AZRI-Bahkar
IBW-96405	KAUZ*2/4/CAR/KAL/BB/3/NAC/5/KAUZ RG 1000-54-010M-0Y	NIFA, Peshawar
V-97046	INQILAB 91/FINK 'S' PB. 255553-1A-0A-0A-1A-0A	AARI, Faisalabad
V-97052	WL 711// F 12.17/COC PB. 26521-LRG-11A-1A-9A-0A	AARI, Faisalabad
D-97603 (Durum)	KHP/D-31708//CM74A.370/CIANO 79/RL 6043/4*NAC PBD 795-21A-2A-3A-0A	AARI, Faisalabad
V-97B2210	KAUZ/ALTAR 84/AOS CM 111633-6M-20Y-10M-10M-2Y-0M-0B	RARI, Bahawalpur
V-97B2333	FCT 3/3/WQ/RM//KAL/BB BR 2404-2B-1B-5B-2B-0B	RARI, Bahawalpur
V-98059	INQILAB 91/PEW 'S' //RL6043/SYR/RL6010/RL*6 PB. 25551-2A-0A-0A-10A-0A	AARI, Faisalabad
Morocco (Check)		

Table 4A. Entries included in National Uniform Wheat Yield Trials 2002/03, Rainfed category

Entry	Parentage or pedigree	Source
	Rainfed	
BARS-1	WL 5023/SNB/SNB	BARS, KOHAT
FD-1	NOT KNOWN	AARI, Faisalabad
MAW-1	TW-161XKARCHIA (Double Haploid) CM85663-6Y-0H-0Y-1M-0Y--0ID	BARI, Chakwal
V-6	URES/PRL, CM83272-16B-02Y-03M-2Y-3B-0Y	ARI, Quetta
SN-7	VAN'S'/3/CNDR'S'/ANA/CNDR'S'/MUS ICW 81-0466-03AP-300-2AP-300L-0AP	ARS, Sarai Naurang
DN-18	KAUZ*2/OPATA//KAUZ, CRG 732-11F-010M-0Y	ARI, D-I-Khan
PR-77	OPATA/RAYON//KAUZ CMBW 90Y 3180-OTOPM-3Y-010M-010M-010Y-10M	CCRI, Pirsabak
V00146	KAUZ*2/OPATA//KAUZ, CRG 737-1Y-10M-0Y	AARI, Faisalabad
NR-206	JUN/GEN, CM85663-6Y-0H-0Y-1M-0Y-0ID	NARC, Islamabad
NR-192	ESDA/VEE# 10, CRG 676-26Y-2Y-2B-0Y-0Y-0ID	NARC, Islamabad
KT-2000	GEN#3/WHEATON	BARS, KOHAT
NRL-9912	BOCRO-2, CM 69599-AP-2AP-3AP-3AP-0AP	NIFA, Peshawar
2KC050	ATTILA/3/HUI/CARC//CHEN/CHTO/4/ATTILA CMBW 90 M 4860-OTOPY-16M-1Y-010M-010Y-1M-015Y-0Y	BARI, Chakwal
V-97B2333	FCT'S'/3WQ/RM//KAL/BB, BR 2404-2B-1B-5B-2B-0B	
V-98C017	NORTINO/AU49//MP/BK/3/AZ/PVN, CH 38-43C-12C-6C-8C-0C	BARI, Chakwal
Morocco	Check	

Table 4B. Entries included in National Uniform Wheat Yield Trials 2002/03, Seeding Date category

Entry	Parentage or pedigree	Source
	Seeding Date	
MAW-1	TW-161XKARCHIA(Double Haploid),	BARI, Chakwal
TD-1	MATS'PJ/EMU'S'/3KITO/PATO-1/9/MO//JUP NORTENO65XH68 CM 59695	WRI, Sakrand
SKD-1	HD 2329 (PAU. ACC 3079)	WRI, Sakrand
V-5	KAUZ*2/YACO//KAUZ, CRG 873-5Y-010M-0Y	ARI, Quetta
DSM-10	Not known	
V-9	MAYA 74'S'/ON////60-147/3/BB/G//, 4CHAT4'S'/5/CROW'S' VEE'S' ICW 90-03-82-5AP-0TS-0BR-2AP-0L-0AP	ARI, Quetta
SD-66	CHIL/ALD/PVN//YECORA 70	NIA, Tandojam
PR-74	KT/BAGE//FN/U/3/BZA/4/TRM/5/ALDAN/6/…..	CCRI, Pirsabak
PR-76	ISD/75-3-1/MO88//PRL/VEE#6 CMBW 90W 4731-OTOPY-42M-3Y-010M-2Y-8M-2KB	CCRI, Pirsabak
SN-122	KAUZ/TRAP//KAUZ CMBW 90Y3330-OTOPM-5Y-010M-010M-010Y-6M	ARS, Sarai Naurang
V-1076	LU26xAE.CYLINDRICAD/PAK 81	NIAB, Faisalabad
V-9189	V-7032XPBW 222	UAF, Faisalabad
V-98059	INQ91/PEW'S'//RL 6040/YR*5//RL6010/RL*6 PB 2551-2A-0A-0A-10A-0A	AARI, Faisalabad
D-98627	ALTAR84/4/FG/3/GS/TC60//STK, PBD 721-14A-2A-3A-1A-0A	AARI, Faisalabad
V-99022	INQ91/3/PB81//F3.71/TRM, PB 25833-11A-0A-0A-6A-0A	AARI, Faisalabad
93T347	TTR'S'/SKA//WL711/3/CHI'S' 1A-0A-1T-3T-1T-0T	AZRI, Bhakar
99B2460	TORIM/CH86 BR 2539-3B-2B-12B-3B-0B	RARI, Bahawalpur
99B2237	SPARROW/INIA//V-7394/WL711/3/BAU'S' BR 2974-2B-1B-9B-0B	RARI, Bahawalpur
Morocco	Check	

Table 5A. Entries in the National Uniform Wheat Yield Trials 2003/04, Rainfed category

Entry	Parentage or pedigree	Source
	Rainfed	
V-00055	PB 81//F3.71/TRM/3/BULBUL//F3/TRM PB 26720-9A-0A-4A-0A	AARI, Faisalabad
PR-80	EVD 2-1 1012/KAUZ, CM 104386-0AP-0L-2AP-0AP-2AP-0TS-0AP	CCRI, Pirsabak
2KC050	ATTILA/3/HUI/CARC//CHEN/CHTO/4/ATILLA CMBW90M4860-0TOPY-16M-1Y-010M-010Y-1M-015Y-0Y	BARI, Chakwal
2KC033	SITTA/CHILL//IRENA CMBW91M03952T-0TOPY-6M-010SY-015MY-010SY-10SY-0M-0SY	BARI, Chakwal
KT-2000	GEN#3/WHEATON	BARS, Kohat
BARS-3	SNB 'S'/5/MAYA 'S'/ON//1160.147/3/BB/GU/4/CHAT'S' ICW 86-0053-0AP-4AP-0L-1AP-0L-0AP	BARS, Kohat
NRL 9912	BOCRO-2 CM 69599-AP-2AP-3AP-3AP-0AP	NIFA, Peshawar
NR-231	KAMBARA 1 CGSS 95B00016F-099Y-099B-099Y-099B-20Y-0B-0SY-01D	NARC, Islamabad
NR-234	FRET 2, CGSS 96Y00146T-099B-099Y-099B-14Y-0B-01D	NARC, Islamabad
Morocco	Check	

Table 5B. Entries in the National Uniform Wheat Yield Trials 2003/04, Seeding Date category

	Seeding Date	
V-00183	LU 26/HD2179//*2 INQ 91, PB28633P-2A-6A-0A	AARI, Faisalabad
V-99022	INQ 91/3/PB81//F3.71/TRM, PB 25833-11A-0A-0A-6A-0A	AARI, Faisalabad
V-00125	BULBUL//F3.71/TRM/3/CROW, PB 26508-9A-0A-0A-1A-0A	AARI, Faisalabad
V-01180	PB96/87094/MH97	AARI, Faisalabad
SN122	KAUZ/TRAP//KAUZ, CMBW 90Y3330-0T0PM-5Y-010M-010M-010Y-6M	ARS-S. Naurang
SARC-5		SARC-UAF
CT-00231	SNI/TRAP#1/BAV 92, CG-25-099Y-099M-4Y-6M-2Y-0B-2Y	NIFA, Peshawar
93T 347	TTR'S'/SKA//WL711/3/CHI'S' 1A-0A-1T-3T-1T-0T	AZRI, Bhakkar
91BT010-84	BLS/KLT'S'/6/HK/38MA/3/4777/REI//Y/4/5/YR/PB76-BIOTECH.DHH-D HL 84	Biotech. AARI, Faisalabad
Diamond	CHIL/2*STAR CM 297-0T0PY-8M-020Y-10M-010Y	WRI, Sakrand
99B 2237	SPARROW/INIA/V-7394/WL711/3/BAU'S' BR 2974-2B-1B-9B-0B	RARI, Bahawalpur
99B 4012	PTS/3/TOB/LFN//BB/4/BB/HD832-5//ON/5/G.V.AVD'S'//HPO'S' BR 3385-3B-1B-0B	RARI, Bahawalpur
99B 2278	PND 88//BB'S'/TOB66 BR 2900-1B-1B-5B-5B-2B-0B	RARI, Bahawalpur
7-03		NIA, Tandojam
RWM-9313		NIA, Tandojam
SD-66	CHIL/ALD/PVN//YECORA 70	NIA, Tandojam
NRDW-1	SUOKUKKO 7 CD 96492-A-1M-030Y-040FAP-9Y-0B-01D	NARC, Islamabad
Wafaq 2001, Inqilab 91 and Morocco as Checks		

Table 6. Relative Resistance Index (RRI) values of selected candidate lines against yellow rust during 2001/02 and 2002/03

Candidate line	Category	Parentage or Pedigree	RRI		
			2001/02	2002/03	Average
SN-7	Rainfed	VAN'S'/3/CNDR'S'/ANA/CNDR'S'/MUS, ICW 81-0466-03AP-300-2AP-300L-0AP	7.9	6.9	7.4
DN-18	Rainfed	KAUZ*2/OPATA//KAUZ CRG 732-11F-010M-0Y	7.9	9	8.5
V-5	Seeding date	KAUZ*2/YACO//KAUZ CRG 873-5Y-010M-0Y	8.9	8.4	8.6
PR-74	Seeding date	KT/BAGE//FN/U/3/BZA/4/TRM/5/ALDAN /6/	8.9	7.8	8.3
Inqilab 91	Check	WL711/CROW 'S' PB1954-9A-1A-0A-0PAK(PAK)	8.9	0	4.4
MH 97	Check	ATTILA CM 85836-50Y-0M-0Y-3M-0Y	8.3	0	4.1
Morocco	Check		0	0	0

Table 7. Relative Resistance Index (RRI) values of selected candidate lines against yellow rust during 2002/03 and 2003/04

Candidate line	Category	Parentage or Pedigree	RRI		
			2002/03	2003/04	Average
V-99022	Seeding date	INQ 91/3/PB81//F3.71/TRM PB 25833-11A-0A-0A-6^{a}-0A	5	7	6
SN-122	Seeding date	KAUZ/TRAP//KAUZ CMBW 90Y3330-0T0PM-5Y-010M-010M-010Y-6M	9	7	8
SD-66	Seeding date	CHIL/ALD/PVN//YECORA 70	9	7	8
93T347	Seeding date	TTR'S'/SKA//WL711/3/CHI'S' 1A-0A-1T-3T-1T-0T	9	8	8.5
NRL 9912	Rainfed	BOCRO-2 CM 69599-AP-2AP-3AP-3AP-0AP	9	8	8.5
KT-2000	Rainfed	GEN#3/WHEATON	8	8	8
Inqilab 91	Check	WL711/CROW 'S' PB1954-9A-1A-0A-0PAK(PAK)	0	2	1
MH 97	Check	ATTILA CM 85836-50Y-0M-0Y-3M-0Y	0	0	0
Morocco	Check		0	0	0

References

Ahmad, S., Rodriguez, A., Sabir, F., Khan, G.R. & Pannah, M. 1991. Economic losses of wheat crops infested with yellow rust in highland Baluchistan. *MART/AZR Project Research Report* #67. ICARDA, Quetta. 15 p.

Aslam, M. 1982. Uniform procedure for development and release of improved wheat varieties. Mimeograph. PARC, Islamabad, Pakistan.

Doling, D.A. 1965. A method for the transformation of field data for comparing the mildew resistance of the cereal varieties and the systemic derivation of the values in NIAB farmer's leaflets. *Journal of the National Institute of Agricultural Botany,* 10: 169–179.

Joshi, L.M. 1976. Recent contributions towards epidemiology of wheat rusts in India. *Indian Journal of Phytopathology,* 29: 1–16.

Loegering, W.Q. 1959. Methods for recording cereal rust data. USDA International Spring Wheat Rust Nursery.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. *Rust diseases of wheat. Concepts and methods of disease management.* CIMMYT, Mexico.

Singh, R.P. 2000. Genetics of slow disease development – the *Puccinia* and *Triticum* system souvenir. National Symposium on Role of Resistance in Intensive Agriculture. Directorate of Wheat Research, Kernal, 15–17 February 2000.

Singh, R.P. & Rajaram, S. 1991. Resistance to *Puccinia recondite* f.sp. *tritici* in 50 Mexican bread wheat cultivars. *Crop Science,* 31: 1472–1479.

Evaluation of International Winter Wheat Improvement Programme (IWWIP) nurseries for resistance to yellow rust in West and Central Asia

A.R. Hede,[1] H.J. Braun,[1] L. Cetin,[2] M. Mosaad,[3] B. Akın,[1] F. Dusunceli,[2] S. Albustan,[2] A. Yahyaoui,[3] Z. Mert[2] and K. Akan[2]

1. CIMMYT International, Ankara, Turkey
2. Central Research Institute for Field Crops, Ankara, Turkey
3. ICARDA, Aleppo, Syria

Introduction

The International Winter Wheat Improvement Programme (IWWIP) is a joint programme of the Ministry of Agriculture of Turkey, CIMMYT and ICARDA, in collaboration with other partners in Central and West Asia and North Africa (CWANA) and other winter-wheat producing areas of the world. The two main objectives of the programme are to develop broadly adapted, disease resistant, high yielding winter wheat germplasm for the winter and facultative wheat growing areas in CWANA, and to help facilitate germplasm exchange among the winter-wheat breeding programmes around the world.

Germplasm exchange and evaluation is facilitated through the yearly shipment of several international nurseries. The Facultative and Winter Wheat Observation Nursery (FAWWON) has served as the main vehicle for facilitating germplasm exchange among winter-wheat programmes. This nursery consists of lines developed by IWWIP and of cultivars submitted by national programmes, university programmes or private companies from countries in CWANA, Western and Eastern Europe, China, South America and USA. The Eurasian Winter Wheat Yield Nursery (EURAWWYN), previously WWEERYT (Winter Wheat East European Regional Yield Trial), consists of around 60 elite wheat cultivars ready for release and developed by breeding programmes in Eastern Europe, Russia, Central and West Asia and the USA. Other international nurseries prepared by IWWIP are WON-IR and WON-SA, and EYT-IR and EYT-RF, comprising elite lines from the IWWIP programme targeted for either irrigated or rainfed conditions.

Yellow rust (YR) is one of the most important leaf diseases for the winter wheat areas in West and Central Asia. Within the last decade, CWANA countries suffered several major YR epidemics, with losses up to 50%. Since wheat is now grown in a continuous belt throughout Central Asia, the traditional cotton and fallow fields no longer form a natural barrier to the rust spores. This paper will evaluate the YR resistance in the most recent elite international nurseries distributed through IWWIP, and discuss the positive impact and potential benefits of having an international testing system in place, monitoring the levels of YR resistance in elite germplasm.

Materials and methods

During the crop cycle 2001/02, the 6EYT-IR, 6EYT-RF, 11th FAWWON and 4th WWEERYT nurseries were distributed to several locations throughout CWANA and data returned from between 20 and 60 locations. Nurseries were evaluated for YR resistance under artificial inoculation in Turkey at the Central Research Institute for Field Crops experimental station in Haymana, 50 km south west of Ankara, and in Tel-Hadya, Syria. At these locations, nurseries were artificially inoculated several times during crop development, and irrigated with mist and sprinkler irrigation to facilitate YR development. At other locations, nurseries were mainly evaluated for YR resistance under natural infestation, and when YR was present, severity was reported and scores converted to a modified Cobb scale (%).

Results

6EYT-IR and 6EYT-RF

The level of YR resistance in elite lines from the IWWIP programme is in general very high, as demonstrated in Figures 1 and 2, showing the YR reactions of each of the checks and lines included in the 6EYT-IR and 6EYT-RF nurseries. The majority of the lines included in 6EYT-IR show high levels of resistance at all three locations (Turkey, Syria and Iran), while the checks (cvs Sultan, Bezostaya and Kinachi) all are medium to high susceptibility, especially when evaluated under artificial inoculation in Turkey and Syria. Similar patterns were observed for 6EYT-RF, where YR data were reported from four locations (Turkey, Syria, Kazakhstan, Kyrgyzstan). Again, the checks included (Suzen 97, Dagdas 94, Kirgiz 95 and Gerek 79) were highly susceptible. YR pressure was in general lower in Kyrgyzstan and Kazakhstan, which is likely because YR presence is due to natural infestation. In general, YR levels of individual lines are very similar between the two locations with artificial inoculations (Turkey and Syria), indicating that the YR races present could be identical.

11th FAWWON

The 11th FAWWON consisted of 146 entries and was distributed for planting in 2001/02 to around 80 co-operators from more than 40 countries. Most lines developed by the IWWIP programme show good levels of resistance, while the majority of lines from other areas of the world are highly susceptible to YR (Figures 3 and 4). The figures show the maximum YR score from evaluation of 11th FAWWON across 9 locations, namely Azerbaijan (1 location), Iran (5 locations), Syria (1 location), Tajikistan (1 location) and Turkey (1 location). Entries within each group of origin (Checks, IWWIP, CAC [Caucasian and Central Asian Countries], Eastern Europe, USA, Western Europe, China and Iran) are sorted by ascending susceptibility. The number on the X-axis refers to entry number in 11th FAWWON. However, since many of these are excellent lines with highly favourable characteristics, it is important that such information is shared with all co-operators in order to more efficiently utilize these lines in breeding programmes. Otherwise, they may be at risk of being discarded by breeders due to YR.

4th WWEERYT

The 4th WWEERYT consisted of 64 genotypes submitted by breeding programmes from twelve countries, and YR data was reported from three locations: Turkey, Iran and Tajikistan (Table 1). Highest disease pressure was observed in Turkey under artificial inoculation, where susceptible checks reached levels of 80S and 90S. High levels of susceptibility to YR were observed for most lines submitted by the majority of the breeding programmes, although a limited number of lines were found to have acceptable levels of resistance to YR.

Discussion

YR has long been a major threat to winter wheat producers in CWANA, and with the disease recently moving into areas (such as the USA) where it has become an important constraint, even more focus is now placed on the development of resistant cultivars. The majority of the lines and cultivars submitted by breeding programmes to be included in the international nurseries (FAWWON and WWEERYT) are high yielding lines and potential candidates for release in several countries. However, if these countries are lacking the facilities for artificial inoculation and other facilities necessary to assure a high degree of disease pressure, and natural epidemics do not occur on a regular basis, then breeding programmes in these countries may run the risk of releasing cultivars that will be highly susceptible under conditions that permit natural epidemics. Having an international testing network, like the one facilitated by IWWIP, where promising lines can be evaluated under conditions assuring good artificial epidemics, reduces this threat.

Table 1. Yellow rust reaction of entries in 4th WWEERYT evaluated in Turkey, Iran and Tajikistan, and origin of germplasm

Entry	Cultivar or cross	Origin	Yellow rust Score			
			Max. score	Turkey	Iran	Tajikistan
		CHECKS				
3	JAGGER	USA (KS)	5	5		0
1	BEZ	Russia (KRA)	80	80	20	0
2	SERI	Mexico	90	90	60	40
		CAUCASUS AND CENTRAL ASIA				
41	AKINCI-84	Azerbaijan	90	90	30	20
42	AZERI	Azerbaijan	90	90	20	20
24	VARDZIA	Georgia	10	10	0	
22	GEORGE	Georgia	90	90	90	60
23	KAKHU	Georgia	90	90	70	60
15	ALMATY	Kazakhstan	70	70	20	0
17	ARAP	Kazakhstan	70	70	20	0
14	BAYANDY	Kazakhstan	80	80	60	35
16	ERITROSPERMUM 350	Kazakhstan	90	90	50	40
		EASTERN EUROPE				
19	KM45/PLOVDIV	Bulgaria (SAD)	20	20	5	15
18	LC924/PETJA	Bulgaria (SAD)	70	70	0	0
32	IVETA NTA-92/89-6	Bulgaria (DOB)	80	80	20	35
33	1078-2KK	Bulgaria (DOB)	100	100	90	90
34	SG-U 8069	Czech Rep.	10	10	0	0
13	MAMBO	Hungary (MV)	15	5	0	15
12	MV PALOTAS	Hungary (MV)	70	70	0	40
6	GK VEVECKY	Hungary (SZ)	70	70	10	50
46	GK FORRAS	Hungary (SZ)	70	70	5	0
5	GK BAGOLY	Hungary (SZ)	80	80	10	40
39	MV 04-96	Hungary (MV)	90	90	80	60
48	MV 05-96	Hungary (MV)	90	90		40
11	MV DALMA	Hungary (MV)	90	90	0	50
26	MANYPA	Moldova	20	20	10	0
25	CAPUZ	Moldova	80	80	50	15
10	EXPRES	Romania (FUN)	0	0	0	0
8	DESTIN	Romania (FUN)	70	70	0	60
7	TURDA 2000	Romania (TUR)	70	70	0	0
9	EFECT	Romania (FUN)	90	90	20	40
45	KNJAZHNA	Russia (KRA)	20	20	5	0
44	KROSHKA	Russia (KRA)	70	70	40	5
43	KUPAVA	Russia (KRA)	90	90	70	15
31	MIRONIVSKA RANNYOSTYGLA	Ukraine (MIR)	1	1	0	0
30	REMESLIVNA	Ukraine (MIR)	30	20	20	30
21	ERYTHROSPERMUM 185	Ukraine (KHA)	70	70	5	10
29	MIRONIVSKA 35	Ukraine (MIR)	70	70	30	35
27	LADA	Ukraine (OD)	70	70	20	15
47	ERYTHROSPERMUM 270	Ukraine (KHA)	80	80	50	20
28	STRUMOK	Ukraine (OD)	100	100	80	25
		IWWIP				
35	TAM200/KAUZ	IWWIP	1	1	0	0
36	TAM200/KAUZ	IWWIP	1	1	0	0
		TURKEY				
37	BAYRAKTAR	Turkey	10	10	0	0
38	DEMIR	Turkey	90	90	10	25

With resistant varieties from IWWIP, the risk of YR epidemics is diminishing. Central Asian breeding programmes have used IWWIP varieties to fortify their own varieties since the mid-1990s, and since 1994, 30 cultivars from the IWWIP programme have been released in Afghanistan, Georgia, Iran, Kyrgyzstan, Turkey and Uzbekistan.

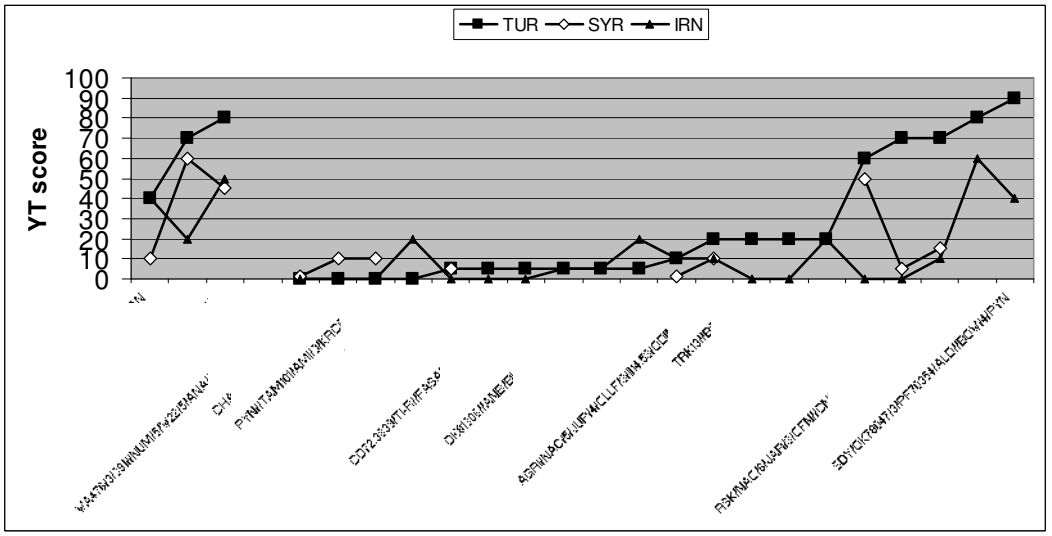


Figure 1. Yellow rust reaction of checks and elite IWWIP lines in 6EYT-IR evaluated in Turkey, Syria, and Iran

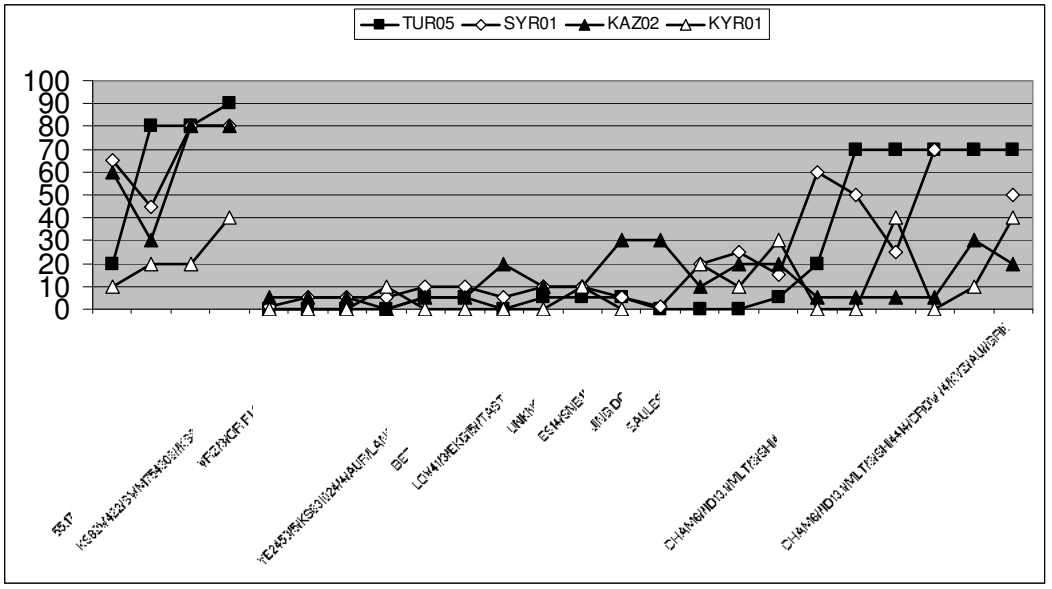


Figure 2. Yellow rust reaction of checks and elite IWWIP lines in 6EYT-RF evaluated in Turkey, Syria, Kazakhstan and Kyrgyzstan

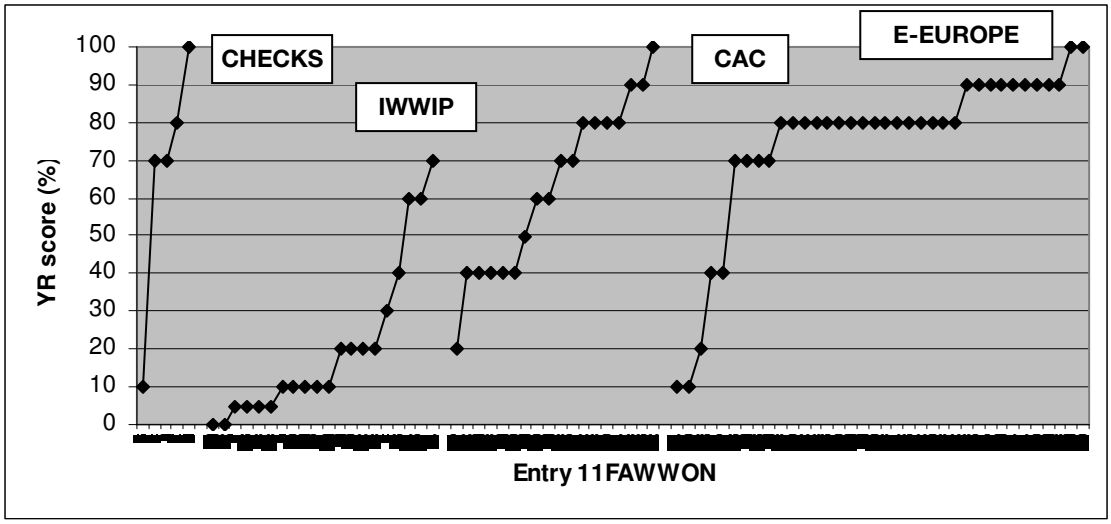


Figure 3. Maximum yellow rust scores across 9 locations in Azerbaijan (1), Iran (5), Syria (1), Tajikistan (1) and Turkey (1). Entries within each group of origin (IWWIP, CAC, E-Europe) are sorted by ascending susceptibility. Number on the X-axis refers to entry number in 11th FAWWON.

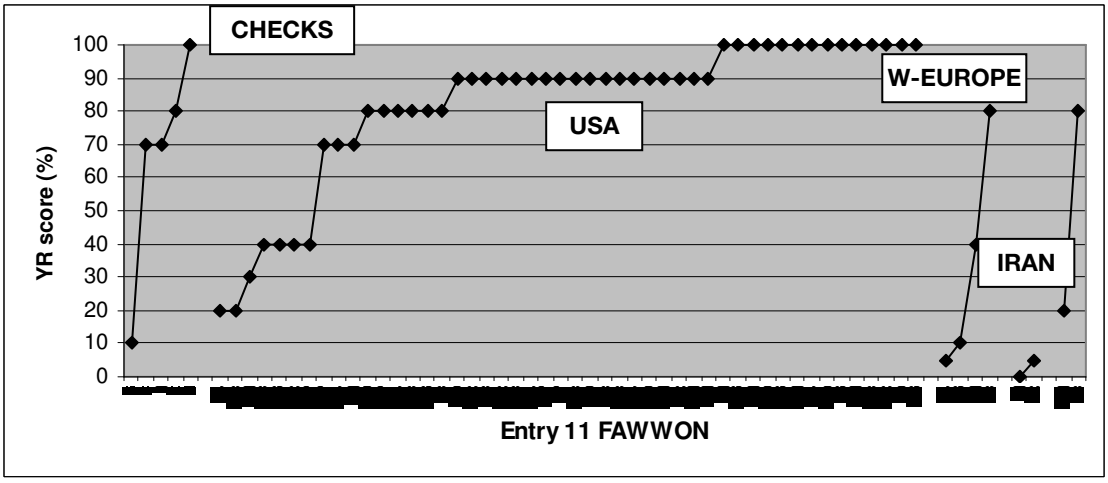


Figure 4. Maximum yellow rust scores across 9 locations in Azerbaijan (1), Iran (5), Syria (1), Tajikistan (1) and Turkey (1). Entries within each group of origin (USA, China, Iran, Western Europe) re-sorted by ascending susceptibility. Number on the X-axis refers to entry number in 11th FAWWON.

Effectiveness of yellow rust resistance genes in Pakistani wheats

S.D. Khanzada,[1] Azhar Rashid,[1] Naseer-ud-Din,[2] Attiq-ur-Rehman Rattu[3] and Amir Raza[1]

1. Nuclear Institute of Agriculture (NIA), Tando Jam, Hyderabad, Pakistan
2. Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera, Pakistan
3. Crop Disease Research Programme (CDRE), IPEP, NARC, Islamabad, Pakistan

Introduction

Wheat, being the most important cereal food, plays a major role in nutrition of the human population. It is the principal staple food crop and a source of nutrition for the people of Pakistan. Annually, it is cultivated on an area of 8.5 million hectare to produce 21 million tonne of wheat, worth Rs 160 billion (Anonymous, 2002b). In the wake of global warming, many environmental stresses, including drought, rising temperatures, salinity, waterlogging and erosion, have presented new challenges for wheat production. Abiotic stresses are responsible not only for direct losses but also make crops more vulnerable to biotic stresses like diseases and pest attacks. Amongst biotic stresses, new races of cereal rust(s), powdery mildew and loose smut have evolved in space and time.

In Pakistan, wheat has suffered heavy losses due to periodic epidemics caused by leaf rust and yellow rust. Besides leaf rust, yellow rust, caused by *Puccinia striiformis* Westend f.sp. *tritici*, has been a major problem in the hills, foothills and plains of NWFP and Northern Punjab. These areas suffered losses estimated at Rs 2.0 billion during 1994/95 and almost similar losses during 1995/96 (Ahmad, 2000). During 2002/03, areas under wheat in NWFP suffered from huge losses due to yellow rust as a consequence of large-scale cultivation of Inqilab 91. Recently, yellow rust has also been recorded infecting wheat in the hotter and dryer climates of southern Punjab and Sindh. Over the years, the threat of yellow rust has demanded far more attention and has occasionally resulted in changes in the varietal spectrum in different areas of the country. In view of the importance of the disease and its aftermaths, a yellow rust monitoring programme has been carried out with the following objectives:

- To identify potential sources of yellow rust resistance.

- To investigate the effectiveness of the functional *Yr* gene(s) over sites, seasons and pathotypes.
- To gain knowledge regarding the diversity of the pathogen population and its sources.

This paper focuses primarily on yellow rust monitoring studies in the country, with special emphasis on changes in the effectiveness of *Yr* genes and their utilization in the commercial wheat cultivars over space and time.

Methodology

In order to investigate the virulence spectrum of yellow rust races and to assess the effectiveness of different yellow rust resistant gene(s) in different agro-climates, trap nurseries were planted in different wheat production zones. The nurseries comprised isogenic and near-isogenic lines of *Yr* genes, and old and current commercial cultivars. Furthermore, to monitor the status countrywide, the wheat disease situation and susceptibility of commercially grown wheat cultivars were assessed at research establishments (provincial and federal) and in farmer fields throughout the country.

For the assessment of different rust-resistance genes and their effectiveness over sites and seasons, and to understand the prevalence of pathotypes in different areas, the composition of the trap nurseries is very important. For this purpose, the nursery was constituted using World, European and Australian stripe rust differential sets (Habgood, 1970; Johnson *et al*., 1972). Three testers, viz. Oxlay (*Yr6*), a resistant selection of Avocet (*Yr*A), and susceptible check Corona W195, were used from Australian sources. In addition, various entries were taken from the Central and West Asian Yellow Rust Trap Nursery (CWAYRTN) to form a nursery consisting of 100 entries. During 2003/04 a new *Yr* differential comprising lines in an Avocet background was added. The purpose of this extended yellow rust nursery was to identify potential sources of resistance from genotypes possessing similar *Yr* genes (Table 1)

The nursery was planted at selected locations throughout Pakistan representing different agro-ecological zones and disease hot-spots, where the conditions are favourable for rust development (Figure 1). Each entry of the nursery was planted as a 1.5 m row, 30 cm apart. A single row of rust-susceptible spreader cv. Morocco was planted after every 10 entries in the nursery, and the entire nursery was bounded by two rows of cv. Morocco as spreader. Observations were recorded at different crop stages upon natural occurrence and first appearance of rust infection on susceptible checks, and final observations were recorded after 100% rust infection on the spreader.

Observations on yellow rust reaction were recorded according to Loegering (1969). The severity was recorded as percentage of rust infection on the

infected plants according to the modified Cobb's Scale of Peterson, Campbell and Hannah (1948).

Table 1. Different sources used for *Yr* gene(s) during monitoring for yellow rust

Yr Gene(s)	No. of sources	Sources
A	1	Avocet 'R' (A/I)
A+18	1	Anza (I)
1	3	Chinese 166 (W/I), Aroona*5/*Yr1* (I), Avocet S*6/*Yr1*
2	2	Kalyansona (I), Sonalika
2+11+25	1	Heines VII (A)
3	2	Vilmorin 23 (W/I)
3N	1	Nord Desprez
4	1	Hybrid 46 (E/I),
5	4	*Triticum spelta* var. *album* (W/I), Aroona*6/*Yr5* (I), Avocet S*6/*Yr5* (I), M2435*6/*Yr5* (I)
6	3	Heinz Kolbe (W/I), Heinz Peko (E/I), Avocet S*6/*Yr6*
7	4	Lee (W/I), Reichersberg 62 (E), Cranbrook (I), Avocet S*6/*Yr7*
7+	1	Reichersberg 42 (I)
6+7	1	Corella (I)
6+APR	1	Oxley (A/I)
8	3	Compair (E/I), Aroona*6/*Yr8* (I), Avocet S*6/*Yr8* (I),
9	4	Reibesel 47/51 (w), Fed4*/Kavkaz (I), Seri 82, Avocet S*6/*Yr9*
9+	2	Clement (W/I), Federation (I)
10	3	Moro (W/I), M2435*6/*Yr10* (I), Avocet S*6/*Yr10*
15	2	Aroona*3/*Yr15* (I), Avocet S*6/*Yr15* (I)
17	2	Aroona*6/*Yr17* (I), Avocet S*4/*Yr17*
18	1	Avocet S*3/*Yr18*
18+	1	Jupateco R (I)
24	1	Avocet S*3/*Yr24*
26	1	Avocet S*3/*Yr26*
27	1	Avocet S*3/*Yr27*
SD	1	Strubes Dickopf (W/I)
SU	1	Suwon 92×Omar
CV	1	Castern V
SP	1	Spaldings Prolific
DW	1	Cham 1
APR	1	Cook (I)
Others	52	Suvon 92/Omar (W/I), Spaldings Prolific (E/I), Strubes Dickopf (W/I), Suwon 92×Omar, Nord Desprez (W/I), Carsten V (W/I), Aroona (I), Avocet "S" (I), M2435 (I), Jupateco S (I), Gereck 79, Almout (W/I), Darab 2 (W/I), Nickenjad (I), M-70-12 Mahdavi (I), M-70-15 Atrak (I), C-70-16 Zarrin (I), C-70-20 Alvand (I), W-18 Bow"S"/NKT(TAJEN) (I), Erith 15236 (I), Lut 17044.12 (I), Lut 20148 (I), Almount/T171/3/Maya//BB/Inia/4/Kardj2/5/Anza (I), Lut 20133 (I), Lut 20161 (I), Lut 20191 (I), Erythrospermum 5678/87 (I), Lutescens 9489 (I), Krasunya Odesskaya (I), Ukranika Odesskaya (I), Vympel Odesskiy (I), Fanatsia ovesskaya (I), Zabava Odesskaya (I), Nadia (I), Zolotava (I), Darunok (I), Porada (I), Strumok (I), Polovchank (I), Knyigzna (I), Demetra (I), Zimorodok, Umanka (I), Pobeda (I), Akho (I), Ophelia (I), Bezostaya (I), Spartanka (F), Yuna (I), Skipyanka (I), Dakha (I), Sphera (I), Eika (I), C-1252 (I), Ikizce-96 (I), Kiziltan-91 (I), Cham 6 (I), Cham 3 (I), Cham 5 (I)
Checks	1	Morocco
Total	106	

KEY: W = World set; E = European set; A = Australian set; I = CAWYRTN; APR = adult plant resistance.

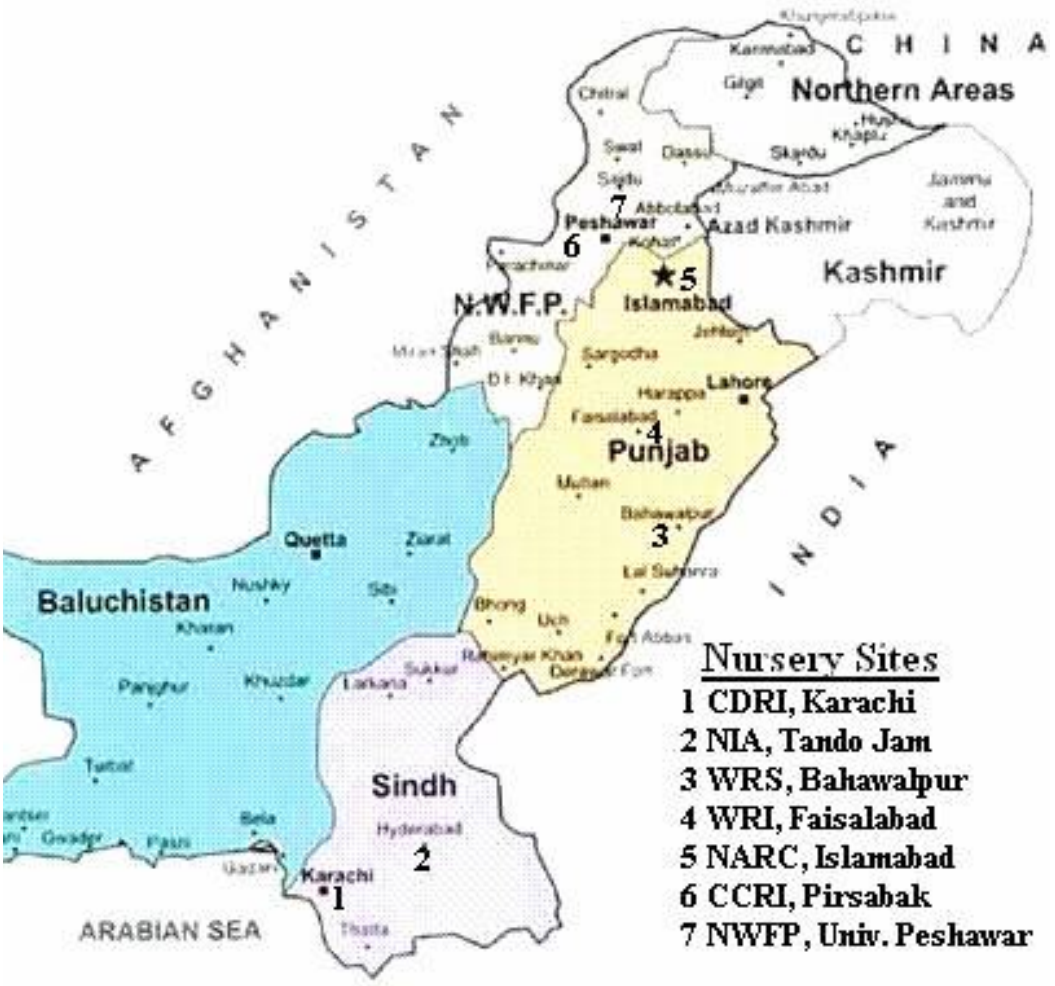


Figure 1. Locations of yellow rust monitoring nurseries planted in different wheat growing areas of Pakistan

Results and discussion

Changes in climate, especially rainfall intensity and pattern, have greatly affected yellow rust development in the past. Heavy rainfalls from 1991 to 1995 resulted in a favourable environment for yellow rust development. As a result of heavy inoculum build-up during these years, yellow rust appeared in epidemic form, particularly in NWFP and Northern Punjab during 1994/95 and 1995/96. This havoc was mainly due to the appearance and build up of race 134E150 (Anonymous, 2001b). This race was capable of overcoming resistance in wheat varieties with gene *Yr9* (Ahmad, 2000). The series of heavy rainfall years were followed by a period of drought throughout Pakistan, and yellow rust infection remained low and restricted to a few areas of Punjab and

NWFP till 2001/2002. Then during 2002/2003 the dry spell broke with heavy rainfall throughout the country, especially in NWFP and Northern Punjab. This change in climate renewed the yellow rust problem in the country. In NWFP and Northern Punjab, epidemic-like situations prevailed, resulting in heavy losses in wheat varieties possessing *Yr6* and *Yr7,* especially Inqilab 91 and Parwaz 94. During 2002/2003 and 2003/2004 a new virulence (166E143A+), commonly called Attila virulence, appeared on MH 97 and changed the whole yellow rust scenario. This virulence is capable of attacking *Yr27* and other *Yr* genes present in other Pakistani commercial cultivars.

Disease monitoring showed a considerable change in temporal and spatial patterns of the yellow rust race spectrum. As a result, behaviour of different yellow rust resistance genes varied from time to time and region to region (Table 2). Similarly, the behaviour of different commercial wheat varieties also varied over time and space (Table 3). *Yr1* showed presence of virulence at NIFA, Peshawar, CCRI, Pirsabak, and Faisalabad, with MR, MS-S and R reactions, respectively. However *Yr1* behaved differently in different backgrounds. *Yr1* in Chinese 166 showed susceptibility from 1997/2002 at Faisalabad, Pirsabak and Peshawar, while *Yr1* in Aroona*5/*Yr1* showed 0 reaction at these locations.

Virulence against *Yr7* was detected during 1995/96 on Zardana. Later, isogenic lines for *Yr7,* namely cvs Cranbrook and Lee, showed MS to S reaction in Punjab and NWFP. Gene postulation studies show that most of the Pakistani wheat cultivars have *Yr7* alone or in combination with *Yr2*, *Yr6* or *Yr9* (Anonymous, 2001a; Kirmani, Rizvi and Stubbs, 1984). It is postulated to be alone in Jauhar 78, ZA 77, Sarsabz and Zardana; in combination with *Yr9* in Pak 81, Pirsabak 85 and Kohinoor; in combination with *Yr6* in Inqilab 91, Soghat, Parwaz 94 and Kiran 95; in combination with *Yr6* and *Yr*A in Pavon; and with *Yr2* in Faisalabad 85 (Anonymous, 2001a). Due to the presence of *Yr7* in most of the commercial cultivars, inoculum build up continued, resulting in heavy yellow rust infection on Inqilab 91 during 2002/03. However *Yr7* in a Reichersberg 42 background was found with 0 to R reaction at different locations.

Virulence on *Yr3* was not found during 1997/98, while in later years *Yr3* showed susceptibility in Vilmorin backgrounds at different locations. The same gene showed 0 reaction in a Nord Desprez background. Races infecting the isogenic lines with *Yr3* were found prevalent at almost all the locations.

Table 2. Terminal reaction of different *Yr*-genes in different backgrounds in different years in Pakistan

Yr Gene	Source	1998/99	1999/00	2000/01*	2001/02	2002/03	2003/04
A	Avocet 'R'	Tr-R-MR	60S	-	Tr-R	90S	-
A+18	Anza	30MR-MS	10MR-MS	-	-	20S	-
1	Chinese 166	10MS-S	-	-	Tr-R	60S	-
	Aroona*5/*Yr1*	20MR-MS	0	-	Tr-R	40MS-S	-
	Avocet S*6/*Yr1* @	-	-	-	-	-	40S
2	Kalyansona	70S	40S	-	10S	90S	-
2+11+25	Heines VII	-		-	-	0	-
3	Vilmorin 23	20MR-MS	20S	-	-	20MS-S	-
3N	Nord Desprez	-		-	0	20MR-MS	-
4	Hybrid 46	0	Tr-R	-	Tr-R	0	-
5	*T. spelta* var. *album*	0	5MR-MS	-	10R-MR	20MR-MS	-
	Aroona*6/ *Yr5*	10MR-MS	5MS-S	-	-	40MS-S	-
	Avocet S*6/ *Yr5*	0	Tr-R	-	Tr-S	90S	5MS-S
	M2435*6/ *Yr5*	0	5S	-	0	0	-
6	Heines Kolben	50MS-S	40S	-	10S	20MS-S	-
	Heines Peko	-	-	-	0	0	-
	Avocet S*6/*Yr6* @	-	-	-	-	-	80S
7	Lee	30S	40S	-	20S	90MS-S	-
	Reichersberg			-	-	-	-
	Cranbrook	10MS-S	30MS-S	-	20S	70MS-	-
	Avocet S*6/*Yr7* @	-	-	-	-	-	80S
7+	Reichersberg 42	-	-	-	-	0	-
6+7	Corella	-	-	-	0	90S	-
6+APR	Oxley	10MR	30MS-S	-	0	10S	-
8	Compair	0	10R	-	60S	5R	-
	Aroona*6/ *Yr8*	20MR-MS	5R-MR	-	Tr-R	40MS-S	-
8	Avocet "S"*6/ *Yr8*	10MR-MS	10MR-MS	-	-	40S	60S
9	Reibesel 47/51	-	-	-	-	0	-
	Fed4*/Kavkaz	30MS-S	10S	-	Tr-R	80S	-
	Seri 82	60MS-S	40S	-	Tr-R	70MS-S	40MS
	Avocet S*6/*Yr9* @	-	-	-	-	-	20S
9+	Clement	-	-	-	0	-	-
	Federation	60S	90S	-	Tr-R	90S	-
10	Moro	20MR-MS	0	-	-	-	-
	M2435*6/ *Yr10*	30MS-S	30S	-	-	-	-
	Avocet S*6/*Yr10* @	-	-	-	-	-	0
15	Aroona*3/ *Yr15*	0	Tr-R	-	10S	40MS-S	-
	Avocet S*6/ *Yr15*	0	10MR-MS	-	-	-	0
17	Aroona*6/ *Yr17*	10MR-MS	5MS-S	-	0	-	-
	Avocet S*4/*Yr17* @	-	-	-	-	-	5MR-MS
18	Avocet S*3/*Yr18* @	-	-	-	-	-	20MS
18+	Jupateco R	10MR-MS	20MR-MS	-	10S	-	30MR
24	Avocet S*3/*Yr24* @	-	-	-	-	-	20MR
26	Avocet S*3/*Yr26* @	-	-	-	-	-	5MR
27	Avocet S*3/*Yr27* @	-	-	-	-	-	30MS
APR	Cook	0	0	-	-	20S	-
SD	Strubes Dickopf	-	-	-	-	-	-
SU	Suwon 92XOmar	-	-	-	-	-	-
CV	Castern V	-	-	-	-	-	-
SP	Spaldings Prolific	-	-	-	0	-	-
	Avocet S*6/*YrSP* @	-	-	-	-	-	0
DW	Cham 1	-	-	-	Tr-R	-	-

NOTES: * = yellow rust free year; @ = Additional differential used during 2003/04; APR = adult plant resistance

Table 3. Terminal reaction of different commercial wheat varieties in different years in Pakistan

Cultivar	*Yr* gene	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04
Bakhtawar 93	9+	40S	30S	Tr-MR	–	0	5R-MR	20MS-S
Chakwal 86	?	20MR-MS	20MR-MS	Tr-MR	–	0	5MR-MS	10MR-MS
Faisalabad 83	7+2	10S	10MR	40S	–	Tr-R	40MS-S	90MR-MS
Faisalabad 85	9+4	20S	0	20S	–	Tr-R	10R	0
Inqilab 91	6+7	20MR-MS	10MR	10MS	–	Tr-R	70MS-S	10MS-S
Kaghan 93	9	50S	30MS-S	20S	–	Tr-R	20MS-S	70MR-MS
Khyber 87	?	50S	30MR-MS	10MR	–	–	40MS	60MS
Pak 81	9	80S	40MS-S	50S	–	–	–	30S
Parwaz 94	6+7	30MS-S	30MS-S	10S	–	5MS-S	20MS-S	20MR-MS
Pasban 90	9	30S	70S	10MS-S	–	Tr-R	10MS-S	10R-MR
Pavon 76	6	–	20MS-S	10MS-S	–	–	40MS-S	50S
Pirsabak 85	9	–	30S	30S	–	–	20MS-S	30S
Pirsabak 91	9	50S	70S	40S	–	–	30MS-S	40S
Punjab 85	?	–	5MR-MS	10MR	–	–	10MR-MS	10MR-MS
Rawal 87	9+	60S	0	0	–	Tr-R	90S	50S
Sarsabz	7	90S	80S	30S	–	Tr-R	90S	50S
Shaheen 94	?	30S	Tr-R	40S	–	Tr-R	60MS-S	Tr-R
TandoJam 83	6+	60S	60MS-S	10S	–	40S	80S	50S
Watan 94	6+	40S	60S	30MS-S	–	30S	60S	5S
WL 711	2	60S	80S	80S	–	20S	40MS-S	50S
Blue Silver	A, 6	30S	30S	40S	–	10S	20MS-S	30S
Kohinoor 83	7, 9	20MS	50MS-S	20S	–	Tr-R	0	Tr-R
Lyallpur 73	?	–	–	–	–	–	–	–
Zardana	7	20S	40MR-MS	40MS-S	–	Tr-R	80MS-S	40MS-S
C-271	?	80S	–	–	–	–	–	–
C-591	?	50S	–	–	–	–	–	–
Kiran 95	?	60S	–	10MR-MS	–	Tr-MR	90S	–
Punjab 96	?	30MS-S	0	10MS-S	–	Tr-R	40MS-S	–
Shahkar 95	6+	40MS-S	0	40MS-S	–	Tr-R	40MS-S	Tr-MS-S
Soughat 90	6+7	30MS-S	0	10MS-S	–			5MS-S
Marvi-2000	?	–	–	–	–	–	0	0

NOTES: 2001/02 was a yellow rust-free year.

Yr10 has been found almost free of yellow rust infection so far. However in some backgrounds, such as Moro, this gene was found with a susceptible reaction, and showed 30S reaction in M2435*6/*Yr10* background during 1997/98. In later years *Yr10* showed susceptibility against both Moro and M2435*6/*Yr10*.

Isogenic lines possessing *Yr9* and *Yr9*+, namely Fed*4/Kavkz, Seeri 82 and Clement, had been showing the presence of a virulent biotype against *Yr9* for many years at almost all the locations tested. *Yr9* has been postulated in many commercial cultivars in Pakistan. It is present as lone gene in Pasban 90, Rohtas 90 and Kaghan 90. In Khyber 87, Punjab 85, Rawal 87 and Bakhtawar 92 it is present with some additional gene (*Yr9*+). Presence of *Yr9* in so many cultivars resulted in breakdown of resistance due to *Yr9*. Epidemic yellow rust in NWFP is the consequence of large-scale cultivation of *Yr9*.

Yr5 showed variable reaction in different backgrounds. Aroona*6/*Yr5*, Avocet "S"*6/*Yr5*, M2435*6/*Yr5* and *T. spelta* showed 0 reaction during 1997/98. However, Aroona*6/*Yr5* was found with MR-MS reaction at some locations during 1998/99. In later years, from 1999 to 2003, virulence was also found infecting *T. spelta* and Avocet backgrounds. This gene has not been postulated so far from any of the Pakistani cultivars. However, this gene has been postulated in some Indian cultivars (Kema, 1992) against which presence of virulence was reported (Nagarajan *et al*., 1986).

During 1999/00 Hybrid 46 showed the attack of some virulence against *Yr4*. This gene was postulated from Faisalabad 85 in combination with *Yr9*. Faisalabad 85 was found showing susceptibility to yellow rust during 1999/00. This gene is very rarely present in Pakistani cultivars and Kirmani, Rizvi and Stubbs (1984) suggested the use of this gene for yellow rust management.

Yr6 is an important gene due to its presence in many Pakistani cultivars in combination with other genes. *Yr6* has showed presence of a virulent pathotype at different locations. The cultivars possessing *Yr6,* namely Inqilab 91, Parwaz 94, Sariab 92 and Shahkar 95, are in large-scale cultivation in Punjab and NWFP. Due to the breakdown of *Yr6*, an epidemic-like situation for yellow rust prevailed in the areas of Punjab and NWFP during 2002/03. *Yr6* along with adult plant resistance (APR) has also showed susceptibility, indicating presence of virulence against APR.

Yr8 showed different reactions in different backgrounds and locations. Generally, the differentials possessing *Yr8* were found showing a 0 to MR reaction in Faisalabad and Peshawar. In an Avocet background, *Yr8* showed MR-MS to S reaction, indicating the presence of virulence. *Yr8* has not been postulated in any Pakistani cultivar so far.

Yr15 was found free of disease at almost all locations. So far no virulence has been reported against this gene. Similarly *Yr17* was also found free of yellow rust in all the backgrounds. Both the genes, i.e. *Yr15* and *Yr17*, are not postulated from any Pakistani cultivar. Hence their utilization could be a good option for yellow rust management (Anonymous, 2001b).

Appearance of new virulence capable of attacking Inqilab 91 and MH 97 (Attila) has been a major change in the virulence spectrum of yellow rust during the last few years in Pakistan. A new pathotype had been reported attacking cultivars possessing *Yr27* in India, Iran, Yemen, Egypt, Ethiopia,

Eritrea, Tajikistan, Uzbekistan and Kyrgyzstan during previous years (Singh, Duveiller and Huerta-Espino, 2004; Afshari, 2004). It has brought over 11 million hectare of the wheat growing area of India and Pakistan alone under threat of yellow rust epidemics, due to cultivation of three most important cultivars—Inqilab 91, MH 97 and PBW 343 (Attila)—possessing *Yr27*. In addition to this, almost all the commercial wheat cultivars, particularly Sarsabz, T.J.-83, Soghat 90, Anmol, Kiran 95 and Mehran 89, cultivated in Sindh province; Kohistan, Parwaz, Bhakhar, Bahawalpur 97, Faisalabad 83, Chakwal 97, Watan, SH 2002, Pasban 90 and Uqab 2000 cultivated in Punjab province; Zargoon 79, Zardana and Sariab 92 under cultivation in Baluchistan province; and Nowshera, Takbeer and Tatara cultivars of NWFP, are also showing varying degree of susceptibility to this virulence. Singh, Duveiller and Huerta-Espino (2004) reported that wheat cultivars, either selections or derivatives of CIMMYT germplasm Attila, Opata, Kauz, Nacozari, Bucbuc and Crow, grown across the CWANA region, are under threat of yellow rust epidemic due to this new virulence.

In India, the race virulent on *Yr27* has been designated as 78S84 (Anonymous, 2002a) and as 166E134A+ in Iran (Afshari, 2004). E. Duveiller, during the Annual Wheat Meeting in Islamabad in 2003, with reference to Ravi Singh of CIMMYT, reported that Inqilab 91 and MH 97 possess only *Yr27* and no *Yr9,* while PBW 343 and Bakhtawar 93 possess both *Yr27* and *Yr9*. During 2002/03 and 2003/04, Inqilab 91, MH 97 (Attila) and PBW 343 have shown susceptibility to yellow rust, while Bakhtawar 93 (Kauz), along with newly released wheat variety Marvi 2000, were found free of yellow rust in rust-prone areas of NWFP. According to E. Duveiller of CIMMYT, these results suggest the prevalence of two virulences: one attacking *Yr27* alone and another attacking *Yr27+Yr9*. However, the latter race attacking PBW 343 should have attacked Bakhtawar 93. Besides, *Yr27* virulence is also capable of attacking Tandojam 83 (Nacozari), Opata, Bucbuc and Crow (Singh, Duveiller and Huerta-Espino, 2004).

Susceptibility of Inqilab 91 to yellow rust has created a very alarming situation for sustainability of wheat production in Pakistan. Since release, Inqilab 91 has been very popular amongst growers due to its wide adaptability and high yield potential under different sowing dates and different cropping systems, like cotton-wheat, rice-wheat and sugarcane-wheat. Initially Inqilab 91 was released for cultivation in southern parts of Pakistan due to rust concerns, but it spread all across Pakistan and at the time of writing covered about 60–70% of the area under wheat in Pakistan (Anonymous, 2004). Inqilab 91 has shown yellow rust development in patches in Punjab since its release, but no widespread epidemic has developed. This is mainly attributed to the check on rust development provided by the slow-rusting and APR mechanism of Inqilab 91. However, during 2002/03 and 2003/04 heavy rains and prolonged low temperature resulted in epidemics of yellow rust on

Inqilab 91 at Nowshera, Swabi and Mardan in NWFP and caused 20–30% losses.

It is evident from the results that the yellow rust problem has different implications in different agro-climatic zones for wheat production. Similarly, behaviour of different rust resistance genes was also different. Furthermore, similar genes behaved differently in different backgrounds. This might be due to some morphological or physiological characteristics regulated by some other genes. Yellow rust-resistant genes *Yr1*, *Yr4*, *Yr5*, *Yr8+*, *Yr10*, *Yr15* and *Yr17* still have the potential for utilization in wheat cultivars for rust management in Pakistan.

The new yellow rust situation prompts the need for a suitable forecasting system and strategy for incorporation and deployment of functional and defeated yellow rust resistant genes singly or in combination. Keeping in view the disease forecasting and management strategies recommended by Nagarajan (1980), gene deployment for yellow rust should be carried out keeping the regional situation in focus to avoid culture of single-gene-based or single genetic background genotypes on a large scale, as in the case of Attila (*Yr27*). Singh, Duveiller and Huerta-Espino (2004) suggested that wheat breeders should take immediate action to identify and promote cultivars that have resistance to the new *Yr27*-virulent race to avoid losses caused by yellow rust. At present most of the wheat varieties being grown in the region, including Pakistan, India, Iran and Kyrgyzstan, are protected by *Yr27* located on the 2BS chromosome, and are under threat. Similarly, Stubbs (1988) suggested continuous monitoring of the virulence spectrum and breeding for disease resistance and evaluation of host resistance in different agro-ecological zones. Reddy and Rao (1979), while recommending the strategy for leaf rust gene deployment, suggested the use of resistant genes in multigene cultivars and gene rotation in different geographical regions to avoid monoculture on a regional basis.

References

Afshari, F. 2004. Challenge of new race of *Puccinia striiformis* f.sp. *tritici* in Iran. (Abstract). *In:* Second Regional Yellow Rust Conference for CWANA, Islamabad, Pakistan, 22–26 March 2004. ICARDA publication. [This volume]

Ahmad, I. 2000. An overview of cereal rust research in Pakistan. Crop Disease Research Institute, NARC, Islamabad.

Anonymous. 2001a. Trap Nursery 1999/2000. Crop Disease Research Institute, NARC, PARC, Islamabad, Pakistan.

Anonymous. 2001b. ICARDA Annual Report. ICARDA, Syria. 32 p.

Anonymous. 2002b. Agricultural Statistics of Pakistan.

Anonymous. 2002a. *Indian Wheat Newsletter*, 8(2).

Anonymous. 2004. Travelling Wheat Seminar 2004. Coordinated Wheat Programme, NARC, Islamabad, Pakistan.

Habgood, R.M. 1970. Designation of physiological races of plant pathogens. *Nature (London)*, 227: 1268–1269.

Johnson, R., Stubbs, R.W., Fuchs, E. & Chamberlaine, N.H. 1972. Nomenclature for physiological races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Kema, G.H.J. 1992. Resistance in split wheat to yellow rust. *Euphytica*, 63: 207–217.

Kirmani, M.A.S., Rizvi, S.S.A. & Stubbs, R.W. 1984. Postulated genotypes for stripe rust resistance in wheat cultivars of Pakistan. pp. 81–85, *in:* Proceedings of 6th European and Mediterranean Rust Conference.

Loegering, W.Q & Harmon, D.L. 1969. Wheat lines near isogenic for reaction to *Puccinia recondita* f.sp. *tritici*. *Phytopathology,* 59: 456–459.

Nagarajan, S. 1980. Epidemiological investigations on the outbreak of wheat rust during 1976 in Pakistan and Spain, with an emphasis on forecasting and management (A report). Troperistitute, Justus-Leibig University, Giessen, Germany. pp. 34–36

Nagarajan, S., Nayar, S.K., Bahadur, P. & Kumar, J. 1986. Race 13 (67S8) virulent on *Triticum spelta* var. *album*. *India Plant Disease,* 70: 173.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Reddy, M.S.S. & Rao, M.V. 1979. resistance genes and their deployment for control of leaf rust of wheat. *Indian Journal of Genetics and Plant Breeding,* 39: 359–365.

Singh, R.P., Duveiller, E. & Huerta-Espino, J. 2004. Virulence to yellow rust resistance gene *Yr27*: A new threat to stable wheat production in Asia. (Abstract). *In:* Second Regional Yellow Rust Conference for CWANA, Islamabad, Pakistan, 22–26 March 2004. This volume.

Stubbs, R.W. 1988. Pathogenicity analysis of yellow (stripe) rust of wheat and its significance in a global context. pp. 23–38, *in:* N.W. Simmonds and S. Rajaram (editors). *Breeding Strategies for Resistance to the Rusts of Wheat*. CIMMYT, Mexico, D.F., Mexico.

Selection of yellow rust-resistant wheat varieties in Tajikistan

H. Muminjanov,[1] Z. Eshonova,[2] F. Qosimov,[2] I. Khusaynov,[2] A. Yorov,[2] N. Hikmatov,[2] A. Ibrohimov,[2] S. Naimov,[2] A. Morgounov,[1] B. Pett[1] and M. Otambekova[1]

1. GTZ/CIMMYT Project, Dushanbe, Tajikistan
2. Tajik Research Institute of Farming, Sharora, Hisor Region, Tajikistan

Introduction

Tajikistan is a landlocked country in Central Asia. The country is located on a latitude similar to Greece, Italy and Spain (36°40' to 41°05'N and 67°31' to 75°14'E). The country covers 143 000 km^2, of which 93% is mountains and hills. It is a country of contrasts, with high mountain peaks and blossoming valleys, stretching from Syrdarya in the north to Piandj in the south. There are arid zones with a very hot climate (Vakhsh valley) and regions with severe polar frosts (Pamirs).

Tajikistan has a long history of agricultural civilization, and today agriculture remains one of the main spheres of activity of the population and source of income in the national economy. In 2003, the share of the agricultural sector in GDP was approximately 26.5%. Agricultural production provided 35% of export income and 35% of taxes and dues.

In Tajikistan, as well as in a number of other Asian countries, bread is the main food product of the population, and cultivation of wheat is considered a basic agricultural activity of Tajiks. There are different bread types and varieties in Tajikistan. Tajiks respect bread as a holy product and prepare special meals from wheat during festivals. *Sumanak* is a kind of sweet that is cooked in *Navruz* – ancient New Year of Aries. However, the existing historical circumstances and changes in socio-political structure have significantly affected the cultivation of wheat and production of grain as a whole. In an agrarian country with limited land resources, use of each hectare of land is considered a sacred duty. Therefore, after the country became independent Government agricultural policy aimed to achieve food security as a whole, and grain independence in particular. Thus the main emphasis has been on cultivation of wheat, as it provides approximately 60% of national needs for food. For the last 10 years the area sown to wheat as a whole in the country has increased almost 2.5 times. Wheat occupies 85% of the total area of grains. In parallel with the expansion of area, the 10 years have also seen growth in production of wheat, and the share of private farms and population has

considerably increased. The peak wheat production of 645 000 tonne was achieved in 2003.

Among the diseases affecting yield during the last 15 to 20 years, smuts were considered as dangerous. However rusts, particularly yellow rust, is becoming a very dangerous disease that significantly decreases grain yield. Infection by yellow rust has been observed in all zones of Tajikistan under both irrigated and rainfed conditions. The increase in yellow rust infection has a direct relationship with expansion of the growing area in all Central Asian countries and a decrease in existing natural barriers. Severe epidemics of yellow rust have occurred in years with high rainfall, and the pathogen damages wheat everywhere. Yellow rust epidemics may totally destroy wheat crops and decrease wheat yield by up to 60–70%. Most of the widely grown wheat varieties are very susceptible to this disease.

Materials and methods

After independence several wheat varieties were introduced and disseminated to farmers by international humanitarian agencies. However, the GTZ/CIMMYT Project aimed to strengthen wheat breeding and the seed multiplication system in Tajikistan. During the implementation of the project since 1999 to present, a number of wheat varieties and advanced lines have been tested in different agro-ecological zones of Tajikistan, varying from 500 up to 1800 masl. The genotypes tested originated from CIMMYT, ICARDA and the breeding programmes of USA, Turkey, Russia, Ukraine, Bulgaria, Hungary, Iran, Kazakhstan and Tajikistan. In addition to yield data, disease resistance, and specifically yellow rust reaction, was used as a criterion to select the best varieties for release and large-scale multiplication. In 2002, 30 entries were tested in multilocational testing nurseries (MLN); 28 in yield trials; and 36 in preliminary yield trials.

Results and discussion

The results of uniform trials show that there are several varieties very well adapted to the climatic conditions of the country, that demonstrate resistance to rust, and produce high grain yield. Among genotypes selected, cultivars such as Jagger, Atay, Sulton 95 and Kinaci became very popular in Tajikistan due to high yield and yellow rust tolerance.

The advanced lines and varieties tested in multilocation nurseries, such as Kauz, Attila, Zander-12, PYN/BAU, CHAM 6/1D13.1/MLT, GRK//ESDA/LIRA, NWT/3/TAST/SPRW//TAW12399.75, DORADE-5, NORKAN//TJB406.892/MON, TAST/PCH//BEZ2B/CGN/3/ZAR VORONA/HD2402 and RSK/CA8055//CHAM-6, showed rust resistance.

These genotypes—depending on the location—were infected by yellow rust to only 5 to 10%, while local varieties Navruz and Sharora were infected 40 to 60%.

Table1. The results of wheat yield trials in different locations, 2003

Variety	Country	Chilgazi		Dangara		Sharora		Vakhsh		Sovetskiy	
		YR %	Yield t/ha	YR %	Yield t/ha	YR %	Yield t/ha	YR %	Yield t/ha	YR %	Yield t/ha
Navruz (local check)	Taj	40	5.0	40	3.2	60	3.6	20	4.2	30	2.5
Somoni	Taj	0	5.0	40	3.5	15	3.9	0	2.7	5	2.1
Jagger	USA	0	6.1	20	3.6	10	4.2	0	3.2	5	3.1
Kauz	Mex	0	6.6	10	3.5	15	4.6	0	4.0	5	2.1
Attila	Mex	0	7.3	5	4.0	20	4.4	0	4.3	10	2.6
Tacicar	Taj-Mex	0	6.2	15	3.6	10	4.2	0	3.7	5	4.3
Norman	Taj-Mex	0	6.5	20	4.0	10	4.1	0	4.0	5	4.6
Zander-12	TCI	0	6.5	50	4.0	10	3.6	0	3.8	0	2.5
CHAM6//1D13.1/ MLT	TCI	30	5.9	10	4.4	10	4.7	0	3.2	5	2.6
KINACI	MX-TCI	0	5.6	40	4.5	15	4.4	0	4.0	5	4.2
VORONA/HD2402	MX-CIT	20	4.6	50	4.5	0	4.0	0	3.8	5	2.5
NORKAN//TJB406 .892/MON	OR-CIT	0	5.5	30	3.4	10	4.1	0	4.2	5	3.4
GRK//ESDA/LIRA	MX-CIT	0	5.1	20	4.1	15	3.6	0	2.5	10	4.6
NWT/3/TAST/SPR W//TAW12399.75	TCI	0	5.5	10	4.6	5	4.2	0	3.8	0	3.5
NECOMP1/5/BEZ //TOB/…	TCI	50	5.0	30	3.4	5	3.8	0	3.0	0	3.2
TAST/SPRW//BLL /7/SOTY/…	TCI	0	5.2	20	3.3	5	4.1	0	3.3	5	4.0
TAM200/KAUZ	MX-TCI	0	5.5	40	3.3	30	4.5	0	3.7	0	4.2
Todora	BG	0	5.2	30	2.4	5	3.8	0	3.7	5	1.8
Kristal	RUS-KR	0	5.5	20	2.7	15	3.7	0	3.3	10	3.5
TX96V2427	KS	0	6.3	10	3.7	90	4.5	0	3.8	5	5.1
PYN/BAU	MX-OR-TCI	0	6.0	10	4.4	0	4.4	0	3.8	0	5.2

Table 2. Winter wheat varieties originating from international nurseries being officially tested in Tajikistan

Year	Variety	Pedigree	Cross ID	Origin
1999	Kauz	JUP/BJY//URES	CM67458	MX
2000	Tacicar	TAST/SPRW//ZAR	ICWH840048	TCI
2000	Norman	OR F1.158/FDL//BLO/3/SHI4414/CROW	ICWH860291	TCI
2002	Alex	PYN/BAU	SWM15182	MX-OR-TCI

In the preliminary yield trial, the advanced lines DYBR1982.83/842ABVD C.50, Almaty Polukovilik, CTY*3/TA2460, TAM200*3/TA2567, VORONA/TR810200, TAM200/KAUZ, Bayaraktar and 1D13.1/MLT//TUI were resistant to yellow rust infection. These genotypes were also characterized as high yielding.

Several new varieties were identified as rust resistant and high yielding on the basis of uniform trials data conducted by the GTZ/CIMMYT Project in the last four years. Among selected genotypes, six were submitted for official variety registration trials as new varieties: Norman, Tacicar, Ormon, Somoni, Ziroat 70 and Alex.

Conclusion

The results of research conducted confirm that further increase in grain production in Tajikistan requires strengthening of the breeding programme, enrichment of wheat germplasm and improvement of management, which should be done in close collaboration with International Centres and breeding programmes.

Sources used

Anonymous. No date. Agriculture of Republic of Tajikistan. *The Statistical Yearbook 2003*. Dushanbe, Tajikistan.

Anonymous. 1982. *Tajikistan (nature and natural resources).* Donish Publishing House, Dushanbe, Tajikistan. 601 p.

Anonymous. Various dates. Reports of the GTZ/CIMMYT Project "Regional network on wheat variety promotion and seed multiplication", 2002–2003.

Reaction of some international wheat genotypes to yellow rust at the adult-plant stage in Iran

A. Malihipour,[1] M. Torabi,[1] M.S. Ahmadian-Moghaddam[2] and A. Tarinejad[3]

1. Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran
2. Mazandaran Agricultural Research Centre, Sari, Islamic Republic of Iran
3. Moghan Agricultural Research Centre, Parsabad, Islamic Republic of Iran

Abstract

In the present investigation, reactions of 140 bread and durum wheat genotypes provided by ICARDA were assessed for yellow rust reaction at three locations in Iran (Karaj, Sari and Moghan). Wheat entries were evaluated under field conditions with artificial epidemic conditions to identify adult plant resistance. The genotypes were planted in November 2000, at 10–15 g of seed in two 1-m long rows spaced 30 cm apart. A susceptible cultivar (Bolani) was planted among the experimental entries. Artificial inoculations of the nurseries were done 4–5 times in a period of two months, starting at tillering stage and using the relevant race for each location. The infection type (IT) of each entry was evaluated when the disease developed well on the susceptible check. The percentage leaf area affected was scored using Cobb's modified scale and at the same time coefficients of infection (CI) were calculated. A heavy epidemic of the disease was established in the nurseries at all locations. Based on data collected, most of entries were resistant to yellow rust in one or more locations, and 132 entries were resistant at all locations. The results of this research were sent to ICARDA for final analysis and to inform the breeding programmes of the region.

Introduction

Yellow [stripe] rust, caused by *Puccinia striiformis* f.sp. *tritici*, is one of the most important diseases of wheat in the world. Yellow rust is principally a disease of wheat grown in cooler climates (2–15°C), which are generally associated with higher elevations, northern latitudes or cooler years. Losses can be severe (50%) due to shrivelled grain and damaged tillers. In extreme situations, stripe rust causes 100% loss.

In Iran, the disease is destructive in various parts of the country. It has been known for many years, but favourable climatic conditions for the pathogen enabled the disease to reach epidemic level during the early 1990s, with the most severe epidemics occurring in 1993 and 1995. Yield losses of 30% were reported for these years (Torabi *et al.*, 1995).

The use of resistant cultivars is the most effective, economic and environmentally safe method of controlling the disease. It is possible to recognize two types of resistance to yellow rust (Zadoks, 1961). The first type is evident at the seedling stage and lasts for the life of the host plant. This type of resistance is race-specific. The second type of resistance to yellow rust is apparent only during the adult plant stage, and its genetic control is currently less well understood. This type of resistance can also be race-specific (Johnson, 1981; McIntosh, Wellings and Park, 1995).

Seedling resistance to *P. striiformis* in wheat can be detected in greenhouse tests, whereas adult plant resistance (APR), although it can be detected in the greenhouse, appears more commonly in field tests (Wellings, 1996).

The objective of this study was to determine the APR of some ICARDA-bred wheat genotypes to yellow rust at the adult-plant stage in Iran in the 2000/01 cropping year.

Materials and methods

Reaction of 140 bread and durum wheat genotypes supplied by ICARDA were assessed for yellow rust reaction at three locations in Iran (Karaj, Sari and Moghan) at the adult plant stage under artificial inoculation in the field in the 2000/01 cropping season. Genotypes used in this research were:

- WYR 2000-2001 – 75 accessions
- DYR 2000-2001 – 50 accessions
- Bread Wheat Germplasm Pool for Yellow Rust Resistance (WYRGP) – 8 accessions
- Durum Wheat Germplasm Pool for Yellow Rust Resistance (DYRGP) – 7 accessions

The nursery was sown in November 2000. The seeds of each entry were planted in two 1-m long rows (as hill plots), spaced 30 cm from each other. Cv. Bolani was used as a susceptible check.

Artificial inoculations of the nurseries were done 4–5 times in a period of two months, starting at the tillering stage, by spraying urediniospores of the relevant race for each location in a mixture with talcum powder, over the whole nursery. Spraying was performed towards the evening, especially on cloudy and moist days and after application of mist irrigation. Yellow rust pathotype 134E134A+ was used for inoculation of the nursery in Karaj. The

nurseries were irrigated with mist and flood irrigation to promote disease development.

The percentage leaf area affected (severity) was scored using the modified Cobb's scale of Peterson, Campbell and Hannah (1948) at the end of the season when leaves were alive and green. Reaction (infection type) of each line or cultivar was evaluated at the same time (Roelfs, Singh and Saari, 1992).

The two scores were then converted to a coefficient of infection (CI). This CI was obtained by multiplying the constant value for infection types (0=0; R=0.2; MR=0.4; I=0.6; MS=0.8; and S=1) and the leaf area affected (severity). The entries were classified according to their CI values.

Results and discussion

A heavy epidemic of the disease was established on the experimental materials in all locations and susceptible cultivars were severely infected at each nursery. The infection type and severity of susceptible check cv. Bolani was 100S in all locations. The uniform disease development allowed successful evaluation of the nurseries for resistance The results showed that 132 entries were resistant to yellow rust in all locations (Tables 1, 2, 3 and 4). Only a few genotypes were moderately resistant, moderately susceptible or susceptible.

The results of this research were sent to ICARDA for final analysis and as input to breeding programmes of the WANA region.

References

Johnson, R. 1981. Durable disease resistance. pp. 55–63, *in:* J.F. Jenkyn and R.T. Plumb (editors). *Strategies for Control of Cereal Diseases.* Blackwell, Oxford, UK.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO Publications, Australia. 200 p.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. *Rust Diseases of Wheat: Concepts and Methods of Disease Management*. CIMMYT, Mexico. 81 p.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildews Bulletin,* 23: 9–12.

Wellings, C.R. 1986. Host:Pathogen Studies of Wheat stripe rust in Australia. PhD Thesis. University of Sydney, Australia. 237 p.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

Table 1. Evaluation of resistance of genotypes of WYR 2000-2001 to yellow rust

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
1	Tsi/Vee'S'//Bol'S'/Pvn'S'	ICW91-0233-0TS-6AP-1AP-1AP-1AP-0AP	WYR-00	Tr-R	0	0
2	Chat'S'//Kvz/Cgn/3/Vee'S'/Nac	ICW92-0162-0AP-1AP-0L-1AP-0L-1AP-0AP	WYR-00	20R	Tr-R	0
3	Tul//Shi#4414/Crow'S'	ICW92-0215-0AP-3AP-0L-3AP-0L-2AP-0AP	WYR-00	15R	0	0
4	Karawan—2/4/Mai's'/Pj//Emu'S'/3/Klto/Pato.19//Mo	ICW92-0275-4AP-0L-5AP-0L-3AP-0AP	WYR-00	0	0	0
5	Kasyon/Genaro.81//Tsi/Vee'S'	ICW92-0281-1AP-2AP-0L-1AP-0AP	WYR-00	0	0	0
6	CHAM 4//Maya'S'/Sap'S'	ICW92-0545-0AP-4AP-0L-1AP-6AP-0AP	WYR-00	Tr-R	0	0
7	Karawan—1/4/Nif/3/Soty//Nad63/Chris	ICW92-0609-1AP-4AP-4AP-0AP	WYR-00	0	Tr-MR	0
8	Shi#4414/Crow'S'/4/Nif/3/Soty//Nad63/Chris	ICW92-0671-4AP-0L-3AP-0L-1AP-0AP	WYR-00	0	0	0
9	Shi#4414/Crow'S'/4/Nif/3/Soty//Nad63/Chris	ICW92-0671-4AP-0L-4AP-0L-1AP-0AP	WYR-00	0	0	0
10	Mexipak (Check 1)	ICW91-0233-0TS-6AP-1AP-1AP-1AP-0AP		60MS	20MS	0
11	Shi#4414/Crow'S'/3/Rmn F12-71/Ska//CA8055	ICW92-0717-1AP-3AP-3AP-0AP	WYR-00	Tr-R	0	0
12	Tr380-16-3A614/Chat'S'//Cmh76-252/Pvn'S'	ICW93-0065-6AP-0L-1AP-0L-1AP-0AP	WYR-00	20R	0	0
13	Cham-6/TUI'S'	ICW93-0035-3AP-0L-2AP-1AP-0AP	WYR-00	Tr-R	0	0
14	Cham-6/TUI'S'	ICW93-0035-3AP-0L-2AP-5AP-0AP	WYR-00	0	0	0
15	KAVZ'S'/CHORIZO	ICW93-0122-7AP-0L-2AP-2AP-0AP	WYR-00	Tr-R	0	0
16	Shuha'S'/Ghurab'S'	ICW92-0718-1AP-1AP-3AP-1AP-0AP	WYR-00	Tr-R	0	0
17	Shuha'S'/Ghurab'S'	ICW92-0718-1AP-2AP-1AP-3AP-0AP	WYR-00	0	0	0
18	Karawan—1/4/Nif/3/Soty//Nad63/Chirs	ICW92-0609-1AP-1AP-2AP-3AP-0AP	WYR-00	0	Tr-R	0
19	Karawan—1/4/Nif/3/Soty//Nad63/Chirs	ICW92-0609-1AP-4AP-7AP-1AP-0AP	WYR-00	0	0	0
20	Snb'S' Pima(Check 2)			Tr-R	0	0
21	Tevee'S'/Shuha'S'	ICW92-0023-1AP-5AP-3AP-1AP-0AP	WYR-00	0	0	0
22	NS732/Her//V-84021	ICW92-0839-AP-2AP-0L-1AP-1AP-1AP-0AP	WYR-00	0	0	0

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
23	Tevee'S'//Bol'S'/Pvn'S'	ICW91-0233-0TS-1AP-1AP-2AP-2AP-1AP-0A	WYR-00	Tr-R	0	0
24	Dobuc'S'/Tracha'S'	ICW92-0758-0AP-3AP-0L-0BR-1AP-1AP-0AP	WYR-00	0	0	0
25	PRINIA	CM90722-2	WYR-00	Tr-R	0	0
26	SH4/CHIL	CM91099-2	WYR-00	0	0	0
27	CBRD/KAUZ	CMBW90M24	WYR-00	10R	Tr-R	0
28	CATBIRD	CM91045-9	WYR-00	Tr-R	0	0
29	969-69-20		WYR-00	0	0	0
30	Mexipak (Check 1)			Tr-R	20MS	0
31	NS732/NER//SHUHA-15	ICW92-0848-0AP-10AP-0L-0BR-1AP-1AP-0A	WKL-00	0	30MS	0
32	ZIDANE 89/3/PEG'S'//HD2206/HORK'S'	ICW93-0020-3AP-0L-4AP-1AP-0AP	WKL-00	Tr-R	Tr-R	0
33	TUI'S'/3/NAI60/HN7//SX	ICW93-0215-0Br-0BR-2AP-2AP-0AP	WKL-00	Tr-R	0	0
34	MG.5262/4/HYS/NO//LVLL.FL/3/FL KVZ/HYS/5/BOCRO-5	ICW93-0631-1AP-0L-3AP-0L-4AP-3AP-0AP	WKL-00	0	0	0
35	CHILERO-1/CV.BURGAS2	ICW93-0108-1AP-0L-5PH-0AP-1AP-0AP	WKL-00	Tr-R	Tr-R	0
36	KAUZ/CHORIZO	ICW93-0122-7AP-0L-5AP-2AP-0AP	WKL-00	0	20MS	0
37	KEA'S'/MN72252//SHUHA-15	ICW94-0128-0L-5AP-1AP-1AP-0APS-0AP	WPD-00	0	0	0
38	KEA'S'/MN72252//SHUHA-15	ICW94-0128-0L-5AP-1AP-2AP-0APS-0AP	WPD-00	0	0	0
39	KEA'S'/MN72252//SHUHA-15	ICW94-0128-0L-5AP-1AP-3AP-0APS-0AP	WPD-00	0	0	0
40	Snb'S' Pima	(Check 2)		0	0	0
41	KEA'S'/MN72252//SHUHA-15	ICW94-0128-0L-5AP-1AP-4AP-0APS-0AP	WPD-00	Tr-R	0	0
42	KEA'S'/MN72252//SHUHA-15	ICW94-0128-0L-5AP-1AP-6AP-0APS-0AP	WPD-00	0	0	0
43	TRACHA-2//NS732/HER	ICW94-0262-0L-3AP-1AP-11AP-0APS-0AP	WPD-00	0	0	0
44	GH'S'/ANZA//NS732/HER	ICW94-0292-0L-2AP-1AP-3AP-0APS-0AP	WPD-00	0	0	0
45	GH'S'/ANZA//NS732/HER	ICW94-0292-0L-2AP-2AP-1AP-0APS-0AP	WPD-00	0	0	0
46	GH'S'/ANZA//NS732/HER	ICW94-0292-0L-2AP-2AP-2AP-0APS-0AP	WPD-00	0	0	0
47	GH'S'/ANZA//NS732/HER	ICW94-0292-0L-2AP-2AP-5AP-0APS-0AP	WPD-00	0	0	0
48	NS 5510/BOW'S'/3/BB/PATO(3)//COC	ICW94-0334-0L-3AP-1AP-8AP-0APS-0AP	WPD-00	0	0	0

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
49	SIBIA/MILAN	CMSS93Y00048S-4AP-1AP-2AP-0APS-0AP	WPD-00	0	0	0
50	Mexipak	(Check 1)		0	80MS	5R
51	VEE#7/KAUZ'S'	ICW94-0029-0L-1AP-1AP-4AP-0APS-0AP	WPD-00	0	0	0
52	VEE#7/KAUZ'S'	ICW94-0029-0L-6AP-3AP-7AP-0APS-0AP	WPD-00	0	0	0
53	Chilero-1/4/VEE'S'/3/HORK'S'/YMH//KAL/BB	ICW94-0052-0L-2AP-1AP-1AP-0APS-0AP	WPD-00	0	0	0
54	Chilero-1/4/VEE'S'/3/HORK'S'/YMH//KAL/BB	ICW94-0052-0L-2AP-1AP-6AP-0APS-0AP	WPD-00	0	Tr-R	0
55	Chilero-1/4/VEE'S'/3/HORK'S'/YMH//KAL/BB	ICW94-0052-0L-2AP-2AP-2AP-2AP-0APS-0AP	WPD-00	0	0	0
56	Chilero-1/4/VEE'S'/3/HORK'S'/YMH//KAL/BB	ICW94-0052-0L-2AP-3AP-2AP-0APS-0AP	WPD-00	0	0	0
57	Chilero-1/4/VEE'S'/3/HORK'S'/YMH//KAL/BB	ICW94-0052-0L-2AP-3AP-4AP-0APS-0AP	WPD-00	0	Tr-R	0
58	KAUZ'S'//MON'S'/CROW'S'	ICW94-0061-0L-1AP-4AP-0APS-0AP	WPD-00	Tr-MR	0	0
59	TJB916.46/CB306//2*MHB/3/BUC/5/ND/VG9144/KAL/BB/3/YACO/4/CHIL	CMSW93Y00499S-8AP-2AP-2AP-0APS-0AP	WPD-00	Tr-R	0	0
60	Snb"s" Pima	(Check 2)		0	0	0
61	SIBIA/MILAN	CMSS93Y00048S-4AP-1AP-5AP-0APS-0AP	WACB-00	0	0	0
62	Bocro-1			Tr-R	0	0
63	GOV/AZ//MUS/3/DODO/BOW	CM79515-044Y-1M-02Y-07M-3Y-3B-0Y-0PZ-4PZ-0Y-2M-010Y-0FUS-2FUS-0AP	WACB-00	10R	0	0
64	CATBIRD	CM91045-9Y-0M-0Y-5M-4Y-0B-4PZ-0Y-3PZ-010Y-0M-1SJ-0Y-0AP	WACB-00	0	0	0
65	BLOYKA-1	ICW84-0008-013AP-300L-3AP-300L-0AP	WACB-00	0	0	0
66	KARAWAN-1/4/NIF/3/SOTY//NAD63/CHRIS	ICW92-0609-1AP-1AP-2AP-2AP-0AP	WACB-00	Tr-R	0	0
67	KARAWAN-1/4/NIF/3/SOTY//NAD63/CHRIS	ICW92-0609-1AP-4AP-3AP-2AP-0AP	WACB-00	0	Tr-MR	0
68	NS732/NER//PRL'S'/CHOVA'S'	ICW92-0850-0AP-1AP-0L-0BR-2AP-1AP-0AP	WACB-00	20R	Tr-R	0
69	NS732/NER//PRL'S'/CHOVA'S'	ICW92-0850-0AP-1AP-0L-0BR-2AP-2AP-0AP	WACB-00	20R	Tr-R	0
70	Mexipak	(Check 1)		40MS	80MS	10R

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
71	NS732/HER	SWM11179-2AP-3AP-1AP-1AP-0AP	WACB-00	0	0	0
72	KARAWAN-1/4/NIF/3/SOTY//NAD63/CHRIS	ICW92-0609-1AP-1AP-1AP-1AP-0AP	WACB-00	Tr-R	0	0
73	TEVEE'S'//BOL'S'/PVN'S'	ICW91-0233-0TS-6AP-1AP-3AP-3AP-0AP	WACB-00	Tr-R	0	0
74	SHUHA-7/4/NIF/3/SOTY//NAD63/CHRIS	ICW92-0671-4AP-0L-4AP-0L-1AP- 1AP-0AP	WACB-00	0	0	0
75	KABY	SWM11027-2AP-2AP-2AP-1AP-0AP	WACB-00	10R	0	0
-	Bolani	(Susceptible check)	-	100S	100S	100S

Table 2. Evaluation of resistance of genotypes of DYR 2000-2001 to yellow rust

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
1	Rec.S.P.(M.E)	R.S.P.(M.E)-93-4AP-0AP-1AP-0TR	DYR-00	Tr-R	5R	Tr-R
2	Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4	ICD92-0150-CABL-7AP-0AP-5AP-0TR	DYR-00	0	Tr-R	0
3	Ossl1/Stj5	ICD92-0976-C-0AP-6AP-0TR-2AP-0AP	DYR-00	0	Tr-R	0
4	Villemur/3/Lahn//Gs/Stk/4/Dra2/Bcr	ICD94-0450-T-0AP-1AP-0AP	DYR-00	0	Tr-R	0
5	Villemur/3/Lahn//Gs/Stk/4/Dra2/Bcr	ICD94-0450-T-0AP-6AP-0AP	DYR-00	0	20MR	0
6	Villemur/3/Lahn//Gs/Stk/4/Dra2/Bcr	ICD94-0450-T-0AP-7AP-0AP	DYR-00	0	5MR	0
7	Mrf2/3/Gdfl/T.dicdsSY20013//Bcr	ICD94-0887-W-0AP-24AP-0AP	DYR-00	0	0	0
8	Bcr//Fg/Snipe/3/GdoVZ578/Swan//Dra2	ICD92-0175-CABL-0AP-5AP-0TR-2AP-0AP	DYR-00	0	5R	0
9	Otb4	ICD91-0811-AB-3AP-0AP-2AP-0AP	DYR-00	0	Tr-R	0
10	WDAL (Check1)			60MS	60MS	0
11	Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4	ICD92-0150-CABL-8AP-0AP-2AP-0TR-4AP-0AP	DYR-00	0	Tr-R	0
12	Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4	ICD92-0150-CABL-8AP-0AP-1AP-0TR-5AP-0AP	DYR-00	0	0	0
13	Ossl-1/Stj-5	ICD92-0976-CABL-0AP-6AP-0TR-2AP-0AP	DYR-00	0	10MR	0
14	Otb-1	ICD91-0811-AB-3AP-0AP-1AP-0AP	DYR-00	0	Tr-R	0
15	Arthur71/Bcr//Ch5	ICD91-0565-M-0AP-2AP-0AP-6AP-TR-7AP-0AP	DYR-00	0	Tr-R	0

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
16	Altar84/Stn//Lahn	ICD92-MABL-0237-5AP-0AP-5AP-0TR	DYR-00	0	Tr-R	0
17	1346/Lahn//Bcr/LKS 4	ICD94-0404-T-7AP-0AP-4AP-0AP	DYR-00	Tr-R	Tr-R	0
18	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-1AP-0AP-4AP-0AP	DYR-00	Tr-R	10MR	0
19	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-2AP-0AP-8AP-0AP	DYR-00	Tr-R	5MR	0
20	Cham1	(Check 2)		Tr-MR	10MR	Tr-R
21	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-2AP-0AP-10AP-0AP	DYR-00	Tr-R	15MR	0
22	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-3AP-0AP-5AP-0AP	DYR-00	Tr-R	10MR	0
23	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-4AP-0AP-1AP-0AP	DYR-00	Tr-R	10MR	0
24	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-4AP-0AP-2AP-0AP	DYR-00	0	10MR	0
25	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-4AP-0AP-6AP-0AP	DYR-00	0	10MR	0
26	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-4AP-0AP-9AP-0AP	DYR-00	Tr-R	10MR	0
27	Bcr/Sbl5//Ae.peregrinacylindros401047	ICD94-0307-WABL-5AP-0AP-5AP-0AP	DYR-00	Tr-MR	10MR	0
28	Bcr/Sbl5//T.urartu	ICD94-0307-WABL-3AP-0AP-2AP-0AP	DYR-00	10R	10MR	0
29	Bcr/Sbl5//T.urartu	ICD94-0307-WABL-3AP-0AP-8AP-0AP	DYR-00	Tr-R	20MR	0
30	WDAL	(Check1)		60MS	60MS	0
31	Heca-1/3/Gdfl/T.dic20013//Bcr	ICD95-1200-W-3AP-0AP-9AP-0AP	DYR-00	Tr-R	Tr-R	0
32	HFN94N MOR NO 37/Mrb5/3/Brch/T.dic 20017//Hcn	ICD95-0638-T-0AP-3AP-0AP	DYR-00	Tr-R	10MR	0
33	Bcr/3/Ch1//Gta/Stk/4/Bcr/Lks4	ICD92-0150-CABL-11AP-0AP-8AP-0TR-4AP-0AP	DKL-00	Tr-MR	5MR	0
34	Bcrch-1	ICD87-0459-0TR-ABL-9AP-0TR-4AP-0AP	DKL-00	20MS	5MR	0
35	1346/Lahn//Bcr/Lks4	ICD94-0404-T-7AP-0AP-1AP-0AP	DKL-00	Tr-R	5R	0
36	Mrf1/Stj2	ICD93-0746-C-TR-3AP-4AP-0AP	DKL-00	20MS	10MR	Tr-R
37	Terbo197-4	ICD92-0150-CABL-8AP-0AP-1AP-0TR-5AP-0AP	DKL-00	Tr-R	Tr-R	0
38	Gcn/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	ICD95-1302-C-2AP-0AP-1AP-0AP	DPD-00	0	Tr-R	0
39	Gcn/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	ICD95-1302-C-2AP-0AP-3AP-0AP	DPD-00	50MS	Tr-R	0
40	Cham1	(Check 2)		0	Tr-R	0

	Name	Pedigree	Source	Location		
				Karaj	Moghan	Sari
41	Gcn/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	ICD95-1302-C-2AP-0AP-5AP-0AP	DPD-00	Tr-R	Tr-R	0
42	Gcn//Stj/Mrb3	ICD95-1303-C-2AP-0AP-1AP-0AP	DPD-00	10MS	Tr-R	0
43	Quadalete//Erp/Mal/3/Unk/4/Gbch2	ICD96-0779-C-5AP-0AP-5AP-0AP	DPD-00	Tr-R	Tr-R	0
44	Lgt3/4/Bcr/3/Ch1//Gta/Stk	ICD94-0918-C-12AP-0AP-4AP-0AP-1AP-0AP	DPD-00	Tr-R	10R	0
45	Sbh/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5	ICD95-0951-C-2AP-0AP-5AP-0AP	DPD-00	10R	10MS	0
46	Bcrch1/Kund1149	ICD97-1158-H-0TR	DPD-00	Tr-R	Tr-R	0
47	1346/Lahn//Bcr/Lks 4	ICD94-0404-T-7AP-0AP-6AP-0AP	DABOON	0	Tr-R	0
48	Ossl-1/Gdfl	ICD92-0940-CABL-0AP-5AP-0TR	DABOON	0	Tr-R	0
49	Msbl-1/4/Quadalete//Erp/Mal/3/Unk	ICD95-1127-T-0AP-1AP-0AP	DABOON	0	Tr-R	0
50	WDAL	(Check1)		50MS	50MS	0
-	Bolani	(Susceptible check)	-	100S	100S	100S

Table 3. Evaluation of resistance of genotypes of Bread Wheat Germplasm Pool (WYRGP 00) to yellow rust (2000-2001)

	Name	Pedigree	Location		
			Karaj	Moghan	Sari
1	4777//Fkn/Gb/3/Vee's'/4/Buc's'/Pvn's'/5/Shi#4414/Crow's'	ICW93-0089-1AP-0L-4AP-0L-0AP	Tr-R	5MS	Tr-R
2	4777//Fkn/Gb/3/Vee's'/4/Buc's'/Pvn's'/5/Shi#4414/Crow's'	ICW93-0089-3AP-0L-2AP-0L-0AP	Tr-R	0	0
3	Tr380-16-3A614/Chat's'//Cmh76-252/Pvn's'	ICW93-0065-8AP-0L-1AP-0L-0AP	0	Tr-R	0
4	4777//Fkn/Gb/3/Vee's'/4/Buc's'/Pvn's'/5/MILLAWA	ICW93-0112-1AP-L-4PH-0AP-0AP	0	Tr-R	0
5	Dove's'/Buc's'//Carp	ICW93-0170-2AP-0L-2AP-0L-1AP-0AP	0	Tr-R	0
6	Dove's'/Buc's'//Carp	ICW93-0170-2AP-0L-3AP-0L-2AP-0AP	0	0	0
7	Tsi/Vee's'//Bol's'/Pvn's'	ICW91-0233-0TS-6AP-1AP-1AP-2AP-0AP	0	0	Tr-R
8	Maya's'/Sap's'	CM59008-6AP-1AP-4AP-2AP-2AP-0AP	0	0	0
-	Bolani	(Susceptible check)	100S	100S	100S

Table 4. Evaluation of resistance of genotypes of Durum Wheat Germplasm Pool (DYRGP 99) to yellow rust (2000-2001)

No.	Name	Pedigree	Location		
			Karaj	Moghan	Sari
1	Bicre/3/Ch 1//Gta/Stk	ICD87-0459-0TR-ABL-9AP-0TR-4AP-0AP	Tr-MR	Tr-R	0
2	Bicre/3/Ch 1//Gta/Stk/4/Bicre/Lks-4	ICD92-0150-CABL-7AP-0AP-4AP-0TR	0	Tr-R	0
3	Bicre/3/Ch 1//Gta/Stk/4/Bicre/Lks-4	ICD92-0150-CABL-7AP-0AP-6AP-0TR	0	0	0
4	Bicre/3/Ch 1//Gta/Stk/4/Bicre/Lks-4	ICD92-0150-CABL-7AP-0AP-7AP-0TR	0	5R	0
5	Bicre/3/Ch 1//Gta/Stk/4/Bicre/Lks-4	ICD92-0150-CABL-8AP-0AP-1AP-0TR	0	0	0
6	Gdo VZ5112/Cit//Ruff/Fg/3/Ente/Mario//Cando	ICD88-1383-ABL-11AP-0AP-6AP-0AP	0	Tr-R	0
7	Outrob3	ICD91-0811-AB-4AP-0AP-4AP-0AP	Tr-R	5R	0
-	Bolani	(Susceptible check)	100S	100S	100S

Role of yellow rust-resistance genes of wheat in Pakistan

A. Hakro and Aly Khan

Crop Diseases Research Institute, Pakistan Agricultural Research Council, Karachi University Campus, Karachi-75270, Pakistan

Introduction

Yellow rust (*Puccinia striiformis* f.sp. *tritici*) is one of the most important diseases of bread wheat (*Triticum aestivum*) in temperate areas of the world. Yellow rust can seriously reduce grain yields, particularly when a severe attack develops before ear emergence. The disease mainly affects the leaves but glumes can also become infected. Doodson, Manners and Myers (1965) reported that infected plants of susceptible varieties have a reduced number of florets and grains per ear and sometimes lower weight of individual grains. Leaves of infected plants are shorter and narrower than those of healthy plants and the dry weight of roots of susceptible plants can be reduced by more than 75% following infection.

The control of yellow rust is almost exclusively by the use of resistant varieties. It has been observed that breeding for resistance to yellow rust has been a major objective in wheat breeding programmes. There are four types of resistance to yellow rust: (1) seedling resistance, in which the host is resistant both as a seedling and as a mature plant; (2) adult plant resistance, in which the host is susceptible as a seedling but resistant as mature plant; (3) environmentally determined resistance (commonly called field resistance), in which resistance can be manifested in seedlings, in the adult plant, or in both, but the expression of which is liable to changes with temperature; and (4) tolerance, in which the host is susceptible but yields well despite infection.

Many workers have confirmed that the expression of resistance to yellow rust can differ greatly at different growth stages of individual genotypes. Stubbs (1968) has shown that even the first and second leaves of wheat plants can show quite different responses to yellow rust. In Pakistan, we have tested commercial varieties carrying *YrA*, *Yr2*, *Yr4*, *Yr6*, *Yr7* and *Yr9* genes alone or in combination, and a few varieties with unknown *Yr* genes, in different agro-climatic zones of the country.

Materials and methods

Commercial varieties carrying *Yr2, Yr2+Yr7, Yr6+, Yr6+YrA, Yr6+Yr7, Yr7, Yr9, Yr9+, Yr9+Yr4, Yr9+7, Yr9+27+6+7,* unidentified *Yr* and without *Yr* genes were planted in cooler locations in Pakistan: 5 in Punjab, 3 in NWFP and 1 in Islamabad. These locations represent different agro-climatic conditions and are suitable places for stripe rust development. Artificial inoculations on spreaders were carried out in February. The observations on response and severity of stripe rust were recorded according to Loegering (1959) and the modified Cobb's scale of Peterson, Campbell and Hannah (1948), respectively.

Results and discussion

Pakistani wheat varieties Mexipak and WL-711 carrying the *Yr2* gene have shown different stripe rust reactions. During 1999/00 the two varieties showed 40S and 70S, whereas in 2002/03 they showed 60S and 40 MS-S, respectively. Virulence against *Yr2* had been detected in most wheat growing areas, and especially in South America (Stubbs, 1985) and Australia (Wellings and McIntosh, 1990). The presence of *Yr2* in a range of wheat distributed by CIMMYT is not clear. The *Yr2* gene is ineffective against some pathotypes in all geographical areas, as reported by McIntosh, Wellings and Park (1995).

The varieties Sariab 92, Shahkar 95, Tandojam 83 and Wattan 94, carrying the *Yr6+* gene(s) have shown 20S, 5S, 40S and Tr-S, respectively, in 1999/00. These varieties showed high susceptibility during 2002/03, i.e. 60MS, 20MS, 80S and 60S, respectively. Dubin, Johnson and Stubbs (1989) found *Yr6* to be less effective at higher greenhouse temperatures. *Yr6* is inherited as a recessive or dominant gene depending on the pathogen culture. The varieties Parwaz 94 and Soghat, carrying *Yr6+Yr7*, gave 10R-MR and 10MS-S, respectively, in 1999/00, whereas these varieties later showed 70MS and 20MS, respectively.

Blue Silver, carrying *Yr6+YrA,* showed 5S in 1999/00 and 80S in 2002/03. The *YrA* specificity occurs alone or in combination with other genes in Australian wheats derived from WW 15. In certain instances these cultivars are heterogeneous and selection was made for *YrA* (Wellings, McIntosh and Hussain, 1988). Stubbs *et al*. (1974) reported that Inia 66 (*YrA*) and Noroesti 66 (*Yr6)* were severely attacked by stripe rust in USA, Chile, Ecuador, Kenya, Iraq and Tunisia.

The varieties Sarsabz and Zardana, carrying *Yr7*, have shown 20MS-S and 5MS-S, respectively, during 1999/00, and both showed 60MS-S in 2002/03. *Yr7* originated from durum cultivar Eumillo and was transferred to Thatcher wheat, and is also present in a range of winter and spring wheats. It is frequently associated with *Sr9g*. *Yr7* is often found in combination with other

genes, such as with *Yr6* in cultivars Corella, Dollarbird and Hermosillo 77 (Wellings, 1986).

Wheat varieties Kaghan 93, Pasban and Pirsabak 9, carrying *Yr9,* had stripe rust infection of Tr-MR-MS, 10MS-S and 30MS-S, respectively, in 1999/00, while Kaghan 93 was 40MS in 2002/03 and Pasban was 40MS-S.

The varieties Bakhtawar 93 and Rawal 87 carry some unknown *Yr* genes in addition to *Yr9*. Both these varieties showed very low stripe rust reaction in both 1999/00 and 2002/03.

Faisalabad 85, carrying *Yr9+Yr4*, showed Tr-R during both seasons, whereas Kohinoor-93, carrying *Yr9+Yr7,* showed Tr-MS in 1999/00 and 20MS in 2002/03. Cv. Inqilab 91, carrying *Yr9+27+6+7,* showed 10S in 1999/00 and 70MS-S in 2001/02.

Many varieties have *Yr9,* which is associated with *Lr26* and *Sr31*. Stubbs and Yang (1988) discussed evidence suggesting that *Yr9* was present in certain triticales. *Yr9* currently remains effective in North America (Line and Qayoum, 1991), India (Kumar *et al*., 1993) and Nepal (Louwers and Sharma, 1992). A severe epidemic was reported in the UK in 1988 and 1989 on several cultivars, in particular cv. Slejpner, which was due to a rapid increase in virulence for *Yr9* in the pathogen population (Bayles *et al*., 1990). Virulence against *Yr4* has been detected in most wheat growing areas and is especially frequent in South America (Stubbs, 1985) and Australia (Wellings and McIntosh, 1990). *Yr4* was effective in India until the emergence of new pathotypes in 1989 and 1991 (Kumar *et al*., 1993).

Chakwal 86, Kiran 95, Shaheen 94 and Punjab 96 carry unidentified *Yr* genes. Their stripe rust reactions during 1999/00 were Tr-R, 10MS, Tr-MS and Tr-MS, but 60MR, 70S, 20MS and 30MS in 2002/03, respectively.

It is therefore concluded from the results that *YrA, Yr2, Yr6*, *Yr7, Yr9* or *Yr27* genes alone are not effective in the wheat fields of Pakistan, whereas *Yr7* and *Yr9* in combination with other genes gave a good response in terms of reducing disease infection and intensity of yellow rust in the field. It is therefore suggested that plant breeders of Pakistan avoid including *Yr2*, *Yr6, Yr9* or *Yr27* genes alone in a crossing block.

Table 1. Highest stripe rust reactions in commercial cultivars carrying different *Yr* genes in 1999/00, 2001/02 and 2002/03

Variety	*Yr* Gene(s)	1999/00	2001/02 (Dry Season)	2002/03
Mexipak	*Yr2*	40S	20S	60S
WL 711	*Yr2*	70S	-	40MS-S
Faisalabad-83	*Yr2*+7	Tr-MR	Tr-R	70S
Sariab 92	*Yr6*+	20S	MR	60MS-S
Shahkar 95	*Yr6*+	5S	Tr-R	20MS-S
Tandojam 83	*Yr6*+	40S	5S	80S
Wattan 94	*Yr6*+	Tr-S	–	60S
Blue-Silver	*Yr6*+A	5S	10MS	80S
Parwaz 94	*Yr6*+7	10R-MR	5MS-S	20MS-S
Soghat	*Yr6*+7	10MS-S	Tr-R	40MS-S
Sarsabz	*Yr7*	20MS-S	Tr-R	60MS-S
Zardana	*Yr7*	5MS-S	Tr-R	60MS-S
Kaghan 93	*Yr9*	Tr-MR-MS	Tr-R	40MS
Pasban	*Yr9*	10MS-S	Tr-R	40MS-S
Pirsabak 91	*Yr9*	30MS-S	Tr-R	–
Bakhtawar 93	*Yr9*+	Tr-MR-MS	0	5MR-MS
Rawal 87	*Yr9*+	Tr-R	Tr-R	Tr-R
Faisalabad 85	*Yr9*+4	Tr-R	Tr-R	Tr-R
Kohinoor-83	*Yr9*+7	Tr-MS-S	Tr-R	20MS-S
Inqilab 91	*Yr9*+27+6+7	10S	Tr-R	70MS-S
Chakwal 86	*Yr*?	Tr-R	0	60MR
Kiran 95	*Yr*?	10MS-S	Tr-MR	70S
Shaheen 94	*Yr*?	Tr-MS	Tr-R	20MS-S
Punjab 96	*Yr*?	Tr-MS-S	Tr-R	30MS-S
Local White	No *Yr* gene	20S	10S	–
Morocco	No *Yr* gene	–	–	90S

NOTES: – = data not available.

References

Bayles, R.A., Channell, M.H. & Stigwood, P.L. 1990. Yellow rust of wheat. United Kingdom Cereal Pathogen Virulence Survey 1989 Annual Report, 11–17.

Doodson, J.K., Manners, J.G. & Myers, A. 1965. Some effects of yellow rust (*Puccinia striiformis*) on 14carbon assimilation and translocation in wheat. *Journal of Experimental Botany*, 16: 304–317.

Dubin, H.J., Johnson, R. & Stubbs, R.W. 1989. Postulated genes for resistance to stripe rust in selected CIMMYT and related wheats. *Plant Disease,* 73: 472–475.

Kumar, J., Nayar, S.K., Prashar, M., Bhardwaj, S.C. & Bhatnagar, R. 1993. Virulence survey of *Puccinia striiformis* in India during 1990–1992. *Cereal Rusts and Powdery Mildews Bulletin,* 21: 17–24.

Line, R.F. & Qayoum, A. 1991. Virulence, aggressiveness, evolution and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America, 1968–1987. *USDA Technical Bulletin*, No. 1788.

Loegering, W.O. 1959. Methods for Recording Cereal Rust Data. USDA International Spring Wheat Rust Nursery.

Louwers, J. & Sharma, S. 1992. Postulation of resistance genes to yellow rust (*Puccinia striiformis* f.sp. *tritici*) in advanced wheat lines from Nepal. *Vorträge für Pflanzenzüchtung,* 24: 270.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Stubbs, R.W. 1968. *Puccinia striiformis* Westend f.sp. *tritici.* The evolution of the genetic relationship of host and parasite (Abstract). p. 198, *in:* First International Congress of Plant Pathology.

Stubbs, R.W. 1985. Stripe Rust. pp. 61–101, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Stubbs, R.W. & Yang, H.A. 1988. Pathogenicity of *Puccinia striiformis* for wheat cultivars with resistance derived from rye. pp. 110–112, *in:* B. Zwatz (editor). Proceedings of the Seventh European and Mediterranean Cereal Rusts Conference.

Stubbs, R.W., Fuchs, E., Vecht, H. & Bassel, E.J. 1974. The international survey of factors of virulence of *Puccinia striiformis* Westend in 1969, 1970 and 1971. *Nederlands Graan-Centrum Techniske Bereicht,* 21: 1–88.

Wellings, C.R. 1986. Host : Pathogen studies of wheat stripe rust in Australia. PhD Thesis. University of Sydney, Australia.

Wellings, C.R., McIntosh, R.A. & Hussain, M. 1988. A new source of resistance to *Puccinia striiformis* f.sp. *tritici* in spring wheats (*Triticum aestivum*). *Plant Breeding*, 100: 88–96.

Wellings, C.R. & McIntosh, R.A. 1990. *Puccinia striiformis* f.sp. *tritici* in Australasia: pathogenic changes during the first 10 years. *Plant Pathology,* 39: 316–325.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

Abstracts of other papers presented at the Second Regional Conference on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region

Islamabad, Pakistan
22–26 March 2004

Yellow rust of wheat in Ethiopia: its importance in a regional context

Ayele Badebo,[1] H. Fehrmann[2] and A. Yahyaoui[3]

1. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia 2. Institute of Plant Pathology and Plant Protection, Georg-August-University, Germany; 3. ICARDA, Aleppo, Syria

Yellow [stripe] rust caused by the fungus *Puccinia striiformis* Westend. f.sp. *tritici* is one of the most threatening wheat diseases in Ethiopia. Monitoring virulences and inventorying resistance genes in the country and in the region will help to plan for appropriate gene management strategies. Since 1998, yellow rust races from Ethiopia have been analysed in Goettingen, Germany, and Kulumsa, Ethiopia, following standard procedures. Moreover, a trap nursery comprising standard yellow rust differentials, commercial cultivars and advanced lines from Ethiopia, Kenya and Yemen were sown at four locations in Ethiopia during 2002/03.

According to the greenhouse and field studies, virulences for *Yr4*, *Yr5*, *Yr10*, *Yr15* and *Yr17* are lacking in major bread wheat producing regions in Ethiopia. Despite the susceptibility of Avocet-*Yr1* under field conditions, virulence for *Yr1* (Chinese 166) has not been detected in greenhouse tests. Virulence for *Yr3V* (Vilmorin 23) was detected for the first time in 2002. The multi-location resistance test indicated that almost all of the commercial cultivars from Yemen and Ethiopia were susceptible at least one of the locations. A high level of yellow rust resistance was observed in some of the Kenyan bread wheat cultivars, and in newly developed bread wheat lines from Ethiopia. The commonalities of yellow rust races among the East African countries and Yemen have often been reported. Therefore, the information generated from this study would be of paramount importance for researchers in the region to anticipate threatening virulences.

Current and future prospects for yellow rust in CWANA

A. Yahyaoui,[1] R.P. Singh[2] and C.R. Wellings[3]

1. International Center for Agricultural Research in the Dry Areas (ICARDA)
2. International Maize and Wheat Improvement Center (CIMMYT)
3. Plant Breeding Institute, Cobbitty, Australia.

Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, is an important wheat disease in the Caucasus, Central and West Asia, North Africa, Nile Valley and the Horn of Africa. In these regions, cereal rust incidences have been of significant historical importance since the earliest recorded histories of civilization. Yellow rust is among the most serious rust diseases of wheat in cool winter areas, and represents a major threat to wheat production in the region. During recent years at least 30–40% yield losses were recorded in major wheat producing areas in Azerbaijan, Kyrgyzstan, south Kazakhstan, Tajikistan and Uzbekistan. High levels of infections were also observed in Egypt, Ethiopia, Eritrea and Yemen. Surveys of yellow rust populations and evaluation of trap nurseries indicated the presence of many virulence types. A wide range of virulent pathotypes (132E136, 230E222, 255E112, etc.) is evolving in this region, causing the breakdown of widely utilized sources of resistance in wheat. The dynamics of yellow rust in this region are now better understood, but the pathways through which the pathogen is spreading are still unknown.

In the region, surveys of pathogen populations and the genetic characterization of resistance continue to provide valuable information to be used to design breeding strategies. Most resistance genes can be detected in seedling evaluations using specific pathotypes. However, detection of a few others requires testing at post-seedling growth stages. Major genes are implicitly vulnerable to pathogen plasticity, and their longevity can range from rapid vulnerability to relative (and often deceiving) durability. While the diversity of the pathogen population creates problems, there is emerging, slowly, more information about the examples of durable resistance to yellow rust of wheat, and more information about the genetic control of such resistance, as reported in several contributions. There is evidence that adequate levels of resistance could be obtained with a few additive genes each of small to moderate effect. The facultative winter wheat germplasm provided by the Turkey, CIMMYT and ICARDA wheat programme contains a high degree of genetic diversity for resistance that is currently effective in the Caucasus and Central and West Asia.

Virulence of stripe rust on differential wheat genotypes and cultivars from Central and West Asia in Ankara in 2002 and 2003

F. Dusunceli,[1] L. Cetin,[1] S. Albustan,[1] Z. Mert,[1] K. Akan,[1] A. Yahyaoui[2] and C.R. Wellings[3]

1. The Central Research Institute for Field Crops (CRIFC), Ulus, Ankara, Turkey; 2. ICARDA), Aleppo, Syria; 3. University of Sydney, Plant Breeding Institute (PBI), Cobbity, Australia

Stripe [yellow] rust (*Puccinia striiformis* f.sp. *tritici*) occurs in all parts of Turkey and frequently causes significant yield losses. Development of resistant cultivars is the most effective method of control, and this requires monitoring of changes in the virulence pattern of the pathogen. In this study, virulence of stripe rust on known stripe rust resistance genes and on some cultivars from Central and West Asia was studied.

The study was carried out at the Central Research Institute for Field Crops (CRIFC) in 2002 and 2003. Four nurseries used for this purpose included: National Yellow Rust Trap Nursery (YRTN); Central and West Asian Yellow Rust Trap Nursery (CWAYRTN; from ICARDA); near-isogenic lines (NILs; from PBI, Australia); and YR differentials (IWWIP; from CIMMYT). The nurseries consisted mostly of international yellow rust differential genotypes carrying known YR resistance genes. YRTN and CWAYRTN also included cultivars from Turkey and from the various countries of Central and West Asia. The nurseries were planted in two locations at the research farm (1050 masl) of CRIFC in kizce – Haymana, 45 km south-west of Ankara, and in Yenimahalle (850 masl) in the city of Ankara. The nurseries were inoculated with the yellow rust population collected in the previous year and preserved in liquid nitrogen. Yellow rust development was encouraged with mist irrigation, and disease occurrence was recorded using a modified Cobb scale. Seedling tests were conducted in greenhouses. Good disease development was recorded at the adult plant stage in both seasons and in seedling tests in the greenhouse. The results indicated that the virulence pattern was similar to that of the previous year, with some minor changes. Virulence was recorded on *Yr2, Yr6, Yr7, Yr9, Yr 12, Yr18, Yr24, YrA+* and *YrSk* at both adult stage and in seedling tests. Of the 42 registered cultivars originating from countries of the region, 12 were found to be resistant to stripe rust in both seasons in Ankara.

Prevalent yellow rust pathotypes in CWANA

A. Yahyaoui,[1] M. El Ahmed,[1] M. Naimi,[1] H. Ketata,[1] A. Morgounov,[2] M. Torabi,[3] L. Cetin,[4] M. Saidov,[5] M. Koyshibaev[6] and M. Djunusova[7]

1. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria; 2. International Maize and Wheat Improvement Center (CIMMYT), El Batan, Mexico; 3. Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran; 4. Central Research Institute for Field Crops (CREFCI), Ankara, Turkey; 5. Agricultural Research Institute (ARI), Baku, Azerbaijan; 6. Plant Protection Institute (PPI), Almaty, Kazakhstan; 7. Kyrgyz Agricultural Research Institute (KyARI), Bishkek, Kyrgyzstan

Virulence surveys of cereal rust fungi have traditionally used differential host lines that express resistance in the primary leaves of seedling plants. In this study, yellow rust populations were characterized using a trap nursery that included 48 bread wheat cultivars organized in five groups. Group I was a world differential set (9 accessions); Group II was a European differential set (8 accessions); Group III was an additional differential set (4 accessions); Group IV included Avocet near-isogenic lines (NILs) (16 accessions); and Group V included common cultivars with known resistance factors (11 accessions). The trap nursery was planted at 30 sites considered to be yellow rust hot-spots. The testing sites were selected in 12 countries in the Nile Valley (Egypt, Ethiopia, Yemen), the Caucasus (Azerbaijan), West Asia (Turkey, Syria, Lebanon, Iran) and in Central Asia (Uzbekistan, Kyrgyzstan, Kazakhstan, Tajikistan).

Disease reaction was recorded at heading stage using a modified Cobb scale. The Avocet NILs (Group IV) allowed better assessment of the reaction of the genotypes to yellow rust compared with rating the differentials in Groups I, II and III, where a good number of cultivars carry more than one resistance gene. In Central and Western Asia, virulence against *Yr* resistance genes was variable. For some genes, virulence was detected only at one site, such as the case of *Yr4+* and *Yr3N* in Tajikistan. Virulence on *Yr10* was noted in Syria. Virulence on *Yr1* and *Yr10* was observed in Tajikistan. Virulence on *Yr9* was found at all the testing sites except those in Turkey and Azerbaijan. Virulence genes recorded at hot-spots at the adult growth stages resulted from new physiological races in the yellow rust populations.

Physiological races identified in Syria and reported by national programmes show great potential for virulence, and new trends recorded. Physiological race 6E0 was first observed in the region in 1972 and has been recovered every year in Syria. This race is virulent for *Yr6,* which is frequent in both winter and spring wheats. 6E0 is also virulent for *YrA,* which is present in many wheat cultivars that are still cultivated over relatively large areas in

Turkey, Lebanon and Syria. Race 38E150 was the second most frequent race in Syria and was found for the last five consecutive years, whereas 134E146 and 38E134 were identified in rust samples for four consecutive years. Those yellow rust races with broad virulence spectrums, such as 198E150, 166E158 and 238E190, occurring in Lebanon; 206E158 and 198E158 in Ethiopia; and races 230E150, 102E210 and 450E109 occurring in Syria, Iran, and Egypt, respectively, should be carefully monitored.

Diallel analysis of resistance components to stripe [yellow] rust in wheat

M. Khodarahmi,[1] M.R. Ghannadha[2] and M. Torabi[1]

1. Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran;
2. Agriculture College, Tehran University, Karaj, Islamic Republic of Iran

Yellow rust is one of the most important and prevalent diseases in Iran. Wheat yellow rust is a fungal disease, with numerous physiological races, virulence factors and ability to produce new races, presenting difficulties in breeding programmes. Determination of genetic components of resistance in cultivars provides better tools for breeders to select the best approaches for their breeding programmes. This study was conducted to investigate by a diallel cross the general combining ability and specific combining ability of five wheat varieties and the type of gene action responsible for resistance to yellow rust. The parents and their crosses were planted in a randomized complete block design with 3 replications in both the greenhouse and the field.

In the greenhouse, resistance components including infection type, latent period, pustule size and pustule density were recorded, while flag leaf disease severity was recorded in the field. Significant general combining ability (GCA) and specific combining ability (SCA) were observed in the analysis of variance. The ratio of GCA sum of squares relative to SCA sum of squares suggested that GCA was more important than SCA. Additive effects played the major role in host response to stripe rust, while non-additive effects were also detected. Hybrid 46 was the best parent for GCA, so can be used in crosses for increasing resistance to yellow rust. Graphic analysis indicated that the majority of the genes responsible for the resistance were recessive. Additive genetic variance (D) was greater than dominant genetic variances (H1, H2) for four components in the greenhouse, whereas it was vice versa in the field.

Development of wheat germplasm resistant to stripe [yellow] rust (*Puccinia striiformis* f.sp. *tritici*) for the inner and coastal areas of Turkey, through integrated studies

F. Dusunceli,[1] L. Cetin,[1] S. Albustan,[1] N. Bolat,[2] A. Aydın,[3] S. Yazar,[1] Z. Mert,[1] K. Akan,[1] M.E. Bayram,[4] G. Karatopak[5] and H. Kılıc[6]

1. Central Research Institute for Field Crops, Ulus, Ankara, Turkey
2. Anatolian Agricultural Research Institute, Eskisehir, Turkey
3. Aegean Agricultural Research Institute, Menemen, Izmir, Turkey
4. Sakarya Agricultural Research Institute, Adapazari, Turkey
5. Cukurova Agricultural Research Institute, Adana, Turkey
6. South East Anatolia Agricultural Research Institute, Diyarbakir, Turkey

Stripe [yellow] rust (*Puccinia striiformis* f.sp. *tritici*) is one of the most important diseases of wheat in Turkey. A number of breeding programmes operate to develop cultivars with resistance to the disease. With this initiative, activities of bread and durum wheat breeding programmes in winter and spring wheat growing areas of Turkey have been integrated to utilize the advantages and resources of research institutes in different locations.

Objectives of this study included monitoring disease occurrence, germplasm exchange and screening of germplasm for stripe rust resistance under artificial inoculation and natural conditions in diverse geographical locations. Five nurseries were established with 1105 entries (863 bread wheat and 242 durum wheat) from 10 institutes located around the country in the inland and coastal areas. The entries included cultivars, candidates for registration, advanced breeding lines and resistance sources for stripe rust and other diseases. The nurseries were sown at 10 locations for screening under natural conditions. Artificial inoculation was also provided at the Ankara, Eskisehir, zmir and Konya sites. Two bread wheat nurseries were also screened at the seedling stage in the greenhouse. Stripe Rust severity was higher in Ankara, Adana, Sakarya, zmir and Eskisehir than at other sites where dry conditions were unfavourable for the disease. The study showed that 547 bread wheat and 138 durum wheat genotypes have a good level of resistance to stripe rust in various locations. Of the 449 bread wheat genotypes subjected to seedling tests, 25.4% showed seedling resistance, and 26% had a good level of resistance at the adult plant stage while showing susceptibility at the seedling stage. The activity facilitated identification of stripe rust-resistant germplasm and its exchange among the breeding programmes around the country.

Evaluation of seedling and adult plant resistance to *Puccinia striiformis* f.sp. *tritici* in some wheat genotypes

F. Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran.

In order to determine the resistance of wheat genotypes in the seedling and adult plant stages an experiment was carried out in cropping season 2002/03. In the seedling stage, 35 cultivars and advanced lines were tested with a hot race of *Pst* 134E134A+ in the greenhouse. This pathotype has virulence on lines with *Yr2, Yr6, Yr7, Yr9* and *YrA*. All genotypes were inoculated with the pathotype in the greenhouse when the second leaves of seedlings were appearing. After inoculation, seedlings were placed in an inoculation room for 24 h at 10°C and 100% RH in the dark. Following inoculation, plants were moved to greenhouse chambers at 18–20°C. Infection types were recorded 15–18 days after inoculation. The aim was to record reactions when the difference between the susceptible controls and the test lines was at a maximum. The results showed that among the seedlings, 25 genotypes carried seedling resistance genes and 10 genotypes were susceptible. In the field, all 35 genotypes were planted in two 1-m rows 30 cm apart under artificial inoculation with race 134E134A+. A susceptible wheat cultivar (Bolani) was planted as spreader around the field and between the rows. The response of plants was evaluated using a modified Cobb's scale when the flag leaf had appeared. Among these lines, 30 genotypes were resistant in the field. All 5 susceptible genotypes in the seedling stage were susceptible in the field. Also, five genotypes susceptible as seedlings were resistant in the field, which is indication of presence of adult plant resistance gene(s) in cv. Mahdavi, S-78-11, C-78-7, N-75-16 and M-78-9 genotypes.

Resistance to stripe [yellow] rust – International Trials

M. Yessimbekova,[5] R. Urazaliev,[5] A. Morgounov,[1] A. Yahyaoui,[3] H. Braun,[2] M. Koyshibaev,[4] A. Kokhmetova,[5] A. Sarbayev,[5] K. Mukin[5] and F. Itenova[5]

1. CIMMYT, Kazakhstan; 2. CIMMYT, Turkey; 3. ICARDA, Syria; 4. KRICP, Kazakhstan; 5. Scientific and Production Centre of Farming and Crop Sciences, Almalybak, Kazakhstan

Stripe [yellow] rust, an aggressive wheat disease, was recorded as an epidemic in the south of Kazakhstan (mountain zone) only twice in a 20-year period (1978–1998). An increase in the areas under winter wheat in the region (Uzbekistan, Kyrgyzstan and Tajikistan) combined with favourable conditions for pathogen survival, unsatisfactory agronomic practices promoting accumulation of inoculum, and the climatic conditions of 1999–2002 triggered a rust epidemic. The grain yield losses from stripe rust around the region reached 50% or more, and in the south of Kazakhstan losses were 30–40%.

High adaptive capacity of the pathogen, long-term use of genetically homogeneous varieties and a tendency to create varieties with an adult resistance mechanism indicate the important role of varietal diversity. International trials organized by international programmes that include Turkey-CIMMYT-ICARDA (IWWIP), CIMMYT-USAID (FAWWON and EURAWWYN), ICARDA (CWARTN) and CIMMYT (Regional nursery) have been a steady source of germplasm for the regional project on yellow rust (CIMMYT, Kazakhstan, Uzbekistan, Kyrgyzstan) and have stimulated national breeding programmes for resistance to stripe rust on the basis of diverse germplasm sources. Germplasm in the international trials were characterized by different resistances to yellow rust in the conditions of Kazakhstan, and breeding programmes such as TCI, USA, Ukraine were mostly launched using samples with high (90% and more) resistance to yellow rust (FAWWON 9-12). From EURAWWYN, 194 resistant forms (77.6%) from 250 tested have been selected from that nursery, which included samples from the breeding programmes of 16 countries. The trial of the Regional nursery showed rather high levels of resistance to yellow rust for the samples from Armenia, Azerbaijan and Georgia (up to 100%).

A low level (35.7%) of resistance was recorded among Kazakhstan germplasm (elite winter wheat cultivars) in the Regional nursery, but the tendency to race non-specific resistance has resulted in creation of winter wheat varieties with a varied genetic basis. In the epidemic year 2002, cvs Almaly, Taza, Naz, Egemen and Ramin were especially highly resistant to this disease. Commercial varieties such as Jetisu, Progress, Steklovidnaya 24 and Bogarnaya 56 showed from average to very low resistance to yellow rust. The Egemen (XWN 84305 BHR5/AGA//SNI/3/TRK3) genotype with a high level

of resistance not only to yellow rust but also to leaf rust, was selected from a CIMMYT international nursery.

CWARTN has been screened for resistance gene sources. All European standards with well-known *Yr* genes—3V, 3N, CV, SP, SD, SU, APR, *Yr10, Yr9, Yr5, Yr4, Yr7, Yr6, Yr2+11+25, Yr6+7, Yr6*+APR—demonstrated resistance to yellow rust and late maturity: differences in heading date with Avocet up to 20 and more days have been achieved. European standards with genes *Yr1, Yr7, Yr6, Yr2, Yr18* and *Yr8+18* showed average susceptibility. The Avocets isogenic lines that included 13 genes have allowed identification of high resistance genes *YrA, Yr5, Yr10, Yr15, Yr17* and *YrSP*. Genes *Yr1, Yr6, Yr7, Yr8, Yr9, Yr18* and *Yr27* have shown susceptible reactions. Genes *Yr9, Yr18, Yr27* (Avocet), *Yr18* and *Yr8+18* showed variable reaction (susceptibility/resistance) depending on season. Genes *Yr6*, *Yr7* and *Yr9*, depending on the genetic background, have been resistant (Heines Peko (*Yr6*), Reichensberg 42 (*Yr7*), Clement (*Yr9*) and Federation/Kavkaz (*Yr9*)) or susceptible (Heines Kolben (*Yr6*), Lee (*Yr7*), Cranbrook (*Yr7*) and Federation (*Yr9*)). The jointly acting *Yr6+Yr7* (Corella) showed a high level of resistance. Finally, cvs Morocco, Avocet, Federation, Kalyansona, Sardari, Ghurab 2, Ak Bugday, Noroeste and Attila have been especially highly susceptible (S60–80).

Study of winter wheat germplasm and varieties for resistance to yellow rust in Kyrgyzstan conditions

J. Akimaliev and M. Djunusova

Kyrgyz Agricultural Research Institute, Bishkek, Kyrgyzstan

A limiting factor for further growth of winter wheat productivity is yellow rust. It is widespread in all wheat regions, and especially a problem in the Issyk-Kul region, Chui valley and foothill zones of Kyrgyzstan. Strong epidemics of yellow rust were reported in 1939–1941, 1946 and 2002.

Since 1999, the Kyrgyz Agricultural Research Institute, in association with scientists from International Centers (CIMMYT and ICARDA), has actively evaluated winter wheat germplasm, and also prospective genotypes of Kyrgyz origin and a special nursery on yellow rust (CWAYRTN).

The study was conducted in Chui valley at the Experimental Station of the Kyrgyz Agricultural Research Institute. The station is located 813 masl, 43° N and 75° E. Average annual precipitation is 350–500 mm.

The study of yellow rust's effects on productivity of prospective varieties has shown that out of 43 varieties, 10 were resistant, 31 were medium resistant and 2 were susceptible.

The productivity of cultivars with high resistance to yellow rust was from 7.0 to 7.9 t/ha.

The genotypes Atay 85, RAN\NE70//36, WULNI, AGRI//NAC/ATTILA and GUN91/MNCH were highly resistant.

The two years of studies with CWAYRTN identified selections with resistance to yellow rust, which are now included in crossings with cultivars of Kyrgyz origin.

Adult plant resistance to yellow rust in the genotypes of the Preliminary Wheat Screening Nursery (PWSN) of Iran in the 2000/01 cropping season

A. Malihipour,[1] A. Tarinejad,[2] S.A. Safavi[3] and R. Houshyar[4]

1. Cereal Pathology Unit, Cereal Research Department, Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran
2. Moghan Agricultural Research Centre, Parsabad, Islamic Republic of Iran
3. Ardabil Agricultural Research Station, Ardabil, Islamic Republic of Iran
4. Miandoab Agricultural Research Station, Miandoab, Islamic Republic of Iran

Adult plant reactions to wheat yellow rust (*Puccinia striiformis* f.sp. *tritici*) were determined for 263 bread wheat genotypes from the Preliminary Wheat Screening Nursery (PWSN) in the 2000/01 cropping year. The experiments were carried at Karaj, Moghan, Ardabil and Miandoab. Wheat entries were planted in November 2000, at a rate of 10–15 g of seed in two 1-m long rows spaced 30 cm apart. A susceptible cultivar (Bolani) was planted among the experimental entries (10-entry intervals). Artificial inoculation of the nurseries was done four times over two months, starting at the tillering stage using the relevant race for each location. The infection type of each entry was evaluated when the disease developed well on the susceptible check. The percentage leaf area affected was also scored using a modified Cobb's scale and the coefficients of infection also calculated. The results showed that most of the genotypes were resistant to yellow rust in one or more locations. A large number of genotypes (140 accessions) were resistant to the disease at all locations. Finally, 77 entries were selected based on yield and pathology data for inclusion in Preliminary Regional Wheat Yield Trials (PRWYT).

Yellow rust reaction, disease development and yield losses in selected spring bread wheat cultivars in West Asia.

O.S. Abdalla, A.A. Yaljarouka and A. Yahyaoui

ICARDA, Aleppo, Syria.

Yellow or stripe rust, caused by *Puccinia striiformis* West. f.sp. *tritici*, is the most important disease limiting wheat production in West Asia. Use of genetic resistance is recognized as the most economical and environmentally sound measure to reduce production losses from this disease. This study was conducted over two years at Aleppo, Syria, to quantify yield losses under high yellow rust pressure in 12 genotypes varying in their reaction to the disease. Fungicide-protected and non-protected plots were used in a split-plot arrangement of a randomized complete block design with three replicates. Highly significant differences were observed among treatments and genotypes. Yields of non-protected plots, on average, were 18% lower than fungicide-protected plots. Yield reductions among genotypes were in the range of 3% to 78%. Yellow rust-susceptible check-cultivars Mexipak and Cham-2 exhibited 59% and 78% yield reduction, respectively. Rate of yellow rust disease development ranged from 1 to 27, and cultivars could be classified in three groups, namely completely resistant, slow-rusting and susceptible, with observed disease development rates of 1, 5 and 26, respectively. Use of slow-rusting in relation to durability of rust resistance is discussed.

Meeting the Challenge of Yellow Rust in Cereal Crops

Proceedings of the Third Regional Conference on Yellow Rust in the Central and West Asia and North Africa (CWANA) Region

Tashkent, Uzbekistan
8–11 June 2006

Jointly organized by:
International Center for Agricultural Research in the Dry Areas (ICARDA)
International Maize and Wheat Improvement Center (CIMMYT)
Ministry of Agriculture of Uzbekistan

Contents

Abstracts only

List of Participants

Afghanistan

Mr Ghiaskdin Gulbudin

Australia

Dr Colin Wellings, Plant Breeding Institute, University of Sydney

Dr Harbans Bariana, Faculty of Agriculture, Food & Natural Resources, University of Sydney

Dr Robert Park, Faculty of Agriculture, Food & Natural Resources, University of Sydney

Azerbaijan

Dr Abidin Abdullaev, Azerbaijan Research Institute of Agriculture

Ms Konul Aslanova, Azerbaijan Research Institute of Agriculture

Denmark

Dr Mogens S. Hovmøller, Department of Plant Protection, Danish Institute of Agricultural Sciences, Slagelse

Egypt

Mr Mustafa Mahmoud Ghazy

Ethiopia

Mr Melaku Degefu Mekonnen, Ethiopian Institute of Agricultural Research, Kulumsa Research Centre, Asella

ICARDA

Dr Amor Yahyaoui, ICARDA, Aleppo Syria

Dr Osman Abdalla, Germplasm Programme, ICARDA, Aleppo, Syria

Dr S. Rajaram, BIGM, ICARDA, Aleppo, Syria

Ms Maha Al Ahmed, ICARDA, Aleppo Syria

Islamic Republic of Iran

Dr Mohammad Reza Jalal Kamali, CIMMYT-Iran Office

Dr Farzad Afshari, Seed and Plant Improvement Institute (SPII)

Kazakhstan

Dr Simbolat Risaliev, Otar Station of PPI

Dr Erlan Dutbaev, Research Institute of Plant Protection

Kenya

Dr Ruth Wanyera, Kenya Agriculture Research Institute, KARI, Njoro

Kyrgyzstan

Dr Valentina Ibragimoval, Kyrgyz Research Institute of Farming

Dr Gulbarchun Kurmanova, Kyrgyz Research Institute of Farming

Dr Rano Chumueva, Kyrgyz Agrarian University

Dr Gulmira Baualieva, Kyrgyz Agrarian University

Pakistan

Mr Atiq ur Rehman Rattu, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Syria

Dr Omar Farouk Mamluk, Consultant Plant Pathologist, Damascus, Syria

Tajikistan

Mr Mahbubjon Rahmatov, Tajik Agrarian University

Ms Tatyana Mikhailovna Sarkisova, Tajik Agrarian University

Dilorom Bassieva, Institute of Plant Protection

Tunisia

Dr Salah Rezgui, Agrarian National Institute of Tunisia, INAT

Dr Mohamed Salah Gharbi

Turkey

Prof. Dr Mahinur Akkaya, Middle East Technical University, METU, Ankara

Mr Zafer Mert, Central Research Institute for Field Crops, Yenimahalle

Mr Lutfi Çetin, Central Research Institute for Field Crops, Yenimahalle

Dr Fazil Dusunceli, Central Research Institute for Field Crop, Ulus, Ankara

United States of America

Mr Alexander Loladze, Washington State University

Uzbekistan

Dr Saidmurad Bobaev, Institute of Genetics

Dr Jorabek Pirnazarov, Institute of Plant Industry (UZRIPI)

Ms N. Sirnazarova, Tashkent State agrarian University

Ms N. Aripova, Gulistan State University

Cereal rust monitoring in Central and West Asia and North Africa: current status and future challenges

A. Yahyaoui,[1] H. Ketata,[1] M. Torabi,[2] A. Morgounov,[3] H. Braun,[3] M. Mosaad,[1] B. Djumakhanov[1] and M. Koichibayev[4]

1. International Center for Agricultural Research in the Dry Areas (ICARDA)
2. Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran
3. Centro International de Mejoramento de Mais y Trigo (CIMMYT)
4. Kazakh Institute of Crop Protection, Kazakhstan

Abstract

Air-borne pathogens, such as the rusts, have a number of characteristics that favour a rapid adaptation rate, such as their short generation time with extensive recombination and asexual propagation throughout the growing season. The rapid formation of the telial stage for *Puccinia graminis* f.sp. *tritici* (*Pst*) and *Puccinia triticina* allows for sexual recombination that can lead to changes in virulence patterns. The common mechanisms driving *Pst* evolution are most likely mutation and parasexual recombination that may have greatly contributed to the frequent virulence shifts of this rust pathogen. The evolution of *Pst* in Central and West Asia and North Africa (CWANA) has possibly followed a series of step-wise mutation events, which have included occasional reversions to avirulence, as is most likely the case for pathogenic changes in Tajikistan. Other possibilities are genetic recombination in *Pst* (hyphal anastomosis) in areas where rust spores of different pathotypes are windblown from different regions, such as the cases of Kyrgyzstan, Azerbaijan and Yemen. Yellow rust continues to be the most widespread and most important bread wheat disease in Central Asia. Resistance genes are becoming ineffective against new evolving races that are rapidly spreading. The commercially grown wheat varieties are limited in number and most of them are highly susceptible to yellow and leaf rusts.

Changes in virulence in the rust diseases coupled with the rapid adaptive response due to the nature of spread of their air-borne spores contribute to the development and appearance of new, adapted rust pathotypes that can be spread relatively quickly by wind over a wide area. Hence, continuous monitoring of the rust pathogen population is very important and could, eventually, allow avoidance of major rust epidemics in the region. Detection of pathogen variation using a series of host differentials has been valuable in providing important insights into the evolution of pathotypes in response to selection pressure imposed by host resistance genes. Knowledge of pathotype evolution is indispensable for the development and strategic deployment of host resistance.

Surveys of yellow rust populations and evaluation of trap nurseries indicated the presence of many virulence types in CWANA. A wide range of virulent pathotypes (132E136, 230E222, 255E112, etc.) is evolving in this region, causing the breakdown of widely utilized sources of stripe [yellow] rust resistance in wheat. Cereal Rust Trap Nurseries (CRTNs) have been a valuable tool in monitoring air-borne rust pathogens; the nurseries include differential sets harbouring known resistance genes for each of the three rusts, commercial cultivars that cover large areas in the region, and selected new elite breeding lines. The availability of comprehensive information on pathogen virulence and variation, and epidemiological information on pathogen movements, should provide the basis for the development of an early warning system to alert farmers growing potentially susceptible cultivars.

Introduction

Wheat is the most important food crop in the Central and West Asia and North Africa (CWANA) region. It provides a substantial component of the human diet, and farming systems of the region revolve around wheat production. Wheat occupies a third of the arable area in the region. However, the average productivity of wheat in CWANA countries is low due to both biotic and abiotic stresses. Despite the fact that 23% of the world's wheat area is in CWANA, the region accounts for only 14% of world production, due to low yields; the average yield for the region is less than 1500 kg/ha, almost one-half of the world average. Yields are particularly low in the recently independent republics of Central Asia. In North Africa, wheat is characterized by high levels of production in the high and moderate rainfall agro-ecological areas. Monoculture of high yielding varieties is rapidly replacing the traditional, lower yielding, landrace cultivars. Nonetheless, most of the available high yielding varieties are susceptible to one or more foliar diseases, with resultant losses in yield and quality that vary from year to year depending mainly on the prevailing climatic conditions. In Algeria, Morocco and Tunisia, wheat leaf rust is among the diseases that present a clear danger to cereal production in the high to moderate rainfall areas.

Yield losses caused by air-borne rust diseases are common and represent an important production constraint. Crop losses of 10–60% have been recorded in many countries. During the last decade, several yellow rust epidemics have occurred in most countries in the region and resulted in severe losses in wheat production. These epidemics occurred in crops seeded both off-season and during the main growing season. In the 1991/92 wheat-cropping season, yellow rust spread into the Baluchistan region of Pakistan for the third consecutive year and caused significant losses in the common cultivar Local White. In 1990, the gross revenue in three of the Baluchistan districts was reduced by an estimated US$ 8 million due to the yellow rust epidemic

(Ahmed *et al.*, 1991). Earlier, epiphytotics were recorded in the same region in 1983. In 1993 and 1995, yellow rust epidemics occurred in most of the wheat-growing areas of Iran and caused over 30% crop loss. Estimated grain losses were of the order of 1.5 million tonne in 1993 and 1 million tonne in 1995 (Torabi *et al.,* 1995). In Turkey, wheat cv. Gerek 79, grown on more than one million hectare, suffered losses of 26.5% due to the yellow rust epidemic in 1991 (Braun and Saari, 1992), and over 50% in 1998. In the Cukurova area of Turkey, a loss of over 500 000 tonne was recorded in Turkey, due to epidemics of yellow rust on cv. Seri 82 (Dusunceli *et al.,* 1996). In Syria, several epidemics have occurred over the last three decades, the most serious one being in 1988, which devastated wheat areas planted to the susceptible cv. Mexipak. In experimental trials, Mexipak showed a loss of 29% in grain yield at a severe infection level (75S). In the Jezireh area alone, Syria experienced an estimated loss of over 100 000 tonne of wheat grain (Mamluk *et al.*, 1989; Mamluk and El-Naimi, 1992). Epidemics caused losses of 30% in national grain production in 1994, when cvs Seri 82 and Mexipak were widely grown. In Ethiopia, yellow rust epiphytotics were recorded in 1977, 1980–1983, 1986, 1988 and 1990. Yield losses in 1988 were severe in bread wheat, and were as high as 58% on cv. Dashen (Badebo and Bayu, 1992). Ethiopia and Yemen form an ecological unit with respect to yellow rust epidemiology and may have an important impact on inoculum development and the evolution of virulence in the Central and West Asia (CWA) region. In Egypt, major epiphytotics were recorded at least once in each decade since the 1960s, with the most recent reported in the Delta region in 1995. The average grain yield loss ranged from 14 to 26% in the Delta region, while the national loss was about 10% (El-Daoudi *et al.,* 1996). Yellow rust epidemics and significant yield losses in 1996 were observed in Azerbaijan. In 1997, the wheat crop in Tajikistan suffered over 60% loss due to yellow rust. During a survey in May 1998, yellow rust was considered a major wheat disease in the country. In Uzbekistan over 60% of the wheat area is spayed annually to control yellow and leaf rusts.

Past studies in Central and Western Asia and North Africa (CWANA) have been sporadic and localized. There is an urgent need to gain a more comprehensive understanding of pathotype variation. Such studies should be complemented with epidemiological investigations of pathogen movement in order to determine the origin of new pathotypes and thus provide an early warning system for farmers growing potentially susceptible cultivars. Furthermore, knowledge of effective *Yr* resistance genes in the region will enable breeders to incorporate these genes in elite wheat germplasm, thus helping the development of cultivars with durable disease resistance.

Current research in CWANA focuses primarily on field evaluation of germplasm and varieties. In Pakistan, systematic but limited studies have provided useful information on pathogen virulence. In Egypt and Iran, greenhouse studies on pathogen virulence have been initiated. Similar studies have been initiated in other countries of the CWANA region, using trap

nurseries. ICARDA, at its headquarters in Aleppo, Syria, has been working on the yellow rust problem in wheat for several years. The work conducted has resulted in (1) an understanding of yellow rust pathogen virulence, especially in Syria and Lebanon (Yahyaoui *et al*., 2002, 2004b), and (2) the development of yellow rust-resistant varieties for commercial use by farmers. ICARDA currently coordinates, in collaboration with NARS pathologists and breeders, a Wheat Rusts Network within the Nile Valley and Red Sea Regional Programme (NVRSP), which includes Egypt, Ethiopia, Eritrea, Sudan and Yemen. Thus, the research led by ICARDA will not only utilize the results of ongoing work in CWA and the Caucasus and create inter-country linkages for work on yellow rust, but will also benefit from the experience and the linkages in the NVRSP Wheat Rusts Network. The objective of this study was therefore to launch a regional monitoring system of cereal rusts through the establishment of rust trap nurseries at hot-spots in cereal growing areas in CWANA. The comprehensive information on pathogen virulence and variation, and the epidemiological information on pathogen movements, would provide the basis for the development of an early warning system for farmers growing potentially susceptible cultivars.

Materials and methods

Annual disease surveys were conducted in Central Asia and Caucasus (CAC), Nile Valley and Red Sea (NVRS) Region, North Africa (NA) and West Asia. The surveys covered major wheat growing areas in 17 countries: four countries in CAC (Azerbaijan, Uzbekistan, Kyrgyzstan, Kazakhstan), 3 countries in North Africa (Algeria, Morocco, Tunisia), 5 countries in NVRS (Egypt, Ethiopia, Eritrea, Sudan, Yemen) and 5 countries in West Asia (Syria, Lebanon, Turkey, Jordan, Iran) over five years (2001–2005). Diseases were diagnosed in farmers' wheat fields and the relative importance of each fungal disease was assessed. The rust pathotypes were determined at ICARDA and at Research Institutes in Iran, Egypt, Pakistan and Ethiopia. Race determination (Johnson *et al*., 1972) was done at seedling stage using a standard set of differential cultivars (Table 1). Pathotypic evaluation at farm level was realized using a trap nursery (Tables 2, 3, 4 and 5) at 2 to 5 locations in each country.

Table 1. Host differential genotypes for *Puccinia striiformis* f.sp. *tritici*

Host cultivar	Resistance gene(s)	Host cultivar	Resistance gene(s)
World differential set		**Supplemental cultivars**	
1. Chinese 166	*Yr1*	Sonalika	*Yr2*, YrA
2. Lee	*Yr7*	Anza	YrA, *Yr18*
3. Heines Kolben	*Yr6*, *Yr2*	Fed.4/Kavkaz	*Yr9*
4. Vilmorin 23	*Yr3*V	Gereck 79	—
5. Moro	*Yr10*	Cham 1	—
6. Strubes Dickopf	*Yr*SD		
7. Suwon 92xOmar	*Yr*SU		
8. Clement	*Yr9*, *Yr2*+		
9. *Triticum spelta*	*Yr5*		
European differential set			
Hybrid 46	*Yr4*+		
Reichersberg 42	*Yr7*+		
Heines Peko	*Yr6*, *Yr2*+		
Nord Desprez	*Yr3*N		
Compair	*Yr8*, APR		
Carstens V	*YrCV*		
Spaldings Prolific	*YrSP*		
Heines VII	*Yr2*+		

NOTES: APR = adult plant resistance.

The trap nurseries included differential sets, commercial cultivars widely cultivated within each country, as well as new elite lines listed for potential release in the region. Two slightly different rust trap nurseries were assembled: one for Central and West Asia and the Caucasus (CWA-CRTN), targeting yellow and leaf rusts, and another for North Africa, Nile Valley and Red Sea regions (NVRS-CRTN) targeting stem and leaf rusts with limited spring-type accessions of Avocet isogenic lines that were adapted to the spring wheat growing areas. The commercial cultivars differed according to regions, whereas the elite lines were constant. The same set of leaf rust differentials was used in both nurseries. All the accessions were evaluated at seedling and adult growth stages following artificial inoculation with yellow, leaf, and stem rusts at ICARDA-HQ, and yellow rust at Haymana (Turkey) and Karaj (Iran). Field evaluation was performed at selected rust hot-spots within each country.

Table 2. Yellow rust differential cultivars in the 4th Central West Asia Cereal Rust Trap Nursery (CWA-CRTN)

No.	Cultivar	Yr gene(s)	No.	Cultivar	*Yr* gene(s)
1	Triticale	—	25	*Yr6*/ 6* Avocet S	*Yr6*
2	Chinese 166 (W)	*Yr1*	26	*Yr7*/ 6* Avocet S	*Yr7*
3	Lee (S)	*Yr7*	27	*Yr8*/ 6* Avocet S	*Yr8*
4	Heines Kolben (S)	*Yr6*	28	*Yr9*/ 6* Avocet S	*Yr9*
5	Vilmorin 23 (W)	*Yr3*V	29	*Yr10*/ 6* Avocet S	*Yr10*
6	Moro (W)	*Yr10*	30	*Yr15*/ 6* Avocet S	*Yr15*
7	Strubes Dickopf (W)	SD	31	*Yr17*/ 6* Avocet S	*Yr17*
8	Suwon 92×Omar (W)	SU	32	*Yr18*/ 3* Avocet S	*Yr18*
9	Clement (W)	*Yr9*+	33	*Yr*SK /3* Avocet S	*Yr27*
10	*Triticum spelta* var. *album* (Inter, *Yr5*) (S)	*Yr5*	34	*YrSP* / 6* Avocet S	*YrSP*
11	Morocco (W)	Check	35	Morocco (W)	Check
12	Hybrid 46 (W)	*Yr4*+	36	Sonalika (S)	*Yr2*
13	Reichersberg 42 (W)	*Yr7*+	37	Anza	*Yr*A, *Yr18*
14	Heines Peko (S)	*Yr6*+	38	Fed.4/kavkaz (S)	*Yr9*
15	Nord Desprez (W)	3N	39	Cham 1	DW
16	Compair (S)	*Yr8*, *Yr18*	40	Cook (S)	APR
17	Carstens V (W)	CV	41	Corella (S)	*Yr6*+*Yr7*
18	Spaldings Prolific (W)	SP	42	Oxley (S)	*Yr6*+APR
19	Heines VII (W)	*Yr2*, *Yr11*, *Yr25*	43	Kalyansona (S)	*Yr2*
20	Morocco (W)	Check	44	Federation (S)	—
21	Avocet S	—	45	Cranbrook (S)	*Yr7*
22	Avocet R	*Yr*A	46	Jupateco 'R' (S)	*Yr18*+
23	*Yr1*/ 6* Avocet S	*Yr1*	47	Jupateco 'S'	—
24	*Yr5*/ 6* Avocet S	*Yr5*	48	Morocco (W)	Check

NOTES: (W) = winter wheat type; (S) = spring wheat type; APR = adult plant resistance.

Under field conditions, spreader rows (mixtures of susceptible cultivars) served as a source of inoculum. Primary infection by air-borne rust spores developed rapidly on the spreader, and subsequent spread of urediniospores occurred naturally to the surrounding plots of the differential cultivars. The trap nurseries were evaluated at all testing sites for five consecutive years (2001–2005). Severity of infection (0–100%) and reaction type (R, S) as designated by Peterson, Campbell and Hannah (1948) were assessed at heading stage (growth stage 85 of Zadoks, Chang and Konzak, 1974). The frequency of infection on each genotype was calculated as the relative percentage of infection on susceptible lines over 5 years at all the testing sites in Syria.

Table 3. Commercial and elite cultivars grown in Central and West Asia and the Caucasus in the 4th Central West Asia Cereal Rust Trap Nursery (CWA-CRTN)

Ref. No.	Cultivar	Country	Ref. No.	Cultivar	Country
89	Ani 326	Armenia	115	Erythrospermum 760	Kyrgyzstan
90	Mirbashir 128	Azerbaijan	116	Lutescens 42	Kyrgyzstan
91	Karakylchyk 2	Azerbaijan	117	Bermet	Kyrgyzstan
92	Pirshahin	Azerbaijan	118	Jamin	Kyrgyzstan
93	Tarragui	Azerbaijan	119	Cham 4	Syria
94	Gobustan	Azerbaijan	120	Cham 6	Syria
95	Azametli 95	Azerbaijan	121	Ghurab 2	Syria
96	Memof 22	Lebanon	122	Bohouth 6	Syria
97	Seri 82	Lebanon	123	Bakht	Tajikistan
98	Sardari	Iran	124	Gereck 79	Turkey
99	Alamout	Iran	125	Bezostaya	Turkey
100	Darab-2	Iran	126	Kinaci 97	Turkey
101	Sabalan	Iran	127	Dagdas 94	Turkey
102	Shirodi	Iran	128	Gun 91	Turkey
103	M-75-10 (Shiraz)	Iran	129	Sultan 95	Turkey
104	M-75-7 (Pyshtaz)	Iran	130	Ak bugday	Turkmenistan
105	C-78-7	Iran	131	Turkmenbashi	Turkmenistan
106	C-78-18	Iran	132	Dustlik	Uzbekistan
107	Steklovidnaya 24	Kazakhstan	133	Polovchanka	Uzbekistan
108	Zhetysu	Kazakhstan	134	Spartanka	Uzbekistan
109	Opaks 26	Kazakhstan	135	Yuna	Uzbekistan
110	Progress	Kazakhstan	136	Skifyanka	Uzbekistan
111	Tilek	Kyrgyzstan	137	Ulugbek 600	Uzbekistan
112	Adyr	Kyrgyzstan	138	Sanzar 4	Uzbekistan
113	Kiyal	Kyrgyzstan	139	Sanzar 8	Uzbekistan
114	Frunzenskaya 60	Kyrgyzstan	140	Yanbash	Uzbekistan

Table 4. Selected elite cultivars with additional resistance genes included in the 4th Central West Asia Cereal Rust Trap Nursery (CWA-CRTN)

Ref. No	Cultivar or line	Resistance gene(s)
141	GAZA (W277) (durum)	*Lr23,* +
142	Altar 84 (durum)	*Lr10,* +
143	ND LINE (durum) IUMILLO (durum)	
144	Local Red (durum)	
145	Yecora 70	*Lr1, Lr13*
146	INIA 66	*Lr13, Lr17*
147	NOROESTE	*Lr1, Lr13, Lr17*
148	Opata85	*Lr10, Lr27+Lr31, Lr34*
149	Anahuac 75	*Lr13, Lr17, Lr27+Lr31*
150	Genaro 81	*Lr13, Lr26* + Slow rusting
151	SUPER SERI#2	*Lr19, Lr23* + Slow rusting
152	BABAX#1	*Lr27+Lr31* + Major APR gene
153	BABAX#2	*Lr26, Lr27+Lr31* + Major APR gene
154	SUPER KAUZ	*Lr26, Lr34* + Slow rusting
155	Tonichi 81	*Lr1, Lr13, Lr27+Lr31, Lr34* + Slow rusting
156	Parula	*Lr13, Lr34* + Slow rusting
157	Pavon 76	*Lr1, Lr10, Lr13, Lr46* + Slow rusting
158	Pastor	*Lr3, Lr10, Lr23* + Slow rusting
159	Attila (CM85836-50Y-0M-0Y-3M-0Y)	Slow rusting
160	Amadina (CRG682-8Y-3B-3Y-2B-0Y-0Y)	Slow rusting
161	Buck Buck	*Lr16* + Slow rusting
162	CAR422/ANA//YACO/3/KAUZ*2/TRAP//KAUZ (CG84-099Y-099M-1Y-2M-1Y-0B)	Slow rusting
163	TRAP#1/YACO/3/KAUZ*2/TRAP//KAUZ (CG96-099Y-099M-17Y-5M-5Y-0B)	Slow rusting
164	SNI/PBW65/3/ KAUZ*2/TRAP//KAUZ (CG36-099Y-099M-27Y-5M-4Y-0B)	Slow rusting
165	VORONA/HD2402	
166	AGRI/NAC//KAUZ	
167	TX71C8130R/TX81V6610/3 RL6010/6*INIA66//KAUZ	
168	494J6.11//TRAP#1/BOW	
169	TX71A983.4/TX69D4812//PYN/3/VPM/MOS83.11 .4.8//PEW	
170	Triticale	

Table 5. Nile Valley and Red Sea Cereal Rust Trap Nursery (NVRS-CRTN): yellow rust differentials and commercial cultivars

Ref. No	Cultivar	Yr-Gene	Ref. No	Commercial Cultivar
89	Avocet S		104	Triticale
90	Avocet R	*Yr*A	105	Cham 4
91	*Yr1*/ 6* Avocet S	*Yr1*	106	Cham 6
92	*Yr5*/ 6* Avocet S	*Yr5*	107	Ghurab 2
93	*Yr6*/ 6* Avocet S	*Yr6*	108	Bohouth 6
94	*Yr7*/ 6* Avocet S	*Yr7*	109	Memof 22
95	*Yr8*/ 6* Avocet S	*Yr8*	110	Seri 82
96	*Yr9*/ 6* Avocet S	*Yr9*	111	Gereck 79
97	*Yr10*/ 6* Avocet S	*Yr10*	112	Bezostaya
98	*Yr15*/ 6* Avocet S	*Yr15*	113	Yuna
99	*Yr17*/ 6* Avocet S	*Yr17*	114	Mirbashir 128
100	*Yr18*/ 3* Avocet S	*Yr18*	115	Gobustan
101	*Yr*SK /3* Avocet S	*Yr27*	116	Azametli 95
102	*YrSP* / 6* Avocet S	*YrSP*	117	Local cultivar
103	Morocco	Check	118–129	12 Local cultivars
			130	Local cultivar

Results and discussion

Disease surveys provide useful information on the prevalence, incidence and severity of diseases on a crop over space and time (Yahyaoui *et al*., 2004a; Wellings *et al*., 2000). The information generated from the surveys was used to describe the level of resistance found in the cultivars or landraces. The disease surveys conducted over the past 5 years revealed that the primary diseases of wheat were yellow, leaf and stem rusts, tan spot and Septoria leaf blotch. Other less prevalent diseases on this crop were common bunt, scab and powdery mildew. The average incidence of these diseases varied according to the zone surveyed. A rapidly evolving disease on both durum and bread wheat is tan spot disease (*Pyrenophora tritici-repentis*). Table 6 summarizes the disease distributions and their relative importance in CWANA countries surveyed. This paper reports on pathotype diversity and distribution as revealed by the use of the rust trap nurseries, with emphasis on yellow rust (*Puccinia striiformis* f.sp. *tritici*) since yellow rust continues to be the most widespread disease in CWANA.

Widely cultivated bread wheat varieties are succumbing to this devastating disease, particularly in Central Asia and the Caucasus. Known yellow rust resistance genes (McIntosh, Wellings and Park, 1995) are becoming ineffective against new evolving races that are rapidly spreading across the region.

Table 7 shows the relative effectiveness of known resistance genes to yellow rust in CWANA.

Virulence on *Yr1* and *Yr17* has spread rapidly in Central Asia (Table 7). Virulence on *Yr1* was first observed in Tajikistan in 1999, but by 2004 it was found across CWA. Virulence on *Yr10* and *Yr17* was observed in Yemen in 1999, while virulence on *Yr1*8, *Yr*27 and *Yr*24 were recorded in 2002, but by 2005 these virulence types were recovered at many other locations in CWANA (Yahyaoui *et al*., 2004b). The resistance of *Yr5* has been high at all sites over the past five years but has not yet been exploited in breeding programmes. The *Yr5* resistance gene has not been exposed on a wide scale, and hence it should be used in combination with other resistance genes. These changes in virulence could have occurred by simple mutation followed by asexual propagation that helped maintain and increase the inoculum of these new pathotypes. Analysis of trap nurseries revealed that most of the commercially grown wheat varieties are highly susceptible. These varieties occupy the largest areas of cultivated wheat in the region (Table 8)

Table 6. Prevalent wheat diseases and their importance in the CWANA Region

Country	Wheat disease							
	Yellow rust	Leaf rust	Stem rust	*Septoria tritici*	Tan spot	Powdery mildew	Common bunt	Scab
Central Asia and Caucasus								
Azerbaijan	•••	••	•	••	••	•	••	••
Kazakhstan	••	••		••	•••	••	•	
Kyrgyzstan	•••	•		••	••	•	•	•
Uzbekistan	•••	••		•	•	••	•	
Tajikistan	•••	•		••	•••	•	•	
Nile Valley and Red Sea								
Egypt	••	••	••			••	•	
Ethiopia	•••	••	••	•		•	•	
Eritrea	••	•••	••	••	•	••	•••	
Sudan		••	••			••	••	
Yemen	•••	••		•		•	••	
North Africa								
Morocco	•	•••	•	•••	••	•	•	
Algeria	••	••	•	•••	••	••	•	
Tunisia	•	•••	•	•••	••	•	•	•
West Asia								
Iran	•••	••	••	•••	••	••	•	••
Syria	•••	•	•	••	••	•	•	
Turkey	•••	•		••	•	•		

NOTES: Values based on average incidence per zone. KEY: • = low incidence; •• = medium incidence; and ••• = high incidence}

Table 7. Field reaction of wheat genotype with known resistance genes to yellow rust at six sites in Western and Central Asia

Genotype	Resistance gene(s)	Testing sites (countries) and reaction to yellow rust					
		SYR	LEB	TUR	KYR	TAJ	AZE
Avocet S	–	S	S	S	S	S	S
Yr1/ 6* Avocet S	*Yr1*	R	MR	R	S	S	R
Chinese 166	*Yr1*	R	R-MS	R	MR-S	S	R
Yr15/ 6* Avocet S	*Yr15*	R	R	S	R	MS	R-S
Yr17/ 4* Avocet S	*Yr17*	S	MR	MS	S	S	R-MS
Yr5/ 6* Avocet S	*Yr5*	R	R	R	R	MS	R
Triticum spelta	*Yr5*	R	R	R	-	MS	R
Nord Desprez	*Yr3* N	R	MR	R	R	MR	R
Clement	*Yr9*	MS-S	MS	R	R	MR	MR-MS
Yr9/ 6* Avocet S	*Yr9*	S	S	R	R	MR	S
Federation	*Yr9*	S	S	MS-S	S	S	S
SERI 82	*Yr9*, *Yr7*	S	S	S	-	S	S
Avocet R	*Yr*A	S	S	R	S	R	S
Kalyansona	*Yr2*	S	S	S	S	S	S
Sonalika	*Yr2*, *Yr*A	S	S	MS	–	S	S
Yr8/ 6* Avocet S	*Yr8*	MS	R	R	S	S	R-S
Compare	*Yr8*, APR	R	MR	MR	R	MR	R
Yr18/ 3* Avocet S	*Yr18*	MS	S	S	S	S	S
Jupateco R	*Yr18*, +	MS	S	MS	S	MS	MS-S
Anza	*Yr18*, *Yr*A	MS-S	S	S	MR	S	MS-S
Jupateco S	–	S	S	MS	S	S	S
Morocco	–	S	S	S	S	S	S

NOTES: Countries are SYR = Syria, LEB = Lebanon, TUR = Turkey, KYR = Kyrgyzstan, TAJ = Tajikistan, AZE = Azerbaijan. APR = adult plant resistance. Reaction = Field reaction to yellow rust at adult growth stage over 2 years (1999–2000).

The detection of yellow rust variation has traditionally relied upon the identification of physiological races in the pathogen population by inoculating a sample of pathogen isolates on a series of host differential cultivars with known resistance genes, and observing the resulting compatible or incompatible disease phenotypes. Seedling resistance is usually race-specific and can be recognized by its characteristic resistance type at all plant growth stages. Despite their limitations, studies of physiological races in cereal rusts have been tremendously valuable in the development and deployment of host resistance, and have provided important insight into the evolution of yellow rust disease in response to host resistance genes.

Table 8. Field reaction of wheat cultivars commonly grown in Central and Western Asia to yellow rust at six locations

Genotype	Testing sites (country) and reaction to yellow rust					
	SYR	LEB	TUR	KYR	TAJ	AZE
Gerek 79	S	S	R	MR	R	S
Seri 82	S	S	R	MR	MR	S
Sardari	S	MS	R	–	S	S
Bezostaya (S)	MS	S	MS	MS	S	MR
Polovchanka (F)	MR	S	R	R	MS	–
Yuna (S)	S	S	S	S	S	S
Skiphyanka (F)	S	S	S	S	S	S
Cham 6 (S/F)	MS	MS	R	-	MS	R
Skifyanka	S	S	S	S	MS	S
Opaks 26	S	S	S	S	MS	S
Mirbachir 80				–	–	S

NOTES: Countries are SYR = Syria, LEB = Lebanon, TUR = Turkey, KYR = Kyrgyzstan, TAJ = Tajikistan, AZE = Azerbaijan. Reaction = Field reaction to yellow rust at adult growth stage in 1999 and 2000 seasons.

Stripe rust race monitoring in CWANA has revealed that race 6E0 (virulent on *Yr6* and *Yr*A) is the most frequent race in the region, and it has been detected every year since 1972. In West Asia, race 38E150 (virulent on *Yr2*, *Yr6*, *Yr7, Yr8*) was the second-most frequent pathotype during the last five years (2001–2005), whereas races 134E152 (virulent on *YrA*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*), 230E150 (virulent on *YrA*, *Yr2*, *Yr6*, *Yr7*, *Yr9*, *YrSU, YrSD*, *Yr17*, *Yr18*) and 119E158 (virulent on *YrA, Yr1*, *Yr2*, *Yr3*, *Yr6*, *Yr7*, *Yr9*, *Yr10*, *Yr17*) were detected in Lebanon, Iraq and Yemen, respectively. Thus, a wide range of virulent races is evolving in this region, causing the breakdown of stripe rust resistance in wheat (Johnson *et al*., 2002; Yahyaoui *et al*., 2002; Wellings *et al*., 2000).

Single-uredinial isolates of *Puccinia striiformis* f.sp. *tritici (Pst)* randomly sampled from some countries in CWA as well as in the NVRS region were characterized for physiological races at ICARDA, Iran (SPII), Pakistan (PARC) and Egypt (ARC). A total of 95 physiological races were identified (Table 9).

Table 9. Yellow rust pathotypes (races) identified or reported in the period 1999–2004

Country	Race or pathotype	Number of races
Azerbaijan	2E0A+; 6E2A; 6E6A+; 22E6A+; 70E6A+; 14E142A+	10
Uzbekistan	6E6A+; 22E6A+; 14E134A+; 14E134A+; 102E134; l38E134A+	8
Nepal	4E0; 4E16; 7E150; 7E158	?
Pakistan	70E0 ; 70E16	?
Egypt	242E100; 458E45; 123E65; 450E109; 456E45	25
Ethiopia	6E16; 198E158; 206158	8+
Yemen	4E148; 38E130; 70E134; 119E158	20
Lebanon	38E22; 6E134; 38E134; 172E146; 182E150; 198E150	40
Iran	0E0; 2E14; 4E32; 34E4; 166E142; 134E134; 134E166	31
Syria	0E0; 6E20; 6E134; 134E134; 230E134; 134E150; 230E150; 19E158	85
Turkey	0E0, 7E150	?

Pst physiological races identified differed in their occurrence within wheat growing areas in the CWA and NVRS regions. With the World differential set, the resistance genes *YrSU* in Suwon 92×Omar and *Yr9*+ in Clement allowed clear discrimination between the races in Syria. Virulence to these genes occurred in 1999. In the case of the European differential cultivars, virulence for the resistance genes *Yr7*+, *Yr6*+, *Yr2*+ and *Yr8,* and avirulence for *Yr4*+, *YrCV.* and *YrSP,* have also been observed since 1994.The World differential set did not allow complete distinction between some races (6E0, 6E18, 6E134, 6E148, 6E150) whereas European differentials showed differential reactions for *Yr7*+, *Yr6*+ and *Yr8* resistance genes. Thus, the combined use of both differentials allows better discrimination between *Pst* isolates. Significant changes in race composition were identified using the World and European differential sets. Changes in physiological race compositions of *Pst* have revealed some interesting trends in CWANA (Johnson *et al*., 2002; Yahyaoui *et al.*, 2002; Yahyaoui and El-Naimi, 2003). Table 9 shows the physiological races identified in the region so far by ICARDA and NARS collaborators in Iran, Pakistan and Egypt. In CWANA, race 166E150 is one of the most virulent races identified and could be among the *Pst* races that contributed to the yellow rust epidemics in this region. Race 166E150 combined virulence to the resistance genes *Yr9*+, *Yr8* and *YrA* that were deployed in many bread wheat varieties in the early 1980s.

This race shows a broad virulence spectrum, and was found in Syria only in 1996, but has been recovered during the last four consecutive years in Lebanon. Virulence on the *YrSU* resistance gene was first recorded in Lebanon in 1999. Physiological race 6E0 was first observed in the region in 1972 and has been recovered in Syria every year since. This race is virulent to the *Yr6* gene that frequently occurs in both winter and spring wheats (McIntosh, Wellings and Park, 1995), both of which are cultivated extensively in the highlands of

Syria, Lebanon, Iran and Turkey. Race 6E0 is also virulent to *YrA* that is present in many wheat cultivars that are still cultivated over relatively large areas in Turkey, Lebanon and Syria. Race 38E150 was the second most frequent race in Syria and was found in the last five consecutive years, whereas 134E146 and 38 E134 were identified in rust samples for four consecutive years. These races originated from durum wheat leaf samples and most of them were not detected in 1999. The frequency of *P. striiformis* virulence genes was determined based on defeated resistance genes under field conditions in Syria.

In Yemen, virulence of yellow rust observed in 2001 and 2002 based on natural infection of the pathogen showed the presence of virulence against resistance genes *Yr7*, *Yr9, Yr10*, *YrA*, *Yr12*, *Yr17*, *Yr18*, *Yr24* and *Yr27*. Virulence on *Yr3*, *Yr6*, and *Yr8* were observed in 1999 but were not recovered during the 2001 and 2002 survey. This could be due to poor development of the winter cultivars that carry these genes.

In Egypt, race 242E100 possessed virulence for Clement, Suwon 92×Omar, Moro, Lee, Spaldings Prolific, Carstens V and Heines Peko. This race, therefore, has virulence for the resistance conferred by *Yr9, Yr SU, Yr10, YrSP*, *YrCV*, *Yr2* and *Yr6*. Race 0E0 was avirulent to all European and World differential cultivars, but virulent to *Yr2*. Race 458E45 reported in Egypt was virulent on *Triticum spelta* var. *album*, Clement, Vilmorin 23, Suwon 92 ×Omar, Carstens V, Nord Desprez, Heines Peko and Hybrid 46, and therefore has virulence for *Yr9*, *YrSU*, *Yr3*, *YrCV*, *Yr2*, *Yr6*, *Yr5* and *Yr4*. Virulence frequencies in the yellow rust population on the differential genotypes tested in the trap nurseries were above 70% for resistance genes *Yr6, Yr7, YrA* and *Yr9*; however, virulence frequencies for *Yr3V* and *YrSD* was less than 5%.

Virulence frequencies on all other lines were between 15 and 70%. These results reveal a broad virulence spectrum of *P. striiformis* under natural field conditions.

At present 30 genes are catalogued for resistance to yellow rust (McIntosh, Wellings and Park, 1995), and over 38 resistance genes identified against leaf rust and 48 against stem rust. A majority of these are race specific, and virulence has been identified for most of them at least somewhere in the CWANA region. Bread wheat cultivars that carry resistance based on a single race-specific gene, or combinations of two of them, are currently grown on a large area in countries where yellow rust has caused major losses or threats in past years, of which development of yellow rust in Pakistan in 2005 is a good example.

Conclusions

While the diversity of the pathogen population creates problems, there are ways to manage rust diseases in CWANA countries, such as through effective deployment of resistance sources and use of durable resistance in an Integrated Regional Cereal Rusts Management Programme. Hence, breeding for disease resistance in CWANA could be achieved using broad-based resistance that could be facilitated by: (1) adequate measures for gene deployment across the region, (2) use of molecular markers to follow the flow and the build-up of resistance in the breeding programmes' germplasm, (3) use of markers to monitor the genetic diversity in the rust populations across the region, and (4) maintenance of an adequate level of host diversity in the breeding programmes to stabilize resistance to the predominant cereal rusts.

References

Ahmed, S., Rodriguez, A., Farid Sabir, G., Roidar Khan, B. & Panah, M. 1991. Economic losses of wheat crops infested with yellow rust in highland Balochistan. MART/AZR Project Research, Report #67. ICARDA, Quetta. 15 p.

Badebo, A. & Bayu, W. 1992. The importance of stripe rust in the major bread wheat producing regions of Ethiopia during 1998–90. pp. 196–202, *in:* D.G. Tanner and W. Mwangi (editors). Proceedings of the 7th Regional Wheat Workshop for Eastern Central and Southern Africa, 16–19 September 1991, Nakuru, Kenya.

Braun, H.-J. & Saari, E.E. 1992. An assessment of the potential of *Puccinia striiformis* f.sp. *tritici* to cause yield losses in wheat on the Anatolian Plateau of Turkey. pp. 121–123, *in:* F.J. Zeller and G. Fischbeck (editors). Proceedings of the 8th European and Mediterranean Cereal Rusts and Mildews Conference, 8–11 September 1992, Wheihenstephan, Germany.

Dusunceli, F., Getin, L., Albustan, S. & Beniwal, S.P.S. 1996. Occurrence and impact of wheat stripe rust *(Puccinia striiformis)* in Turkey in 1994/95 crop season. p. 309, *in:* G.H.J. Kema, R.E. Niks and R.A. Daamen (editors). Proceedings of the 9th European and Mediterranean Cereal Rusts and Powdery Mildews Conference, 2–6 September 1996, Lunteren, The Netherlands.

El-Daoudi, Y.H., Shafik, L., Ghanem, H.E., Abu El-Naga, S., Mitkees, R., Sherif, S., Khalifa, M.O. & Bassiouni, A.A. 1996. stripe rust occurrence in Egypt and assessment of grain yield loss in 1995. pp. 341–351, *in:* B. Ezzahiri, A. Lyamani, A. Farih and M. El-Yamani (editors). Proceedings of the Symposium Regional sur les Maladies des Cereales et des legumineuses Alimentaires, 11–14 November 1996, Rabat, Morocco.

Johnson, R., Stubbs, R.W., Fuchs, E. & Chamberlaine, N.H. 1972. Nomenclature for physiological races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Johnson, R., Yahyaoui, A., Wellings, C.R., Saidi, A. & Ketata, H. (editors). 2002. *Meeting the Challenge of Yellow Rust in Cereal Crops*. Proceedings of the [First]

Regional Conference on Yellow Rust in the Central and West Asia and North Africa Region, 8–14 May 2001, Karaj, Iran. 280 p.

Mamluk, O.F. & El-Naimi, M. 1992. Occurrence and virulence of wheat yellow rust in Syria. pp. 115–117, *in:* F.J. Zeller and G. Fischbeck (editors). Proceedings of the 8th European and Mediterranean Cereal Rusts and Mildews Conference, 8–11 September 1992. Weihenstephan, Germany.

Mamluk, O.F., Haware, M.P., Makkouk, K.M. & Hanounik, S.B. 1989. Occurrence, losses and control of important cereal and food legume diseases in West and North Africa. pp. 131–140, *in:* Proceedings of the 22nd International Symposium on Tropical Agriculture Research, 25–27 August 1988, Kyoto, Japan.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildews Bulletin,* 23(1): 9–12.

Yahyaoui, A. & El Naimi, M. 2003. Occurrence and virulence of wheat yellow rust in Central and Western Asia. *in:* 8th Arab Congress of Plant Protection, Libya, October 2003.

Yahyaoui, A., Hakim, M.S., Al Naimi, M. & Rbeiz, N. 2002. Evolution of physiologic races and pathogenicity of *Puccinia striiformis* of wheat in Syria and Lebanon. *Plant Disease,* 86: 499–504.

Yahyaoui, A., Hovmøller, M., Ezzahiri, B., Jahoor, A., Maatougui, M.H. & Wolday, A. 2004a. Survey of barley and wheat diseases in the central highlands of Eritrea. *Phytopathologia Mediterranea*, 43: 39–43.

Yahyaoui A., Abdalla, O. ,Ketata, H., Morgonouv, A., Torabi, M., Cetin, L., Saidov, M., Koshibaev, M., Djunusova, M., Malhotra, R. & Mosaad, M. 2004b. Occurrence of stripe rust and effectiveness of resistance genes in Western and Central Asia and the Caucasus (WCAC). ASA-CSSA-SSSA International Annual Meetings, 31 October–4 November 2004, Seattle, WA, USA.

Wellings, C.R., McIntosh, R.A., Singh, R.P. & Yahyaoui, A. 2000. International surveillance to detect pathogenic variation in *Puccinia striiformis. In:* 6th International Wheat Conference, 4–6 June 2000, Budapest, Hungary.

Zadoks, J.C., Chang, T.T. & Konzak, C.F. 1974. A decimal code for the growth stages of cereals. *Weed Research*, 14: 415–421.

Improvement of yellow rust resistance of wheat under multilocational trials in Central Asia

A.M. Kokhmetova,[1] X.M. Chen,[2] A.I. Morgounov,[3] M.A. Yessimbekova,[4] M.K. Koishibayev,[4] M.K. Zhunusova,[5] S. Rsaliev[4] and A.T. Alshoraz[4]

1. Institute of Plant Physiology, Genetics & Bioengineering, Almaty, Kazakhstan
2. USDA-ARS and Washington State University, Pullman, USA
3. CIMMYT-CAC, Almaty, Kazakhstan
4. Scientific-Production Centre of Management and Plant Growing, Kazakhstan
5. Kyrgyz MIS, Kyrgyzstan

Abstract

Central Asia is one of the most important wheat producing regions in the world, growing 5 million hectare of winter or facultative wheat and 10 million hectare of spring wheat. Wheat yellow rust (*Puccinia striiformis* f.sp. *tritici*) is a major factor adversely affecting both wheat yield and quality, with considerable economic damage. In 2003, in the major wheat producing regions of Azerbaijan, Kyrgyzstan and south Kazakhstan, yield losses reached 30–50%. In Uzbekistan, 50% of the wheat growing areas were sprayed with fungicides. Use of genetic host resistance is the most effective, economical and environmentally safe method of controlling stripe [yellow] rust

Seedlings of winter wheat cultivars and advanced breeding lines from central Asia, Russia, CIMMYT and ICARDA were tested for resistance to five races of *P. striiformis* f.sp. *tritici* in the USA under controlled greenhouse conditions at Washington State University, USA. The more harmful North American races of *P. striiformis* to germplasm from Central Asia were by *Pst*-17 and *Pst*-100.

Results of evaluating wheat differentials in trap nurseries in four Central Asian locations (Almaty, Shymkent and Zhambyl oblasts of Kazakhstan, and Byshkek oblast of Kyrgyzstan) identified some resistance sources. Local and international nurseries screened for agronomic traits and disease resistance included 150 wheat entries. These materials were studied at five locations and screened for yellow, leaf and stem rusts, *Septoria nodorum* and *Tilletia caries* under natural infections. Evaluation for agronomic traits was conducted for productivity, heading date, lodging resistance and quality of grain. Thirty-five advanced lines were selected that had a high level of yield potential and

moderate and high levels of resistance to the major diseases and pests tested in all locations. From hybrid populations with effective donors of resistance, about 100–120 advanced lines across all locations were selected. In 2005/06 these breeding materials were currently being tested in four locations.

Introduction

Central Asia is one of the most important wheat producers in the world. Wheat is grown on 15 million hectare, including 5 million hectare of winter or facultative wheat and 10 million hectare of spring wheat. In this area over the past several years, wheat yellow rust (*Puccinia striiformis* f.sp. *tritici*) was among the major factors that adversely affected both wheat yield and quality and caused considerable economic damage. In 2003 in the main wheat producing regions of Azerbaijan, Kyrgyzstan and south Kazakhstan, yield losses reached 30–50%. In Uzbekistan, 50% of the wheat growing area was sprayed with fungicides. Use of genetic host resistance is the most effective, economical and environmentally safe method of controlling stripe rust (Johnson and Bimb, 1997; Kumar *et al.,* 1999). The aim of our research is to study genetics of wheat resistance to yellow rust in a set of wheat lines and cultivars and to develop germplasm resistant to yellow rust.

Materials and methods

The material used for the research comprised the differentials from the Central and West Asia Yellow Rust Trap Nursery (CWAYRTN, including World differentials, European differentials, Cobbity differentials and North American differentials); advanced lines of winter wheat from various International Trial Nurseries from CIMMYT and ICARDA; entries from national breeding programmes of Kazakhstan, Kyrgyzstan and Uzbekistan (150 entries annually); and homozygous lines selected from F_4–F_5 hybrids resulting from crosses between adapted local cultivars and effective sources of resistance. Experimental material was grown in 2004–2005 at 5 locations in Central Asia with differing soil conditions and temperature and moisture patterns. Disease severity (percentage of rust infection on the plant) and plant response (infection type – IT) were recorded following McIntosh, Wellings and Park (1995). Five infection types were described: 0 – immune; R – resistant; MR – moderately resistant; MS – moderately susceptible; S – susceptible. Cultivar Morocco and local cv. Steklovidnaya 24 were used as susceptible checks for multiplication of the pathogen in the greenhouse and as the spreaders in the field tests. In the field, wheat genotypes were screened for stripe rust races predominant in the region. Seedlings of winter wheat cultivars and advanced breeding lines from Central Asia, Russia, CIMMYT and ICARDA were tested

for resistance to five races of *P. striiformis* f.sp. *tritici* currently or previously prevalent in the USA (*Pst*-100, *Pst*-45, *Pst*-43, *Pst*-37, *Pst*-17). The seedling reactions were evaluated at the two–leaf stage using methods described by Chen and Line (1992).

For each plant, the IT based on a 0–9 scale was recorded 20 days after inoculation. Evaluation for agronomic traits was done each year in all selected material for the most important traits of productivity (height of plant, tillers per plant, length of spike, number of kernels per spike, weight of kernels per spike, weight of kernel per plant, 1000-kernel weight), heading date, lodging resistance and quality of grain. Statistical analysis was done based on ANOVA.

Results

Seedling tests for resistance to yellow rust were done on 14 wheat genotypes (Table 1). Plants were grown and tested under controlled greenhouse conditions at Washington State University, USA.

Table 1. Seedling resistance to North American races of *Puccinia striiformis* f.sp. *tritici*

Entry	Origin	Infection type				
		***Pst*-100**	***Pst*-45**	***Pst*-43**	***Pst*-37**	***Pst*-17**
Almaly	Kazakhstan	8	8	8	8	8
Arap	Kazakhstan	8	8	8	8	8
Taza	Kazakhstan	8	2	2	2	8
Naz	Kazakhstan	8	8	8	8	8
Sapaly	Kazakhstan	8	8	8	8	8
Steklovidnaya 24	Kazakhstan	8	8	8	8	8
Krasnovodopadskaya-25	Kazakhstan	2	2	2	2	8
Sanzar 8	Uzbekistan	8	8	8	8	8
Ulugbek-600 (*Yr9*)	Uzbekistan	2	2	2	2	2
Sharora	Tajikistan	8	2	2	2	2
Adyr	Kyrgyzstan	8	8	8	8	8
MK-3796 (Bez 2B/CGN//VR2)	Mexico	8	8	8	8	8
BWKLDN-95(KASYON/ GENARO.81// TEVEE-1/ICW92-02.81.1AP-2AP.OL-3AP-1AP-OAP	ICARDA	8	8	8	8	8
Umanka	Russia	8	8	8	8	8

Resistance to race *Pst*-100 was detected in Krasnovodopadskaya 25 and Ulugbek 600. Race *Pst*-100 was virulent on cultivars Almaly, Arap, Taza, Naz, Sapaly, Steklovidnaya 24 and other commercial cultivars. Resistance to race *Pst*-45 was observed in wheat cultivars Taza, Krasnovodopad 25, Ulugbek 600 and Sharora, while it was virulent on genotypes Almaly, Arap, Naz, Sapaly, Steklovidnaya 24, Sanzar 8, Adyr, MK-3796, BWKLDN, Knyazhna and

Umanka. The same disease reaction was observed when genotypes were tested with races *Pst*-43 and *Pst*-37. Race *Pst*-17 was virulent on most of genotypes studied, except for Ulugbek 600 and Sharora, on which a resistant reaction was detected. Thus, the more harmful North American races of *P. s.* f.sp. *tritici* for germplasm from Central Asia are represented by *Pst*-17 and *Pst*-100. According to Chen (2005), race *Pst*-100 is virulent on North American differentials Lemhi (*Yr21*), Heines VII (*Yr2*, *Yr25, YrHVII*), Produra (*YrPr1, Pr2*), Yamhill (*Yr2*, *Yr4a*, *YrYam*), Stephens (*Yr3a*, *YrS*, *YrSte*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*), Express, (*Yr8*, *Yr9*), Clement (*Yr9*, *Yr25*, *YrCle*) and Compare (*Yr18*, *Yr19*).

Based on seedling tests, cultivars Taza, Krasnovodopadskaya 25 and Ulugbek 600 have all-stage resistance (also called seedling resistance).

Based on field tests, entries from a Trap Nursery (CWAYRTN) were screened for *P.s.* f.sp. *tritici* to assess the effectiveness of known resistance genes, resistant commercial cultivars and advanced lines. Analysis of the trap nursery at three locations in Central Asia is shown in Table 2. In conditions of Almaty oblast (NPCZR) and Zhambyl oblast (Otar) the reactions of differentials and isogenic lines were approximately the same. However, in Kyrgyzstan, reactions of these entries were different.

The most effective against *P. striiformis* in the region were the sources of genes *Yr2+*, *Yr4+*, *Yr5*, *Yr10* and *Yr15*, which demonstrated R-MR infection type. The carriers of *Yr1* were susceptible: 60-80S on Chinese 166 and 30-80S on the isogenic line *Yr1*/6*Avocet S. Heines VII demonstrated a high level of resistance (IT 0), but cultivars Kalyansona and Sonalika, which have *Yr2*, were not resistant. The same reaction was observed on carriers of *Yr3*: cultivar Vilmorin 23 (*Yr3a, YrV23*) was resistant, but cultivar Nord Desprez (*Yr3a*, *YrND*) was susceptible. Hybrid 46 (*Yr4b, YrH46*) was moderately resistant (10MR) in 2005. However, in previous years this cultivar was highly resistant to yellow rust. A high level of resistance (0) in many locations was consistently observed for *Yr5* both in the original source of this gene (*Triticum spelta* var. *album*) and in the isogenic line *Yr5*/6*Avocet S. Cultivar Heines Peko (*Yr6*, *YrHP*) had a variable reaction, from MS-S (10S-30MS-90S) to highly resistant (R), while the isogenic line *Yr6*/6*Avocet S was susceptible (60-80S). Cranbrook (*Yr7*) and Lee (*Yr7*, *Yr22*, *Yr23*) demonstrated susceptible reactions (20-30S). However, Corella (*Yr6+Yr7*) and Reichenberg 42 (*Yr7*) were resistant.

Table 2. Field responses to stripe rust among the differentials in CWAYRTN in 2004 and 2005

Cultivar, entry	NPCZR, Almaty reg., Kazakhstan, 2005	OTAR, Zhambyl reg., Kazakhstan, 2005	ISSYK-KUL, Kyrgyz Republic, 2004
Vilmorin 23 (*Yr3*v)	R	5R	0
Moro (*Yr10*)	R	0	0
Clement (*Yr9*+)	R	5R	20MS
Hybrid 46 (*Yr4*+)	R	5R	R
Heines Peko (*Yr6*+)	R	10S	90S
Nord Desprez (3N)	R	20S	R
Heines VII (*Yr2*+)	R	10R	5R
Yr1/6* Avocet S	60S	80S	70S
Yr5/6* Avocet S	R	5R	R
Yr6/6* Avocet S	40S	80S	90S
Yr7/6* Avocet S	80S	80S	90S
Yr8/6* Avocet S	30S	75S	90S
Yr9/6* Avocet S	20S	20S	20MS
Yr10/6* Avocet S	R	5R	R
Yr11/6* Avocet S	25S	20S	15S
Yr12/6* Avocet S	90S	60S	50S
Yr15/6* Avocet S	R	R	R
Yr17/6* Avocet S	20MS	10MS	5MR
Yr18/6* Avocet S	40MS	60S	70S
Avocet S	80S	60S	70S
Oxley (*Yr6*+APR)	R	15R	10R
Cook (APR)	R	R	R
Anza (*Yr18*+A)	20MS	20S	30MS
Morocco (susceptible check)	90S	80S	100S

NOTES: APR = adult plant resistance

The presence of genes *Yr8* and *Yr19* in cultivar Compair had an MR reaction in 2005, but under severe yellow rust development was susceptible (20-40S), especially at SRAI. Isogenic line *Yr8*/6*Avocet S also showed high susceptibility (40-90S). The source of *Yr9*, Federation 4/Kavkaz, and the *Yr9*/6*Avocet isogenic line were moderately susceptible to susceptible. A consistent resistant reaction was observed in the *Yr10*/6*Avocet S and *Yr15*/6*Avocet S isogenic lines. The *Yr18*/6*Avocet S isogenic line was more susceptible than cv. Anza (*YrA, Yr18*). Cv. Cook, with adult-plant resistance, was resistant (IT 0). Among the USA differentials, cultivars that were resistant to both yellow rust and leaf rust included Paha, Druchamp, Riebesel 47/51, Lee, Tres, Express, Clement, Heines VII and Hybrid 46. Virulences to resistance

genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8* and *Yr9* have occurred in the region. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* are the races virulent to these genes.

In order to select and develop useful germplasm we evaluated breeding material from different CIMMYT nurseries and local breeding programmes. In the first stage, 150 entries with resistance to yellow rust and high yield potential were selected. This material was tested at 6 sites. Most attention was paid to resistance to yellow rust, high yield quality of grain and resistance to main diseases and pests. Entries were screened for tan spot, *Tilletia caries*, *Septoria* sp., leaf rust and stem rust.

From the first stage, 35 entries (Table 3) with a complex of valuable traits were selected. They demonstrated advantages at all tested sites. This group includes the entries combining high yield and quality of grain with resistance to the main diseases. The length of vegetative period is very important for plant development. Regarding diseases resistance, this trait reflects the ability to avoid strong development of disease. It was found that the entries with late heading date were more resistant, but in southern Central Asia, such late ripening genotypes cannot be successful because they are, as a rule, low yielding. Among selected resistant entries were the 24 most early maturing genotypes: LC924/PETJA, VLASTA, PASTOR/3/ KAUZ*2/OPATA//KAUZ, AGRI/NAC//ATTILA, PI/MZ//CNO67…, TURDA 2000, LOV41/3/EKG15//…, MUNIA/PICUS, 1D13.1/MLT//KAUZ, PRINIA/STAR, SKAUZ/4/ TJB916.46/, CTK/3/ATL66/CMN//TX2607-6/4/SS8/…, CRR/ATTILA and MK 4364.

Almost all selected lines were semi-dwarf types with plant height 85–100 cm, excluding KE90-282/MILAN…, LOV41/3/EKG15//…, CTK/3/ATL66/… и G-15397-3, with plant height 123–145 cm. A number of entries were selected with large spikes (11.5–12.5 cm): RENAN/MV1 5…, KE90-282/MILAN…, TURDA18.94…, ZCL/3/PGFN//-CN067…, PRINIA/STAR…, G-15397-3, G-16459/1. Most of the varieties had a high number of grains per spike (48–66), although entries G-16408-1, MK-4365, Vorona/HD2402, KE90-282/MILAN… had 72–75 grains per spike. The weight of grain per spike varied from 2.0 to 3.8 g.

The 1000-grain weight (TGW) reflected growing conditions. In NPCZR, TGW varied from 36.3 to 53 g. In the conditions elsewhere, TGW varied broadly: 27.8–49.6 g at Otar and 38.4–54.4 g at Narynkol. The best level of productivity of plant and TGW was at SRIPP (Narynkol) in entries Ugur, Mirbashir 128, Vlasta, LC 924/Petja, Brea, SG-Ru 24, Saskia, Boka, Mambo, MV0596, GK Raba, Steklovidnaya 24, Karlygash, Arap and Agri/Nac/Attila. Data analysis of productivity per plant in two locations has shown that at experimental station Red Falls the entries BOKA, Naz, KIZILTAN, LOV41/3/EKG15//.., SKAUZ/4/… and CRR/ATTILA were the highest yielding. At SRAI, Otar, most productivity was observed in breeding lines

PI/MZ//CNO67/3/LFN/4/ANT/5/ATTILA, 1D13.1/MLT//KAUZ, BREA, Mirbashir 128, BOKA, Naz, and CRR/ATTILA.

The 35 entries selected combined high yield in most productivity traits with resistance to species of rust. Data of the evaluation of this material to yellow rust conducted in 5 locations is shown in Table 3. These lines had high to moderate resistance to both *Puccinia striiformis* West. and *Puccinia recondita* Desm. There was strong development of leaf rust in 2005 at NPCZR, Almalybak, and Red Falls station. Stable high and average resistance level of development for both species of rust was shown in entries LC924/PETJA, VLASTA, Naz, PASTOR/3/…, KE90-282/MILAN, AGRI/NAC//ATTILA, PI/MZ//CNO67..., T 53-97 TURDA, LOV41/3/EKG15…, ZCL/3/PGFN//…, MUNIA/PICUS, 1D13.1/MLT//KAUZ, VORONA/ATTILA//…, PRINIA/STAR, SKAUZ/4/…, CTK/3/ATL66/…, 11/155, CRR/ATTILA and Knyazhna.

Genotypes highly resistant to stem rust were BREA, Mtskhetskaya 1/65,Renan/MV15, Pastor/3/…, KE90-282/MILAN, Agri/NAC/ATTILA, TURDA 2000, T 53-97 TURDA and others. Susceptible reactions to *Puccinia graminis* f.sp. *tritici* were observed in entries Mirbashir 128, LC924/PETJA, G-15123-7, G-16459/1, G-16439/3 and G-16408/1. A total of 21 genotypes were characterized as resistant, but most lines studied were moderate susceptible.

Conclusions

- More harmful North American races of *P. striiformis* for germplasm from Central Asia were *Pst*-17 and *Pst*-100. Cultivars Taza, Krasn. 25, and Ulugbek 600 have seedling resistance.
- The most effective resistant sources against stripe rust in the region were genes *Yr2+*, *Yr4+*, *Yr5*, *Yr10* and *Yr15*, which demonstrated R-MR infection types.
- Among the USA differentials, cultivars that were resistant to both yellow rust and leaf rust included Paha, Druchamp, Riebesel 47/51, Lee, Tres, Express, Clement, Heines VII and Hybrid 46. Virulences to resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8* and *Yr9* have occurred. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* are the races virulent to these genes.
- 35 advanced high yielding genotypes having a moderate to high level of resistance to the major diseases across environments were selected. From hybrid populations, 100–120 advanced lines across all locations were selected. In 2005–2006 this breeding material was being tested at 4 locations

Table 3. Resistance to yellow rust in selected wheat entries

Entries	NPCZR	Otar	Naryn-kol	Red Fall	MIS-Kyrg
Mirbashir 128	10MS	10MS	10MR	0	5R
LC924/PETJA	0	0	10MR	0	0
VLASTA	0	0	5R	0	5R
BREA	0	0	20MS	0	5R
BOKA	0	0	5R	0	0
Mtskhetskaya 1/65	0	0	10MR	0	0
RENAN/MV1 5	5MR	0	0	0	0
Naz	0	0	5MR	0	5MR
PASTOR/3/KAUZ*2/OPATA//KAUZ	0	0	0	0	0
KE90-282/MILAN	0	0	5R	0	0
AGRI/NAC//ATTILA	5MS	0	R	0	0
PI/MZ//CNO67/3/LFN/4/ANT/5/ATTILA	0	0	5R	0	0
TURDA18.94	0	0	5R	0	0
TURDA 2000	0	0	5R	0	0
T 53-97 TURDA	5R	0	5R	0	0
KIZILTAN	5MR	0	5R	0	10MR
LOV41/3/EKG15//TAST/SPRW/4/ES84.24	0	0	0	0	0
ZCL/3/PGFN//CN067/SO(ES86-8)/4/ SERI /5/UA-2837	0	5R	0	0	0
MUNIA/PICUS	0	0	0	0	0
1D13.1/MLT//KAUZ	0	5R	0	0	5R
PRINIA/STAR	0	0	5R	0	0
KE90-282/MILAN-1	0	0	5R	0	0
49	0	0	20MS	0	10MS
VORONA/ATTILA//HATUSHA	10MR	0	5R	0	0
SKAUZ/4/TJB916.46/CB306//2*MHB/3/BUC	0	0	5MR	0	0
CTK/3/ATL66/CMN//TX2 607-6/4/SS8/ LLFN/3/BEZ/ NAD//KZM74/BB//CC/ CNO*2/3/TOP156/BB/5/GUN91	0	0	0	0	0
G-15123-7	0	0	0	0	0
G-15397-3	0	0	5R	0	0
11/155	0	0	0	0	0
CRR/ATTILA	0	0	0	0	0
MK 4364	0	10MS	0	0	0
Knyazhna	0	0	5R	0	0
G-16459/1	5MR	0	0	0	0
G-16439/3	20S	20S	5R	0	10MS
G-16408/1	0	20S	5R	0	0

References

Chen, X.M. 2005. Epidemiology and control of stripe rust (*Puccinia striiformis* f.sp. *tritici*) on wheat. *Canadian Journal of Plant Pathology*, 27: 314–337.

Chen, X.M. & Line, R.F. 1992. Identification of stripe rust resistance genes in wheat genotypes used to differentiate North American races of *Puccinia striiformis*. *Phytopathology*, 82: 1428–1434.

Johnson, R. & Bimb, H.P. 1997. Breeding resistance to yellow (stripe) rust in wheat. CIMMYT Wheat Special Report (WPSR), No. 41. 20 p.

Kumar, J., Singh, R.P., Nagarajan, S. & Sharma, A.K. 1999. Further evidences on the usefulness of Lr34/*Yr18* gene in developing adult plant rust resistant wheat genotypes. *Wheat Information Service*, 89: 23–29.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia.

Monitoring bread wheat genotypes for their resistance to yellow rust in Ethiopia (1995–2005)

Melak Degefu,[1] Temesgen Kebede,[1] Naod Betesilasse,[1] Ayele Badebo[3] and Kebede Tadesse[2]

1. Ethiopian Institute of Agricultural Research, Kulumsa Research Centre, Asella, Ethiopia
2. Oromia Agricultural Research Institute, Sinana Research Centre, Bale Robe, Ethiopia
3. Ethiopian Institute of Agricultural Research, Debre Ziet Research Centre, Ethiopia

Abstract

Yellow rust of wheat (*Triticum aestivum* L.) caused by *Puccinia striiformis* f.sp *tritici* is one of the most important biotic factors affecting the production of this crop in the highlands of Ethiopia. An Ethiopian Wheat Rust Trap Nursery that consisted of commercial cultivars and advanced lines of bread wheat was tested at 12 locations in Ethiopia from 1995 to 2005. However, only six locations at which yellow rust occurred each year are considered in this paper. The objective of this experiment was to monitor the resistance of commercial cultivars and promising genotypes of bread wheat against yellow rust populations in the country. The results indicated that Ethiopian bread wheat genotypes, such as K6295-4A, ET13-A2, Pavon-76, Enkoy, Mitikie, Tusie, Tura, Simba, Sirbo and KBG-01, were moderately susceptible with low severity to the yellow rust population in Ethiopia. Similarly, Kenyan cultivars such as Kenya-Leopard, Africa-Mayo, Bonny and Kenya-Plume showed moderately resistant to moderately susceptible reactions, with low severity to yellow rust. Advanced lines of bread wheat used as supplemental yellow rust differential lines, such as KVZ/7C, HAR 421, HAR 723, HAR 727, HAR 1349, HAR 729, HAR 934, HAR 1038 and HAR 820, also remained resistant to yellow rust compared with the susceptible check. This experiment showed that most of the commercial bread wheat cultivars released during 1997 later became susceptible to yellow rust shortly after the year of release. As a result, yellow rust remained one of the most important challenging factors to bread wheat production in Ethiopia. Relatively old bread wheat cultivars originating from Kenya, however, demonstrated durable resistance in Ethiopia. Most of these cultivars are considered to have slow-rusting or a quantitative type of

resistance to the yellow rust populations in Ethiopia, which requires further confirmation through greenhouse studies. To sustain wheat production in the region, particularly in Ethiopia, monitoring of races and inventorying of resistance genes are of prime importance.

Introduction

Yellow rust caused by *Puccinia striiformis* f.sp *tritici* is an important disease of wheat in the highlands of East Africa (Ethiopia, Kenya, Uganda and Tanzania) and in Yemen. The different planting dates in different agro-ecological zones and the presence of volunteers in wheat fields provide continuous sources of inoculum within or between countries in the area (Bonthuis, 1985). Due to similarities in the distribution of cereal rust races among the East African countries, a common epidemiological zone has been proposed (Saari and Prescott, 1985; Stubbs, 1988). Rust spores are carried by wind among East African countries, and it could even extend to West Asia (Dubin and Rajaram, 1996). Similarity of races had often been reported from East Africa (Danial, 1994) and the West Asian countries (Hakim and Mamluk, 1996). For instance, the yellow rust virulence for the CIMMYT-originated bread wheat cv. Attila 'S' was detected in Uganda some time before it appeared in Ethiopia in 1998. Yield losses due to yellow rust could be 58 to 96% depending on the susceptibility of the cultivars and environmental conditions (Eshetu, 1985).

A number of cultivars have been released in Ethiopia for use by farmers. However, the cultivars become susceptible soon after release. There are also cases where advanced lines became susceptible before their release. Therefore, knowledge of effective resistance genes in the country and region would enable breeders to target those useful genes in their breeding programmes, with the hope of avoiding rust epidemics and subsequent crop losses in the future. Hence, the resistance of commercial cultivars and advanced lines of bread wheat must be monitored regularly to determine their effectiveness against the existing yellow rust pathotypes. The objective of this study was to monitor the resistance of commercial cultivars and promising genotypes of bread wheat against the prevailing yellow rust population.

Materials and methods

An Ethiopian Wheat Rust Trap Nursery that consisted of commercial cultivars and advanced lines of bread wheat (Tables 1 and 2) was tested at 12 locations in Ethiopia during the main season of 1995–2005. However, only six locations at which yellow rust occurred each year are considered in this study. The locations considered hot-spots for yellow rust were Kulumsa, Asasa, Bekoji, Meraro, Arsi Robe and Sinana. The locations range in altitude from 2200 to

3000 masl. Susceptible check cv. Morocco was included in every 20 entries. The entries were planted as two 1-m long rows, with fertilizer and other inputs applied as per the recommendations for each location.

Rust scores were assessed using the modified Cobb scale of Peterson, Campbell and Hannah (1948) twice during the growing season. The data scored in each location was summarized and the highest score across location was taken for that specific year.

Table1. Cross or pedigree of old and current Ethiopian and Kenyan bread wheat cultivars in the study

Variety	Year	Cross/Pedigree	Variety	Year	Cross/Pedigree
Lakech	1970	PJ62/GB55	Shinna	1999	GOV9AZ//MUS"S"/3/R37/GHL121//KAL/BB/4/ANI"S"
Dereselign	1974		Wetera	2000	MON"S"/VEE"S"//SARA
Enkoy	1974	(HEBRARD SEL/ WIS245 XSUP51)×(FR-FNM)	Hawi	2000	CHIL/PRL
K6290 bulk	1977	AF.MAYO × ROMANY	Simba	2000	PRINIA
K6295-4A	1980	K6295-4A	Dodota	2001	BJY/COC//PRL/BOW
ET-13 A2	1981	UQ105 Sel × ENKOY	Sirbo	2001	MILAN
Pavon 76	1982	VCM/CNO "S"/7C/3/KAL/BB	KBG-01	2001	(300/SM+501M)/HAR 1709
Dashen	1984	VEE 17 KUZ-BUHO "S" × KAL-BB	Bobicho	2001	BURRION
HAR 407	1987	VEE#5,KUZ-BUHO"S" × KAL-BB	Kenya Nyangumi		
HAR 416	1987	BOW28,AU x KAL-BB/WOP"S"	Kenya Leopard	1966	Lagagedinho/3*Kenya 381p//CI 12632/3*354p
Mitike	1993	FSYR20.6/87 BOW28 × RBC (ET1297)	Africa Mayo	1960	Africa/Mayo 48
Wabe	1994	MRL"S"-BUC"S"	Trophy	1968	Timstein/2*Kenya//Yaqui 50
Kubsa	1994	Attila	Bounty	1967	Timstein/Kenya 582//2*Bonza
Galama	1995	4777(2)//FKN/GB/3/PVN"S"	Bonny	1967	Yaqui 53/2*Bonza
Tusie	1997	Cook/VEE"S"//DOVE"S"/SERI	Frontach	1963	Frontana/K58//Newthatch
Abola	1997	BOW"S"/BUC"S"	Kenya Kudu	1966	Kenya 131/Kenya 148p
Magal	1997	F3.71/TRM//BUC"S"/3/Lira"S"	Kenya Plume	1965	Mida/McMurachy//Exchange/3/Kenya 184p
Katar	1999	Cook/VEE"S"//DOVE"S"/SERI/3/BIY"S"/COC	Shinna	1999	GOV9AZ//MUS"S"/3/R37/GHL121//KAL/BB/4/ANI"S"
Tura	1999	ARO YR SEL. 60/89	Wetera	2000	MON"S"/VEE"S"//SARA

NOTES: Year is release year.

Table 2. Cross or pedigree of some CIMMYT advanced lines used as supplemental yellow rust differentials in the nursery

Line	Cross or pedigree
KVZ/7C	
HAR 719	LIRA" S"
HAR 727	Peg "S"
HAR 720	Carpento OR Carp
HAR 627	BOW 74 , AV × KAL - BB/ WOP"S"
HAR 1331	L2266-1406 101 × BUC "S" / VPM-MOP 83.11.48 × NAC
HAR 1349	KIME #23/4/CN067/1C//KAL/BB/3/PCI"S"/S/BOW"S"
HAR 729	
HAR 1003	ZD"S"/PATO(B)//CHRC"S"/3/ALDAN"S"/B/T"S"
HAR 421	BOW 74
HAR 723	CHILERO, (4777(2)XFKN-GB/VER"S") BUS"S'-PVN"S"
HAR 934	TIJ 788.1039/PVN76
HAR 1018	2109.36/VEE"S"/4/WRM//RAL/BB/3/KAL/BB//ALO"S"
HAR 1038	KVZ/3/TOB/CTFN//BB/4/B/BW"S"/S/TSH"S"
HAR 743	BOW"S"-VEE"S"
HAR 733	
HAR 820	(4777(2) × FKN -GB/VEE"-PVN"S"
HAR 845	MYNA"S"-VUL"S"

Results and discussion

Although the Ethiopian Wheat Rust Trap Nursery was tested at 12 locations in Ethiopia, only at six locations did yellow rust epidemics occur every year, namely Meraro, Bekoji, Sinana, Arsi Robe and Kulumsa. Hence the conclusions of this experiment depend on the data from only these locations. Table 3 indicates the reaction to yellow rust of commercial cultivars released from 1970–1997. The results indicate that commercial cultivars originating from Kenya, such as Enkoy and K62954-A, and the Ethiopian cultivar ET-13A2 have been moderately susceptible to yellow rust, with low severity until 2001. K62954-A and ET-13A2 have been grown for more than two decades and are still widely grown by large-scale state farms and small-scale subsistence farmers.

Pavon 76, which is believed to have the *Sr2* gene complex, has also been moderately susceptible to yellow rust, with low severity until 2000. However, the severity of yellow rust increased in 2001 and 2002. This cultivar is also believed to have partial resistance to yellow rust. At the same time, cultivars recently released, such as Wabe, Kubsa, Abola and Magal, are becoming susceptible to yellow rust.

Table3. Disease severity and reaction of commercial cultivars to yellow rust at six locations in Ethiopia

Variety	Released	1995	1996	1997	1998	1999
Lakech	1970	50S	70S	60MS	50MS	60S
Dereselign	1974	40MS	60S	60MS	70S	70MS
Enkoy	1974	15MS	Tr-MS	—	—	15MS
K6290 BULK	1977	40MS	30MS	30MS	50MS	60MS
K6295-4A	1980	30S	20MS	25MS	20MS	40S
ET-13-A2	1981	10MS	20MR	15MS	10MS	30MS
Pavon 76	1982	30MS	40MS	30MS	40MS	25MS
Dashen	1984	1MS	20MS	50MS	40S	70MS
HAR 407	1987	0	10MS	40MS	20MS	60MS
HAR 416	1987	Tr-MR	10MS	0	10MS	10MS
Mitike	1993	15MS	Tr-MS	20MS	10MS	20MS
Wabe	1994	Tr-R	10MR-R	5R-MR	60S	75S
Kubsa	1994	0	Tr-MR	0	10MS	20S
Galama	1995	4MS	0	Tr-MS	1MS	Tr-MR
Tusie	1997	0	Tr-MS	10MS	30MS	20MS
Abola	1997	20MS	10MS	5MS	25S	40S
Magal	1997	0	5MS	5MS	15MS	—
Morocco (check)		100S	100S	100S	100S	100S
Lakech	1970	60S	100S	100S	70S	80S
Dereselign	1974	60S	100S	100S	30S	80S
Enkoy	1974	25MS	15S	50MS	50MS	15MS
K6290 BULK	1977	40S	95S	90S	45S	50S
K6295-4A	1980	25MS	30MS	50MS	40MS	40S
ET-1- A2	1981	40S	40MS	50MS	50MS	60S
Pavon 76	1982	30MS	95S	90S	40S	80S
Dashen	1984	40S	80S	70S	60S	80S
HAR 407	1987	15MS	20MS	—	30MS	25S
HAR 416	1987	10MR	15MS	40MS	30S	25S
Mitike	1993	10MS	40S	40S	40MS	40S
Wabe	1994	30MS	60S	80S	45S	80S
Kubsa	1994	30MS	70MS	100S	70S	80S
Galama	1995	0	40MS	50MS	40S	25S
Tusie	1997	10MS	60MS	30MS	30S	25MS
Abola	1997	30MS	70S	50S	70S	60S
Magal	1997	20MS	-	60S	70S	50S
Morocco (check)		100S	100S	100S	100S	100S

Table 4. Disease severity and reaction of Ethiopian cultivars to yellow rust at six locations in Ethiopia

Genotype	Released	2000	2001	2002	2003	2004	2005
Katar	1999	40MS	80S	100S	60S	60S	80S
Tura	1999	10MS	20MS	30MS	45S-MS	10S	20S
Shinna	1999	30S	80MS	90S	80S	70S	100S
Wetera	2000	15MS	50MS	90MS	80S	40S	60S
Hawi	2000	15MS	40S	40MS	15S	25S	20MS
Simba	2000	Tr-MS	—	10MR	5MS	10S	20MS
Dodota	2001	—	50MS	90MS	60S	60S	80S
Sirbo	2001	—	10S	5S	10S	15S	5MS
KBG-01	2001	—	20MS	40MS	40S-MS	Tr-MS	30S
Bobicho	2001	—	—	30MS	70MS-S	30S	20S
Morocco (check)		100S	100S	100S	100S	100S	100S

Table 4 shows the reactions of cultivars released during 1999–2001, such as Katar, Shinna, Wetera, Dodota and Bobicho, which were becoming susceptible shortly after release. Shinna was released for the northern part of Ethiopia, which is believed to have low levels of rust epidemics compared with central and south-eastern Ethiopia, where rust epidemics occur from time to time. However, cv. Shinna was widely adopted by the wheat growers in south-eastern Ethiopia and became susceptible immediately after its release. Cv. Dodota was tested in moisture-stress areas and released for lowland areas in which yellow rust is not prevalent. Unfortunately, it was adopted by the farmers in the highland areas and as a result became susceptible to yellow rust. In contrast, cultivars such as Simba, Sirbo and KBG-01 were resistant to yellow rust populations in the country.

Tables 5A and 5B shows the reaction of Kenyan cultivars to yellow rust. Cvs Kenya Leopard, Africa Mayo, Bonny and Kenya Plume showed moderately resistant to moderately susceptible reactions to yellow rust populations in Ethiopia. As reported by Danial (1994) and Danial and Stubbs (1992), these cultivars have shown a high level of resistance to yellow rust populations in Kenya over the periods 1976–79 and 1986–91 and the incomplete resistances of these cultivars have lasted 20 to 30 years in Kenya. The resistance of these cultivars to yellow rust populations in Ethiopia for 7 years may also confirm durability of the resistance of these cultivars. Such resistance has been reported in many parts of the world. However, from 2003 these genotypes have been attacked by yellow rust, but with relatively low severity. In addition to yellow rust resistance, Kenyan genotypes Kenya Leopard, Bonny and Kenya Plume have also been resistant to stem rust populations in Ethiopia. Such cultivars with durable resistance to yellow rust can be utilized in a breeding programme

with great effect, particularly in areas in which race-specific resistance is rapidly overcome by the pathogen.

As indicated in Tables 6A and 6B, the CIMMYT advanced lines used as supplemental differentials, namely KVZ/7C, HAR 727, HAR 1349, HAR 729, HAR 421, HAR 723, HAR 934, HAR 1038 and HAR 820, showed moderately susceptible to susceptible reactions with low severity compared with the susceptible check. However, KVZ/7C, HAR 727, HAR 729, HAR 421, HAR 723, HAR 934 and HAR 820 have been only resistant to stem rust population in Ethiopia. Similar to this field study, a seedling study by Ayele *et al.* (1990) showed that these cultivars were resistant to most of the yellow rust isolates tested. Hence these cultivars could also be used in a breeding programme.

Table 5A. Disease severity and reaction of Kenyan cultivars to yellow rust at six locations in Ethiopia, 1997–2000

Variety	Year of release	1997	1998	1999	2000
Kenya Nyangumi	—	—	40MS	30S	40MS
Kenya Leopard	1966	15MS	30MS	15MS	5MR
Africa Mayo	1960	0	5MS	5MS	5MS
Trophy	1968	30MS	70MS	40MS	30MS
Bounty	1967	10MS	50MS	30MS	20MS
Bonny	1967	10MS	10MS	20MS	10MR
Frontach	1963	10MS	40MS	40S	30MR
Kenya Kudu	1966	20MS	20MS	40S	30MR
Kenya Plume	1965	0	Tr-MS	5MR	0
Morocco (check)	1966	100S	100S	100S	100S

Table 5B. Disease severity and reaction of Kenyan cultivars to yellow rust at six locations in Ethiopia, 2001–2005

Cultivar	Year of release	2001	2002	2003	2004	2005
Kenya Nyangumi	—	60MS	100S	80S	50S	80S
Kenya Leopard	1966	20MS	25S	40MS	25S	50S
Africa Mayo	1960	5S	30MS	5MS	10MS	40S
Trophy	1968	60S	40MS	40MS-S	30S	80S
Bounty	1967	80S	40MS	25S	30S	80S
Bonny	1967	20MS	25MS	5MS	20S	50S
Frontach	1963	80S	90MS	30S	50S	80S
Kenya Kudu	1966	80S	90MS	15MS	30S	70S
Kenya Plume	1965	5MS	20MR	5MR	10MS	30S
Morocco (check)	1966	100S	100S	100S	100S	100S

Table 6A. Disease severity and reaction of advanced lines to yellow rust at six locations in Ethiopia, 1995–1999

Line	1995	1996	1997	1998	1999
KVZ/7C	5MS	Tr-MR	0	5MS-MR	5MS
HAR 719	0	Tr-MS	0	10MS	10MS
HAR 727	0	5MR	0	5MS	10MR
HAR 720	0	0	0	5MR	Tr-MS
HAR 627	Tr-MS	Tr-MS	90S	100S	10MS
HAR 1331	0	Tr-MR	0	10MS	5S
HAR 1349	0	Tr-MR	Tr-MR	5MS	—
HAR 729	Tr-MS	Tr-MS	10MS	20S	30MS
HAR 1003	5MS	20MS	20MS	25MS	30MS
HAR 421	Tr-R	5S	0	Tr-MS	10S
HAR 723	Tr-R	5S	0	Tr-MS	10S
HAR 934	0	5MS	5MS	20MS	30S
HAR 1018	0	—	—	—	40S
HAR 1038	0	0	0	Tr-MS	Tr-MR
HAR 743	Tr-MS	20MS	10MS	5MS	10MS
HAR 733	0	0	10MS	5MS	20MS
HAR 820	0	5MS	0	0	Tr-MR
HAR 845	0	0	0	5MS	80S
Morocco (check)	100S	100S	100S	100S	100S

Table 6B. Disease severity and reaction of advanced lines to yellow rust at six locations in Ethiopia, 2000–2004

Line	2000	2001	2002	2003	2004
KVZ/7C	Tr-MS	15MR	20MS	15S	20S
HAR 719	10MS	20MS	50S	50S	80S
HAR 727	5MS	15MS	15MS	15S	15S
HAR 720	Tr-MS	40MS	50S	50S	40S
HAR 627	5MS	15MS	30MS	30MS	10MS
HAR 1331	0	10MR	15MS	10MS	25S
HAR 1349	–	–	–	40MS	10S
HAR 729	10MS	20S	30MS	40S	–
HAR 1003	30MS	40S	60MS	70S	30S
HAR 421	5MS	30MS	20MS	10S	20S
HAR 723	5MS	15MS	20MS	10S	20S
HAR 934	20MS	40S	30MS	30S	20S
HAR 1018	10MS	60S	20S	30S	20S
HAR 1038	Tr-MS	10S	5S	30MS	20S
HAR 743	15MS	40MS	50MS	60S	40S
HAR 733	10MS	40MS	70S	70S	40S
HAR 820	5MS	40S	20S	10S	15S
HAR 845	5MS	70MS	30MR	10S	20MS
Morocco (check)	100S	100S	100S	100S	100S

Conclusion

Relatively old bread wheat cultivars of Ethiopia originating from Kenya, Kenyan cultivars and CIMMYT advanced lined used as supplemental yellow rust differentials demonstrated durable resistance in Ethiopia. However, it can be concluded that most of the commercial cultivars released during 1997 became susceptible to yellow rust shortly after release. The recurrent outbreaks of yellow rust disease could be due to a combination of lack of information about recent developments of the pathogen races in the region and the continuous release of cultivars with similar parentage. Future breeding programmes should involve the exploitation of genes present in the cultivars that have proven to have a quantitative type of resistance. To sustain wheat production in the region in general, and particularly in Ethiopia, monitoring of races and inventorying of resistance genes are of prime importance.

References

Ayele Bedebo, Stubbs, R.W. van Ginkel, M & Getinet Gebeyehu. 1990. Identification of resistance genes to *Puccinia striiformis* in seedlings of Ethiopia and CIMMYT bread wheat varieties and lines. *Netherlands Journal of Plant Pathology*, 96: 199–210.

Bonthuis, H. 1985. Survival of stripe [yellow] rust (*Puccinia striiformis*) on wheat in the Kenyan highlands and the consequences for virulence. *Mededelingen Faculteit Landbouwwe-tenschappen Rijks Universiteit Gent*, 50(3b): 1109–1117.

Danial, D.L. & Stubbs, R.W. 1992. Virulence of yellow rust races and types of resistance in wheat cultivars in Kenya. pp. 165–175, *in:* D.G. Tanner and W. Mwangi (editors). 7th Regional Wheat Workshop for Eastern, Central and Southern Africa.

Danial, D.L. 1994. Aspects of durable resistance in wheat to yellow rust. PhD thesis. Wageningen Agricultural University, The Netherlands. 143 p.

Dubin, H.J. & Rajaram, S. 1996. Breeding disease-resistant wheat for tropical highlands and lowlands. *Annual Review of Phytopathology,* 34: 503–526.

Eshetu Bekele. 1985. A review of research on diseases of barley, tef and wheat in Ethiopia. pp. 79–108, *in* Tsedeke Abate (editor). *A Review of Crop Protection Research in Ethiopia.* IAR, Addis Ababa, Ethiopia.

Hakim, M.S. & Mamluk, O.F. 1996. Virulences of wheat yellow rust pathogen in Syria and Lebanon. p. 141, *in:* Proc. of 9th European and Mediterranean Cereal Rust and Powdery Mildew Conference, 2–6 September 1996, Lunteren, The Netherlands.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. *Canadian Journal of Research,* 26c(5): 496–500.

Saari, E.E. & Prescott, J.M. 1985. World distribution in relation to economic losses. pp. 259–298, in: A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts,* Vol. II. *Diseases, Distribution, Epidemiology and Control.* Academic Press, Orlando, USA.

Stubbs, R.W. 1988. Pathogenicity analysis of yellow (stripe) rust of wheat and its significance in a global context. pp. 23–38, *in:* N.W. Simmonds and S. Rajaram (editors). *Breeding strategies for resistance to the rusts of wheat.* CIMMYT, Mexico.

Abstracts
of other papers presented at the
Third Regional Conference on Yellow Rust in
the Central and West Asia and North Africa (CWANA) Region

Tashkent, Uzbekistan
8–11 June 2006

Global perspectives in wheat yellow rust: meeting the challenges of dynamic shifts in pathogen populations

C.R. Wellings[1] and R.F. Park[1, 2]

1. The University of Sydney, Plant Breeding Institute, Cobbitty, Australia;
2. Seconded from NSW Department of Primary Industry

There have been several notable movements in the global *Puccinia striiformis* pathogen population over the past decade. The sequential appearance of *Yr9* virulent pathotypes over a 10-year period from the Horn of Africa, through the Nile Valley and West Asia, and eventually to Central and South Asia, resulted in epidemics that caused serious yield losses in popular cultivars that have carried the corresponding *Yr9* resistance gene. More recent pandemics in China (2002), North America (from 2000) and Australia (from 2002) have been the result of the evolution of new pathotypes or the migration of pathotypes to new areas. Despite the commitment and success of breeding programmes to achieve resistance to local pathotypes, severe epidemics and crop losses in the USA and Australia have served to highlight the vulnerability of wheat varieties to foreign incursions of new pathotypes. Meeting the immediate challenge of unforeseen epidemics has frequently meant the use of fungicide strategies, especially in the short term. The expense of fungicides has traditionally precluded their widespread use in stripe [yellow] rust control, although the expiry of patent coverage for some active chemicals has meant that certain materials, such as triademefon, are now produced as generic products at significantly reduced cost to the farmer. This has caused many crop protection specialists to re-think their approach to employing strategic fungicide applications, especially in the transition phase while developing and deploying new resistant varieties. Breeding for resistance, and the parallel requirement to monitor pathogen populations, will continue to form the long-term strategy for yellow rust control. Post-release management is also a crucial phase, and the capacity to remove susceptible varieties from cultivation will reduce the opportunity for pathogen survival.

Wheat Rust in Europe

Mogens S. Hovmøller

Department of Integrated Pest Management, Danish Institute of Agricultural Sciences, Flakkebjerg, Slagelse, Denmark

The three cereal rusts—yellow rust, leaf rust and stem rust—are among the most damaging cereal diseases in Europe. Yellow rust is predominant in NW Europe and in coastal areas, whereas leaf rust is more prevalent in Central and Eastern Europe. This is also the area where stem rust may cause damage, although stem rust has not been considered a major problem in the last two decades. The prevalence of leaf and stem rusts in Central and Eastern Europe is probably due to generally warmer summers in these areas. The eradication campaigns of the alternate host of stem rust, *Berberis vulgaris*, have decreased survival of the fungus outside the main wheat growing season, and this may further explain why stem rust epidemics have become less frequent. However, the reduced attention to resistance to stem rust in European plant breeding in the last 30–40 years, and possible effects of warmer weather due to global warming, and warmer and more humid summers, may increase the significance of stem rust in the future.

In many areas in Europe, wheat is grown as a high-input crop, and one to two fungicide treatments are common, in particular in the humid areas where other damaging diseases on wheat, namely powdery mildew and *Septoria tritici*, may be prevalent. However, the increasing costs of agrochemicals and environmental concerns about pesticides may put more emphasis on breeding for disease resistance. In fact, breeding for resistance to the cereal rusts has been successful in the last couple of decades. At present, about half of the wheat area in NW Europe is grown with varieties highly resistant to yellow rust.

Breeding and extension services are supported by annual pathogen and disease surveys in a number of countries, including UK, France, Denmark, Germany, Czech Republic and Hungary, and inoculated disease nurseries, where the most recent and complex pathotypes are used for assessing vulnerability of new breeding lines and commercial varieties, are also carried out in several countries. During the 1990s, collaborative networks to collate data on pathotype frequency dynamics and exchange of wheat germplasm and exposure to 'local' leaf and yellow rust pathotypes were developed. The European and Mediterranean Cereal Rust Foundation established a home page (www.crpmb.org) where news concerning cereal rust research, breeding, surveys, networks and meetings could be accessed.

Yellow rust in Central and West Asia: past experience

Omar F. Mamluk

ICARDA, Aleppo, Syria

Yellow rust, *Puccinia striiformis* f.sp. *tritici*, is a major wheat disease in the cooler and more humid wheat growing areas, and became a major constraint on wheat production in Central and West Asia during the 1990s. Several factors have contributed to the development of severe epiphytotics, including a shift of virulence in the pathogen population. Epiphytotics causing substantial yield losses were observed in Baluchistan, Pakistan, (1991, 1992) on landrace Local White; in Iran (1993, 1995) on cvs Falat (Seri 82), Quds, Navid and Sardari; in Iraq (1995, 1996) on cv. Saber Beek; in Turkey (1991) on cv. Gerek 79; in Syria (1988) on cv. Mexipak; in Lebanon (1993, 1994, 1995) on cvs Seri 82 and Mexipak; in Yemen (1988, 1989, 1993) on cvs Sonalika, Muchtar and Aziz (Seri 82); and in Egypt (1995, 1997) on cv. Gemiza 163. There was no indication of a shift in the virulence pattern of the pathogen, at least in Syria and Lebanon. In 1993/94, new virulence on *Yr9* in the line Fed.4/Kavkas and *Yr9*+ in cv. Clement were detected, and virulence for *Yr*SD in cv. Strubes Dickopf, *Yr6*+ in cv. Heines Peko and *Yr2*+ in cv. Heines VII was observed. Origin and progress of the new virulences remained unknown. Prevailing virulences, up to the 1994/95 season in Syria were: *Yr6*, *Yr7*, *Yr10*, *YrSD*, *YrSU*, *Yr9*+, *Yr6*+, *Yr7*+, *Yr8*, *Yr2*+, *YrA* and *Yr9*. Prevailing virulences in Lebanon were *Yr6*, *Yr7*, *YrSD*, *Yr9*+, *Yr6*+, *Yr7*+, *Yr2*+, *Yr8*, *Yr*A and *Yr9*. Data from the two seasons, 1993/94 and 1994/95, indicated that the number of virulence genes per race and range in virulence factors in the yellow rust pathogen population have increased considerably in Syria and Lebanon. Bread wheat cvs were mostly affected during the years of epiphytotics. It was assumed that the yellow rust population developed and multiplied on the widely grown bread wheats. The host-preference phenomenon has been investigated in the greenhouse in a passage-effect test of the pathogen over bread wheat, durum wheat and *Aegilops* spp. Excluding the differences in the genetic background of bread wheat and durum wheat, our results indicated that a type of host-preference for yellow rust towards bread wheat does exist. It is anticipated that the presence of the D-genome and the passage-effect through the same host over time, has led to adaptation of the pathogen to successfully infect bread wheat.

Emergence of *Yr*27-virulences of wheat stripe [yellow] rust in India

M. Prashar, S. C. Bhardwaj and B. Mishra
DWR Regional Station, Flowerdale, Shimla-171002 (HP), India

Stripe (yellow) rust caused by *Puccinia striiformis* f.sp. *tritici* is most prevalent in cooler parts of the world, such as North America, Europe, Australia, Asia and Africa. Cultivating susceptible varieties can lead to heavy yield losses, assessed at US$ 27 million in 2000 in the USA. In India, this rust is important in the NWPZ and Northern Hills regions of the country. These zones contribute about 40% of total national wheat production. Growing varieties susceptible to stripe [yellow] rust in this zone would result in yield loss, thereby threatening the food security of the country. Therefore, it is imperative that this zone be regularly monitored for pathogenic changes and that the crop be diversified for increased rust resistance.

The wheat rust laboratory in Shimla monitors new variation from farmers' fields. This information is then shared with wheat workers in the country, thereby providing support for rust resistance breeding. Since the introgression of the 1B/1R translocation in wheat, the varieties bearing this translocation are becoming widely prevalent due to increased yield advantage. During a routine survey in 1996, a rust-infected sample from Punjab (NWPZ), India, yielded a pathotype virulent on *Yr27* and *Yr9*. This pathotype threatened the cultivation of varieties with and without this translocation, such as HS240 (Veery#5), UP2338 and HD2329. It spread very quickly in both zones. Just before it could attain damaging levels, PBW 343 (Attila) proved resistant to this pathotypes and was released in 1996 and remained resistant for a long time.

This cultivar became predominant very quickly and cultivation spread to more than 6 million hectare, forming an extensive monoculture. This facilitated selection of an isolate virulent on this variety, which was picked up in pathogenicity surveys during 2001. It had combined virulence for both *Yr9* and *Yr27*. Further monitoring of this pathotype has revealed that it either did not multiply in nature and was not picked up in nature or remained below threshold level of detection until 2004, when it was identified in only a few samples. However, populations of this pathotype had built up by 2006 and were identified in many samples from these zones. In order to keep pace with the ever-evolving pathogen of wheat rusts there is a strong need to fortify cultivar resistance. To address such a threat, we have developed some genetic stocks: Flw13 (WH542/*Yr15*) and Flw14 (UP2338/CD) in the background of predominant cultivars like PBW 343, UP2338 and WH542. These genetic stocks are now being used by wheat breeders to incorporate resistance against these virulences.

Outputs of the ten-year evaluation of IWWIP germplasm for yellow rust (*Puccinia Striiformis* f.sp. *tritici*) resistance in Turkey

L. Çetin,[1] F. Düşünceli,[1] S. Albustan,[1] Z. Mert,[1] K. Akan,[1] H.J. Braun,[2] A. Morgounov,[2] A. Hede,[2] B. Akın,[2] A. Yahyaoui[3] and S.P.S. Beniwal[2]

1. The Central Research Institute for Field Crops, Ulus, Ankara, Turkey; 2. CIMMYT-Turkey, Ankara, Turkey; 3. ICARDA, Aleppo, Syria

Yellow rust (*Puccinia striiformis* f.sp. *tritici*) is among the most widely occurring diseases of wheat. Due to its air-borne-spread nature and recent epidemics in the last decade it has become a priority disease in many parts of Asia and Africa, as in other continents. Therefore, international collaboration has become vital for management of the disease. In this respect, the International Winter Wheat Improvement Programme (IWWIP) managed by TAGEM (Turkey), CIMMYT and ICARDA, has played an important role for germplasm development for more than 50 countries in the world. This study has been undertaken in order to identify yellow rust-resistant germplasm among the IWWIP nurseries. The study began extensively in the 1994–95 season and has continued until 2005. Field screening tests were carried out at the experimental research facilities of the Central Research Institute for Field Crops (CRIFC) in İkizce-Haymana and Yenimahalle in Ankara, Turkey. Genetic material included crossing blocks, preliminary and advanced nurseries generated within IWWIP for different growing environments, as well as specific germplasm pools of ICARDA and introduced materials from various regions. In the 10-year study, 41 873 entries were evaluated in 219 nurseries. The study started with 967 entries in the 1994/95 season and the number of entries varied between 1805 and 7167 in subsequent years. The nurseries were inoculated with local yellow rust populations using established inoculation methods such as injection, spraying in mineral oil and talc powder. A susceptible genotype was sown after every 10 entries and mist and furrow irrigation was provided to promote disease development. Good disease development was achieved in all 10 years, and this allowed effective identification of resistant genotypes. The proportion of entries showing high and moderate levels of stripe [yellow] rust resistance was 9.2% in 1995, with virulence for *Yr9* recorded for the first time. In subsequent years, the percentage of resistant entries varied between 17.7% and 63.1%. In total, 41.3% of the 41 873 entries tested over the ten years showed moderate or high levels of resistance, indicating a significant improvement for yellow rust resistance in the germplasm. Of the resistant genotypes, 280 have been selected for having long-term yellow rust resistance and good stand in Ankara conditions.

An overview of wheat yellow rust pathotypes (*Puccinia Striiformis* f.sp. *tritici*) in Iran

Farzad Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran.

Yellow [stripe] rust of wheat is one of the most important diseases in Iran. Since 1993, several epidemics have occurred in Iran, caused by the breakdown of widely utilized sources of resistance in wheat cultivars. During the last two years, in greenhouse conditions, 27 pathotypes were determined. Pathotypes 6E6A+, 6E22A+, 6E130A+, 6E134A+ 6E142A+, 6E158A+, 134E130A+ and 134E142A+ were more common during this study. Virulence on plants with gene(s) *Yr2, Yr6, Yr7, Yr8, Yr9, Yr24, Yr25, YrSD, YrSP, Yr3N, Yr2+, Yr6+, Yr9+, Yr7+, Yr32+* and *YrA* were detected under greenhouse conditions. The majority of isolates with high frequency (>88%) were virulent on plants with *Yr2, Yr6, Yr7, Yr9, YrA* and *Yr24* genes. No virulence was detected on plants with *Yr1, Yr3V, Yr4, Yr5, Yr10* and *YrSU*. In the greenhouse, test population virulence to wheat genotypes with *Yr32+, YrSP* and *YrSD* was less than 7%. Virulence to all other wheat genotypes was between 19 and 100%. In three years of study in the field, virulence on cvs Heines Kolben (with genes *Yr2* and *Yr6*), Kalyansona (*Yr2*), Lee (*Yr7*), Avocet R (*YrA*), Federation*4/Kavkaz (*Yr9*) and TP1295 (*Yr25*) was common. No virulence was observed on plants with *Yr1, Yr3V, Yr3N, Yr4, Yr5, Yr8, Yr10, Yr18, Yr24, Yr32+, YrSP, YrSD* and *YrSU* genes in the trap nurseries. The coefficient of infection (CI) of adult plant resistance gene *Yr18* was between 16 and 64, with a moderately susceptible reaction, and it is going to be used in the breeding programme with a combination of resistance sources.

Yellow rust resistance of bread wheat varieties of Eastern Europe in Azerbaijan

M.H. Seidov, A.M. Abdullaev, E.R. Ibrahimov and K.K. Aslanova

RI of Agriculture, Baku, Azerbaijan

Over a decade (1998–2007), bread wheat accessions from ICARDA, CIMMYT and other countries were investigated in different agro-ecological regions of Azerbaijan. Yield and infection levels of fungal yellow rust were studied. Bread wheat varieties of Eastern Europe provided relevant data. Investigations were carried out in Fate Garabaq's irrigated Tarter Regional Experimental Station and Mountainous Shirvan's (Gobustan RES) rainfed area. Following observation, it was shown that in comparison with recognized local wheat varieties Qobustan, Ruzi-84 and Azamatly-95, Eastern European varieties showed 80–90% infection of yellow rust. Some, such as SG-RU 6148, BURBOT-4, AGRI/NAC//KAUZ, EST4-SITTA//AGRI-NAC, W 409/СПН and TAM200/7/85ZHONG 56/8/KS82 were highly resistant to yellow rust. These varieties showed high resistance levels (R-MR) to yellow rust under both irrigated and rainfed conditions. In the mountainous Shirvan region, yellow rust severity on cv. Jagger was very low. This variety showed resistance (MR) to this disease and has been sown in breeding nurseries. Yield of Eastern European varieties was not low in both regions. In rainfed areas, most of these varieties had a yield of 3.0–5.7 h/ha, in some cases 6.2 t/ha. Investigations for several years show that due to the late appearance of yellow rust disease, yield losses were low. In 2003, yellow rust appeared in the Garabaq region at the end of May and in the Shirvan region at the beginning of June. It should be noted that in some varieties with an increased incidence of yellow rust, yield decreased sharply, indicating the potential for yield loss among susceptible varieties. For example, in Qobustan, RES ARLIN-KS89H130, TAM-200-FUNDULLA, KS90WGRC10SIB-RS92WGRC-16, T-53-97TURDA and TAM-107-83WN-55 showed high disease incidence (90-100S), and yields were severely reduced (2.0–2.5 t/ha). Since yellow rust occurrence is very frequent, the cultivation of tolerant varieties should be promoted to minimize crop losses.

Pathotypes and human-guided evolution of *Puccinia striiformis* West. f.sp *tritici* in Pakistan

Munawar Hussain,[1] M.A.S. Kirmani[1] and Ehsan-ul-Haque[2]

1. Crop Disease Research Programme, NARC, Islamabad, Pakistan;
2. Crop Disease Research Programme, Murree, Pakistan

Analysis of yellow [stripe] rust collections during the 1969–1995 crop seasons yielded 46 pathotypes (race groups). Amongst these race groups, 16E16, 66EO, 38E16, 64EO, 66EO, 67EO, and 66E(16) were predominant. These races carry virulence for genes *Yr1*, *Yr7* and Suwon 92×Omar. The local tall genotypes, like C-271, C-273, C-591 and cv. Local White, were susceptible to these races, while extensively cultivated semi-dwarf wheats, e.g. Mexipak 65, Chenab 70, Khushal 69, Barani 70 and SA 42, were resistant. The reduction in acreage under rust-susceptible tall cvs and large-scale cultivation of resistant varieties bred by wheat breeders increased pathogen selection pressure. As a result cvs Mexipak 65 and Chenab 70 succumbed to yellow rust pathotype 66EO in 1973.

The pathotype remained most prevalent during 1973–76, Wheat cvs SA 42, Blue Silver, Lyallpur 73, Yecora, Pari 73 and Sandal 73 showed resistance to this pathotype. Later, with changing varieties during 1977–80, the race pattern also changed, and race groups 6E16, 38E16 and 6(38)E16 were predominant. These pathotypes were responsible for the stripe rust epidemic of 1978. These pathotypes were virulent on YR host genes *Yr2*, *Yr6*, *Yr7*, *Yr8*, *YrA* and Strobes Dickopf. The pathotypes attacked cvs possessing *YrA*, (ArZ, Bahawalpur 79, Chenab 79, Nuri 70), *YrA, Yr6* or *YrA+Yr6* (cvs LU 26, Lyallpur 73, Pari 73, Sandal 73, Yecora, etc.), and cvs carrying *Yr2* (Blue Silver, Sonalika and WL711).

After 1980, a number of wheats with IB/IR translocation carrying *Yr9* singly or in combination with *Yr27* were released. At that time the pathogen population did not carry matching virulence for *Yr9*. By the early 1990s these cvs occupied very large areas in the yellow rust-prone area of Pakistan. As a result of selection pressure exerted by cultivation and release of rust resistant cvs by the breeders, progressive increase in virulence on these cultivars was observed during 1997 and 1998. The pathotype responsible for these epidemics was 134E150. Wheat cvs Pak 81, Kohinoor, Faisalabad 85, Pirsabak 85, Punjab 85, Sutlej 86, Khyber 87, Rawal 87, Rohtas 90, Pasban, Pirsabak 91, Bakhtawar 93 and Kaghan 93 were found susceptible.

It is evident from these studies that the course of evolution of yellow rust is guided by breeders, and races with low virulence have developed into pathotypes with greater virulence.

Influence of weather conditions on yellow rust in Central Asia

M. Koishibaev and M. D. Kurmanov

Research Institute of Plant Protection, Almaty, Kazakhstan

Yellow rust epidemics have become more frequent during the last ten years in the irrigated foothill-steppe zones of south and south-east Kazakhstan. The increase in pathogen presence may be due to the considerable increase in area of wheat production in Tajikistan and Uzbekistan. Analysis of weather conditions in Gissar Valley of Tajikistan showed that the minimum temperature in January is 3–5°C and the pathogen can hibernate on winter wheat shoots as the uredino mycelium stage. In April and May, during wheat heading, precipitation is 120–160 mm. Moreover, not only winter, but also spring and facultative wheats are sown, i.e. their vegetative period is very long. It is also possible that yellow rust infection is carried into Central Asia from East Asia, where facultative wheat is sown predominately. Weather conditions in the foothill and steppe zone of south and south-east Kazakhstan and Kyrgyzstan are favourable for yellow rust development in spring and the beginning of summer. In April, during winter wheat development, air temperature is +10–15°C, precipitation 60–100 mm and humidity 70–75%, and in May, during wheat heading, it is +16–19°C, with 60–90 mm precipitation and 55–70% RH. In July and August, the daily air temperature goes up to +35–40°C and humidity falls to 40–45%. Winter wheat is harvested in July, and is sown in September–October. The preservation of the pathogen in natural conditions during this period is unlikely and infection of wheat shoots in autumn is impossible, because all vegetation is destroyed using field burning. Weather conditions in the mountain zone of Almaty Oblast and Issyk-Kul Valley of Kyrgyzstan is very favourable for yellow rust to hibernate as the uredinio stage on winter wheat. Air temperature in July and August is usually no more than 15–17°C, precipitation in summer is 150–200 mm and humidity 60–75%. Because of the cool and short summer, the harvest period of one crop and emergence of shoots of the next occur at the same time, and rust development in some years can reach 90–100%. Regression analysis showed the dependence of yellow rust development on weather conditions, especially precipitation, humidity and air temperature. High correlation was established between the amount of precipitation and humidity in April and yellow rust development in Kazakhstan and Uzbekistan. In 1999/00, during epiphytotics of this disease, humidity was very high (65–75%) and precipitation was 80–150 mm. In 2001, 2004 and 2005, when there was a low incidence of rust problems, the humidity was low (50–60%) and precipitation was 40–50 mm.

The weather conditions in April and in the first ten days in May were dry, but the precipitation in the second half of May and in June did not lead to disease development. In South Kazakhstan Oblast we observed a high correlation between yellow rust development on winter wheat and weather conditions in May, particularly with humidity (r=0.93±0.18) and precipitation (r=0.76±0.30). In Kyrgyzstan and in Uzbekistan it was weaker (r=0.48-0.76). Negative dependence was observed between rust development and air temperature in April and May.

Wheat stripe [yellow] rust disease in Iran

M.R.J. Kamali and F. Afshari

Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran

Wheat is the most important crop in Iran, grown on more than 6.5 million hectare. Stripe [yellow] rust on wheat caused by the fungus *Puccinia striiformis* f.sp. *tritici* is an important disease in some wheat growing areas of Iran. Economic appraisals of national losses have ranged from $US150 to 180 million due to the 1994 yellow rust epidemic in Iran. The use of resistant cultivars is the most effective, economical and environmentally safe method to control the disease. Extensive research on stripe rust resistance in wheat has been carried out over many years and has resulted in the release of many rust-resistant cultivars to farmers. Adult plant resistance is considered in our breeding programme, which can be defined as resistance that develops during the post-seedling stages. In the breeding programme for rust resistance it is necessary to identify sources of resistance and the number of gene(s) conferring resistance in any cultivar. When resistance is controlled by more than one or two genes, a single mutation in the pathogen cannot break down the resistance in commercial cultivars in a short time. In 1994, wheat yield loss due to the appearance of a new pathotype of stripe rust was estimated at 1 million tonne in Iran. The wide spread of susceptible cultivars in irrigated wheat areas, such as Falat (Seri 82), sown on thousands of hectares for their wide adaptation to abiotic stresses and different rotation systems, is perhaps the major reason for stripe rust outbreaks in Iran in 1993 and 1994. Currently, Chamran (Attila 50Y) is the most widely grown cultivar, grown on more than 500 000 ha in Iran. This cultivar has become susceptible since 2003 with the appearance of a new race, 166E134A+, in Fars Province. The monitoring of yellow rust pathotypes and their change over time to guide pyramiding of resistance genes from different genetic backgrounds are important considerations in the wheat breeding programme in Iran.

Virulent pathotypes of yellow rust and effective *Yr* genes in south Kazakhstan

Rsaliyev Shynbolat

Scientific Research Agricultural Institute (SRAI), Gvardeiskiy, Kazakhstan

The structure of the yellow rust population in Kazakhstan has been studied by SRAI from 1970. Analysis of yellow rust samples taken from wheat crops, from experimental plots of collected varieties as well as from wild grasses in the southern and south-eastern regions of Kazakhstan allow determination of the various races of this fungus. Until 2000, six pathotypes were the most prevalent races on susceptible winter wheat varieties. When virulence of yellow rust races was assessed by use of isogenic *Yr*-lines, Kazakhstan races of yellow rust appeared to have the following virulence formulations (resistant/susceptible): 7E150 (N) – *Yr3*, 4, 5, 9, 10 / *Yr1*, 2, 6, 7, 8; 7E156 (X_1) – *Yr3*, 4, 5, 8, 9, 10 / *Yr1*, 2, 6, 7; 7E158 (31, a–8) –*Yr3*, 4, 5, 8, 9, 10 / *Yr1*, 2, 6, 7 (8); 15E148 – *Yr2*, 3, 4, 5, 8, 9, 10 / *Yr1*, 6, 7; 15E150 (MA) – *Yr2*, 3, 4, 5, 9, 10 / *Yr1*, 6, 7, 8; and 39E158 (X) – *Yr3*, 4, 5, 9, 10 / *Yr1*, 2, 6, 7, 8.

Recently, yellow rust has been spreading intensively in the southern and south-eastern parts of Kazakhstan, where winter wheat is mainly grown. Starting from 2002, there was up to 75–100% development of the disease on susceptible wheat varieties (Steklovidnaya 24, Karlygash). At the same time cv. Bezostaya 1 was affected only to the extent of 20–40%. Yellow rust pustules were also recorded on barley (up to 60–80%) and on wild grasses (lyme grass, goat grass) up to 80–100%. The conclusion was that the fungus population structure had changed. To differentiate pathotypes, yellow rust samples taken from commercial wheat varieties and wild grasses, as well as from collections of cereal specimens in SRAI, were used. Seven lines of the International set and eight of the European set were used as differentials. Pathotypes were numerated according to the decimal system of physiological race description. Moreover, to assess pathotype virulence, two additional cvs, Bogarnaya 56 and Bezostaya 1, were used. The experiments were carried out in the greenhouse and in the climate chamber, and 39 yellow rust pathotypes were determined. Their virulence varies from 0 to 82.3%: 7 low virulence pathotypes (0–25%); 26 average virulence pathotypes (26–50%); 5 highly virulent pathotypes (51–75%); and 1 strongly virulent pathotype (>75%). Alongside these pathotypes, new highly virulent pathotypes appeared in the yellow rust population: 47E159 (70.6% virulence), 47E223 (64.7%), 79E146 (52.9%) and 111E159 (82.3%). These pathotypes affect all commercial wheat varieties and differentiating varieties except Moro (*Yr10*), Carstens V (*YrCV*) and Spaldings Prolific (*YrSP*). By using isogenic *Yr*-lines of Avocet and differentiating varieties, the effectiveness of

wheat resistance genes to yellow rust was studied. It has been shown that *Yr5* (*T. spelta*), *Yr10* (Moro), *Yr15* (from *T. dicoccoides*) and *YrSP* (Spaldings Prolific) are highly effective genes against Kazakhstan populations of yellow rust. *Yr9* (Clement), *Yr1*8 (Jupateco R) and *Yr*24 genes provide moderate resistance of plants. Local yellow rust populations appeared to be avirulent to the USA differentiating varieties: Heines VII (*Yr2*, HVII), Druchamp (*Yr3*a, Dru1, 2), Riebesel 47/51 (*Yr9* +?), Produra (YrPr1, Pr2), Yamhi II (*Yr2*, 4a, Yam) and Clement (*Yr9*, YrCle).

Yellow rust: a revolving disease that threatens wheat production in Tunisia

S. Rezgui,[1] M. Fakhfakh,[2] A. Nafti[3] and A. Yhayaoui[4]

1. Institut National Agronomique de Tunis, Tunisia; 2. Centre Technique des Céréales, Tunisia; 3. Direction Générale de la Producion Agricole, Tunisia; 4. ICARDA, Aleppo, Syria

Yellow rust caused by *Puccinia striiformis* West. is an unpredictable disease causing major yield losses in Tunisia, particularly if humid and cool conditions persist in March to April, coinciding with the booting to heading growth stages. This disease, although not frequently encountered has a negative impact not only on yielding ability of most cultivars grown but also on potential reduction in use of new high yielding cultivars. During 2002/03 a major epiphytotic of yellow rust affected Tunisia, causing major crop losses, mainly on bread wheat and to a lesser degree on durum wheat. The proportion of areas infected ranged from 80% in sub-humid regions to 57% in semi-arid areas, with severity ranging from 15 to 100%. In total, 76% of the area was affected, causing an average increase of production cost of 16%. Yield loss assessment was based on survey of treated and untreated fields carried out in hot-spot locations using two bread wheat cultivars: Tebica (susceptible) and Utique (tolerant). Results showed that fungicide use has limited the severity of rust on two bread wheat cultivars that ranged from 7 to 9% in Utique and 10 to 18% in Tebica. The differential grain yield under fungicide use between the two cultivars was 0.5 t/ha. In untreated fields, severity scores reached 100% on Tebica, but did not exceed 30% on Utique. However, grain yield in Utique was not affected by the rust, whereas a decrease in grain yield of 3 t/ha was recorded for Tebica. This yield decline was attributed to the greater severity (100%) noted in the flag and F-1 leaves, disrupting the efficiency of grain filling, as shown by the limited thousand-kernel weight of 13 g. Although the advent of use of high yielding bread wheat cultivars in Tunisia has been

associated with a greater yielding ability that dramatically increased wheat production, particularly when abiotic and biotic stresses are not prevailing, epidemics of yellow rust have led to these high yielding sources being discarded. The narrow genetic base of genotypes used (only 4 bread wheat cultivars) and lack of any integral screening in the selection process are among the factors that promoted yellow rust during favourable growing conditions.

An integrated approach for development of yellow rust (*Puccinia striiformis* f.sp. *tritici*) resistant wheat germplasm in Turkey

F. Düşünceli,[1] L. Çetin,[1] S. Albustan,[1] Z. Mert,[1] K. Akan,[1] S. Yazar,[1] T. Akar,[1] N. Bolat,[2] R. Ünsal,[3] M.E. Bayram,[4] İ. Özseven,[4] H.O. Bayramoglu,[5] N. Dinçer,[6] H. Kılıc,[7] T. Kahraman[8] and A.F. Yıldırım[2]

1. Central Research Institute for Field Crops, Ulus, Ankara, Turkey; 2 Anatolian Agricultural Research Institute (ARI), Eskisehir, Turkey; 3. Aegean ARI, Menemen, İzmir, Turkey; 4. Sakarya ARI, Adapazari, Turkey; 5. Black Sea ARI, Samsun, Turkey; 6. Cukurova ARI, Adana, Turkey; 7. South East Anatolia ARI, Diyarbakir, Turkey; 8. Thrace ARI, Edirne, Turkey.

As in many wheat producing countries, stripe [yellow] rust (*Puccinia striiformis* f.sp. *tritici*) is one of the most important diseases of wheat in Turkey. A number of breeding programmes operate to develop bread and durum wheat cultivars in different regions. However, not all the programmes have the capacity to emphasize resistance to yellow rust. In order to facilitate development of yellow rust-resistant cultivars, a national network was established in 2002. With this integrated approach, activities of bread and durum wheat breeding programmes in winter and spring wheat growing areas of Turkey have been linked. In total, 10 research institutes from both winter and spring wheat growing areas were involved in the activity. Objectives of the study included monitoring occurrence and virulence of yellow rust in the country, germplasm exchange and screening of joint nurseries for stripe rust resistance under artificial inoculation and natural conditions in diverse geographical locations. For the 2004/05 season, 15 nurseries were established for joint use. Of these, 10 nurseries were established with 1219 entries from the institutes located in winter wheat growing areas, while 5 nurseries with 584 entries were established in the spring wheat growing areas. The entries included cultivars, candidates for registration, advanced breeding lines and resistance sources for stripe rust and other diseases. Trap nursery lines including genotypes carrying resistance genes were also included among the nurseries. The nurseries were

sown by hand in rows 1 to 2 m long, with a differential after every 10 entries. The nurseries were sown in 10 locations and irrigation was provided where facilities were available. In 2005, stripe [yellow] rust was recorded at low severity levels at the Eskişehir and Samsun locations, but severity was high in Ankara owing to irrigation and artificial inoculation. In other locations, dry conditions were unfavourable for disease development. The study indicated that of the 1219 entries from the winter wheat breeding programmes, 106 (27.3%) showed good levels of resistance to yellow rust, while the number of yellow rust-resistant entries among the 584 entries from the spring wheat breeding programmes was 355 (61%). In total, 689 (38.2%) entries were found to have good levels of resistance. The data from the yellow rust trap nursery indicated that *Yr1*, *Yr3*V, *Yr4*+, *Yr5*, *Yr15*, *YrSP* and *YrCV*. were still resistant, while other differentials were scored susceptible, intermediate or variable. The resistance sources identified through the activity have been distributed to all the programmes.

Slow-rusting resistance: a strategy to enhance durability of yellow rust resistance in bread wheat in the Central and West Asia and North Africa (CWANA) Region

O. Abdalla, S. Yaljarouka and A. Yahyaoui

ICARDA, Aleppo, Syria

In the Central and West Asia and North Africa (CWANA) Region, bread wheat is the most important food crop. However, both productivity and total wheat production in CWANA are generally low, failing to meet an increasing demand for wheat products. This is partly due to the many abiotic stresses, mainly drought, and to biotic stresses, particularly foliar diseases, that significantly affect wheat production in CWANA. Yellow [stripe] rust caused by the fungus *Puccinia striiformis* West. f.sp. *tritici* is a major foliar disease of wheat in CWANA. In the past decade, severe yellow rust epidemics occurred in a number of countries in Central and West Asia and caused significant yield losses (10 to 40%). Because of both its ability to form new races and its air-borne dispersal mechanism, yellow rust continues to threaten stable wheat production in CWANA.

Genetic resistance is widely used for the control of rust diseases and is recognized as the most economical and environmentally friendly control measure. The past three decades witnessed notable progress in breeding for rust resistance. However, until recently, most of the resistance used has usually

been based on a single major gene or combinations of a few major genes. Experience has shown that resistance based on race-specific genes is not durable, usually being effective for about five years. In contrast, race-non-specific (slow-rusting) resistance slows the rate of disease development and despite the ultimate expression of a high infection type, its effect on grain yield is negligible. Such resistance has proven to be more durable than major gene resistance.

To develop durable resistance, ICARDA's spring bread wheat improvement programme strategically shifted its resistance-breeding methodology in 1998, and embarked on routinely identifying slow-rusting lines in the field. Early products of this shift in strategy are now available to national programmes. In this presentation the methodology used to enhance durability of rust resistance is outlined and achievements are highlighted.

Wheat breeding for resistance to yellow rust (*Puccinia striiformis*) in Iran

M.R. Jalal Kamali and F. Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Wheat is the most important crop in the agro-ecosystems in Iran. It is grown on more than 6.6 million hectare both as irrigated (2.6×10^6 ha) and rainfed (4×10^6 ha). Yellow rust (*Puccinia striiformis*) is the most serious disease threatening the wheat crop in the country. Severe epidemics of yellow rust occurred in the 1994 and 1995 cropping seasons, which caused a big yield loss in the wheat crop. Resistance of widely adapted cultivars such as Falat (Seri 82) broke down. The yield loss was estimated to be about 1.5 million tonne, which was about 15% of the total harvested crop. Susceptible cultivars such as Falat, Roshan, Ghods and Sardari were immediately replaced by more resistant, improved cultivars. Currently, more than fifty wheat cultivars, with different source of resistance and levels of reaction to yellow rust, are commercially grown across the country and contribute to the management and control of disease. However, the resistance of Chamran (Attila 50Y), a widely grown cultivar (grown on more than 0.5×10^6 ha) has been broken since 2003 due to the appearance of a new race (166E134A+, *Yr27*) in Fars province, in the temperate agro-climatic zone in the central part of the country. Some chemicals are applied to control the disease on susceptible cultivars such as Falat, but not on a large scale. However, adoption of resistant cultivars is the best choice for farmers to control yellow rust. Breeding programmes for resistance to yellow rust have been initiated and strengthened since the severe epidemics, and

teamwork between pathologists and breeders has been established and encouraged.

The main objective is to develop wheat cultivars with durable resistance to yellow rust, or at least to carry a combination of adult plant and seedling resistance genes, which can be considered as durable resistance. Two strategies are followed in breeding programmes for the development of resistant cultivars: 1. Study the pathogen and interactions with the host, monitoring pathogen and virulence factors in different part of the country, and determining sources of resistance to be utilized in breeding programmes; and 2. Incorporate sources of resistance into different susceptible cultivars with high yield potential and desirable agronomic performance.

To implement these strategies, Trap Nurseries and national and international yellow rust screening nurseries have been established on over 30 sites in wheat growing areas that are known to be hot-spots for the disease. In Trap nurseries, in addition to standard sets (Differentials) for yellow rust with different *Yr* genes, more than 60 advanced lines and commercial cultivars have been evaluated. The main objective of growing trap nurseries in different part of the country is to identify changes in the pathogen. Spore samples are also collected from different sites and race identification is carried out in the greenhouse. All breeding lines from preliminary to advanced lines are evaluated and screened for resistance to yellow rust at the seedling stage. The seedling resistance genes that are effective throughout the plant life cycle are preferred. Segregating generations, Preliminary Regional Yield Trials (PRWYT), Advanced Regional Yield Trials (ARWY) and Elite Regional Yield Trials (ERWYT), as well as introductions, are evaluated and screened under artificial inoculation in the main yellow rust hot-spots.

To achieve these goals and to follow the strategies, different methodologies and techniques are employed and practiced, including:

- Conventional breeding methods (hybridization and selection in segregating generations).
- Gene deployment by pyramiding resistance genes from different sources.
- Haploid breeding to develop doubled haploid lines resistant to yellow rust.
- Marker assisted selection (MAS) is also planned to facilitate the selection for adult plant and durable resistant genes.
- Outstanding resistant cultivars and promising lines have been developed and released to farmers or are in the pipeline.

Monitoring stripe [yellow] rust pathotypes in the Horn of Africa, Caucasus, West and Central Asia

A. Yahyaoui, M. Naimi, M. El Ahmed, N. Marrawi, R. Malhotra and O. Abdalla

ICARDA, Aleppo, Syria

Stripe [yellow] rust is a major foliar disease limiting wheat production in the Caucasus, Central and West Asia and North Africa (CWANA), Nile Valley and the Horn of Africa. In the last two decades the evolution of new virulent rust pathotypes has resulted in frequent rust epidemics with significant economic impacts. Detection of pathogen variation using a series of host differentials has been valuable in providing important insights into the evolution of pathotypes in response to selection pressure from host resistance genes, and such information is indispensable for the development and strategic deployment of host resistance. Stripe Rust race monitoring in CWANA has revealed that race 6E0 (virulent on *Yr6* and *Yr*A) is the most frequent race in the region and it has been detected every year since 1972. In West Asia, race 38E150 (virulent on *Yr2*, *Yr6*, *Yr7*, *Yr8*) was the second most frequent pathotype during 2000–2003), whereas races 134E152 (virulent on *YrA*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*), 230E150 (virulent on *YrA*, *Yr2*, *Yr6*, *Yr7*, *Yr9*, *YrSU*, *YrSD*, *Yr17*, *Yr18*) and 119E158 (virulent on *YrA*, *Yr1*, *Yr2*, *Yr3*, *Yr6*, *Yr7*, *Yr9*, *Yr10*, *Yr17*) were detected in Lebanon, Iraq and Yemen, respectively. Thus a wide range of virulent races are evolving in this region, leading to breakdown of resistance in wheat.

Occurrence of stripe [yellow] rust and effectiveness of resistance genes in the Caucasus, Western and Central Asia

A. Yahyaoui,[1] O. Abdalla,[1] M. Mossad,[1] M. Saidov,[2] A. Morgounov,[3] M. Koyshibaev,[4] M. Djunusova,[5] M. Torabi,[6] L. Cetin[7] and H. Ketata[1]

1 ICARDA; 2. ARI, Azerbaijan; 3. CIMMYT; 4. PPI-Almaty, Kazakhstan; 5. KARI-Bishkek, Kyrgyzstan; 6. SPII-Karaj, Islamic Republic of Iran; 7. CRIFCI-Ankara, Turkey

Stripe [yellow] rust disease continues to pose a significant threat to stable wheat production in the Caucasus, Western and Central Asia, and Nile Valley and Red Sea (NVRS) regions. Over the past two decades, stripe rust epidemics have caused significant yield losses in these regions. In this study, known stripe rust-resistance genes were evaluated for their effectiveness in West Asia

(Lebanon, Iran, Syria and Turkey), Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan), the Caucasus (Azerbaijan) and NVRS (Egypt, Ethiopia, Eritrea, Sudan and Yemen), utilizing a regional trap nursery that included 48 bread wheat cultivars. The trap nursery was evaluated at 30 yellow rust hot-spot sites in 14 countries. Results revealed that the effectiveness of *Yr*-resistance genes exhibited great variability across sites. Ineffective resistance genes across regions were: *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr1*8, *Yr27*, *YrA* and *YrSD* in Central Asia; *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr1*8, *Yr27* and *YrA* in West Asia; and *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr1*8, *Yr27* and *YrA* in the Caucasus. Thus, some genes were ineffective at all testing sites (*Yr6*, *Yr7*, *Yr8*) whereas at certain sites some were effective (*Yr9* in Azerbaijan) or ineffective (*Yr4*+ and *Yr3*N in Tajikistan). The impact of these results on resistance breeding is discussed.

Winter and facultative wheat breeding strategy for yellow rust resistance

M. Mosaad,[1] H. Braun,[2] A. Hede,[2] H. Ketata,[1] M. Jarrah,[1] A. Yahyaoui,[1] L. Cetin[3] and F. Dusunceli[3]

1. ICARDA, Aleppo, Syria; 2. CIMMYT International, Ankara, Turkey; 3. Central Research Institute for Field Crops (CRIFC), Ankara, Turkey.

Yellow rust (YR), caused by the fungus *Puccinia striiformis* f.sp. *tritici*, is the most damaging disease of winter and facultative wheat, and has continued to attract more attention from researchers, due to important wheat losses (30% to 70%) it has caused in CWANA. The development of wheat cultivars resistant to diseases leads to higher grain yield and reduced use of chemicals, thus benefiting human health and the environment.

Through the International Winter Wheat Improvement Programme (IWWIP)—a partnership between ICARDA, CIMMYT and Turkey and other NARS in the CWANA region—efforts have been increased to develop resistant wheat germplasm. Multidisciplinary teams of scientists regularly conducted artificial inoculation in the field to screen germplasm for YR resistance at Tel Hadya, Syria, and Haymana, Turkey, in addition to seedling stage screening for YR at the greenhouse in Tel Hadya. Acquired resistance is verified by multi-location evaluation at disease hot-spots in collaboration with NARS. This strategy has significantly increased YR resistance levels in germplasm developed through IWWIP.

Genetic stocks with yellow rust have been developed, used in crossing programmes and made available to NARS.

Pathotype and molecular variability of yellow rust in Western and Central Asia, in a global context

Mogens S. Hovmøller and Annemarie F. Justesen

Department of Integrated Pest Management, Danish Institute of Agricultural Sciences (DIAS), Slagelse, Denmark.

Genetic diversity is often low at a both field and regional scales in populations of *Puccinia striiformis* f.sp. *tritici.* The diversity is higher when taking into account the changes that may occur over time (years) and among samples representing larger geographical areas. Information about diversity and the dynamics of the pathogen population is vital due to its impact on the expected control of yellow rust by host resistance, either leading to a decrease or an increase in the ability of specific sources of resistance to control yellow rust in specific areas.

Almost 100 *Pst* samples were collected from 2003 to 2005 from Central Asia, Pakistan, Nepal, Azerbaijan and Iran. The samples have been multiplied and pathotyped in spore-proof and controlled environmental conditions at DIAS, Denmark. In addition, selected samples chosen according to pathotype and origin were analysed using Amplified Fragment Length Polymorphism (AFLP). In general, the samples were collected from a wide range of host varieties, locations, field trials and farmers' fields in these regions.

A total of 16 pathotypes were observed when all samples were taken into account. All isolates carried virulence for *Yr6, Yr7* and *Yr8*, despite some isolates giving intermediate to low infection type (IT) on Compair (*Yr8*) and high IT on the Avocet S (*Yr8*) NIL. Virulence for *Yr3, Yr5, Yr15, Yr17* and *Yr32* was not detected, whereas virulence for *Yr1, Yr2, Yr9* and *Yr27* varied in frequency. Virulence for *Yr4* was observed as an (unusual) intermediate IT on Hybrid 46 in samples from Nepal, but was otherwise absent. In Iran, we observed wheat isolates showing incompatibility on Avocet S and all NILs (IT 1 on a 0–9 scale). Isolates from durum wheat showed virulence for *Yr10* and *Yr24,* whereas isolates from barley gave low IT on all differentials except the susceptible control, wheat cv. Cartago.

Diversity in terms of number of clones (defined by AFLP phenotypes) was generally low within geographically separated populations, but in contrast to samples from many other regions, these AFLP phenotypes were often quite different based on their AFLP phenotype. In particular, yellow rust from Nepal and Pakistan was highly divergent from Central Asian *Pst* samples, even more distant than samples originating from barley and durum wheat. The co-existence of highly divergent individuals within the region may suggest a

pathogen population being persistent across years and exposed to limited selection, i.e. presence of plenty of host plants with few or no *Yr*-genes.

We observed Central Asian isolates that were closely related to isolates from the Mediterranean area and South Africa, and another group of isolates had fingerprints that were almost similar to those of isolates from Europe and NE Africa. This could suggest that spores of the yellow rust fungus potentially may move across very large distances within a relatively short time, a fact that highlights the need for multinational disease and pathogen surveys.

Breeding for durable stripe [yellow] rust resistance using conventional and marker assisted selection in wheat

H.S. Bariana

University of Sydney Plant Breeding Institute, Cobbitty, Australia.

Wheat cultivation around the world has been severely affected for over a decade by stripe [yellow] rust. *Puccinia striiformis* f.sp. *tritici* appears to have acquired the ability to infect wheat at relatively higher temperatures. This attribute has resulted in increased levels of this disease in geographical regions that were traditionally thought to be at low risk for stripe rust. Although combinations of major genes will not provide the sought-after durability, it would increase genetic diversity. Pyramiding of three or more adult plant resistance (APR) genes would ensure potential durability of resistance. This investigation describes the identification, characterization and deployment of stripe rust genes in new cultivars. Breeding strategies to achieve gene combinations through marker assisted selection is also discussed. Practical examples from the Australian wheat breeding experience are presented.

Functional analysis of yellow rust resistance-related genes

Mahinur S. Akkaya

Middle East Technical University, Chemistry Department, Biochemistry and Biotechnology Programmes, Ankara, Turkey

Puccinia striiformis f.sp. *tritici* is the causal pathogen of yellow rust disease. The disease is a global problem for wheat production, resulting in huge yield losses, especially in the Middle East and West Asia. However, little is known about the molecular mode of infection, molecular basis of host resistance and disease progression. To gain understanding of the molecular events that take place during plant-pathogen interactions, the detection of genes that are differentially expressed upon virulent and virulent infections was investigated using a differential display (DD) method, and micro-array expression analysis (Wheat Affymetrix Gene-Chips). Changes in the expression levels were quantified by 'Real Time' RT-PCR. The sequence homology analysis showed the genes such as receptors like kinases, LRR-containing proteins, PR proteins as well as some novel genes, which may play important roles in disease resistance. These are the genes involved in ubiquitinylation and apoptosis. Specifically, the most important are UBX, RAD6, F-Box, cyclophylin like, putative disease resistance protein, o-methyl transferase, Pr5, Pr1.2, alpha-tubulin, syntaxin, Mla-like, photo-system I, ubiquitin. We are currently in the process of silencing the genes identified with DD-RT and performing micro-array analyses to confirm their roles in relation to the other genes by both assessing level of silenced genes and their expressional affects on the other genes of interest by Real Time RT-PCR (qRT-PCR).

Wheat yellow rust situation in Egypt

M.M. EL-Shamy

Wheat Disease Department, Plant Pathology Institute, ARC-Egypt.

In the last fifty years, severe yellow rust epidemics (*Puccinia striiformis* f.sp. *tritici*) occurred in 1958, 1967 and 1995. Sporadic infections have been observed, particularly in the Northern Delta areas, and slight infections were also recorded in Middle and Upper Egypt. As a result of the epidemics, several cultivars were discarded (Gemmeiza 1, Giza 163 and Sakha 69). In the last ten years, races of yellow rust were identified in the greenhouse at Sakha Research Station. Twenty-four yellow rust races were identified from 2000–2004

growing seasons on plants in the seedling stage. Race 0E0 was the most prevalent, followed by 0E6, 6E16, 28E2, 70E20, 70E26, 134E158, 174E158, 198E150 and 238E190. The most effective yellow rust genes at the seedling stage were *Yr1*, *Yr10*, *YrSD*, *Yr5*, *Yr4+* and *YrSP*. At the adult stage *Yr1, Yr6, Yr3a, Yr7, Yr8, Yr15* and *Yr18* were the most effective in several governorates. In the 1995 epidemic, the total average area affected by stripe [yellow] rust was 1 130 630 feddan and the overall average loss in grain yield reached 25.50%. The average loss in Western Delta governorates was higher than in the East, which reached 29.94% and 10.25%, respectively. Of the Egyptian wheat cultivars, Giza 168, Gemmeiza 7, Gemmeiza 9, Gemmeiza 10, Sakha 94 and Sakha 95 were the most resistant to yellow rust and currently remain so.

Characterization of resistance to wheat rusts in Central Asian and Caucasus wheat cultivars

K. Nazari,[1] C.R. Wellings[2] and R.F. Park[2, 3]

1. ICARDA; 2. University of Sydney, Plant Breeding Institute Cobbitty, Australia; 3. Seconded from NSW Department of Primary Industries, Australia

Three wheat rust diseases—stripe [yellow] rust caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*); leaf rust caused by *P. triticina* (*P. recondita* f.sp. *tritici*) (*Pt*); and stem rust caused by *P. graminis* f.sp. *tritici* (*Pgt*)—are major challenges in breeding for high yielding cultivars in Central Asian and Caucasus (CAC) countries. Postulation of resistance genes in CAC cultivars will assist to identify and remove susceptible varieties, determine currently deployed resistance genes and introduce genetic diversity into breeding germplasm. Presence of stripe rust (*Yr*), leaf rust (*Lr*), and stem rust (*Sr*) resistance genes were investigated in 32 wheat cultivars in seedling tests using 8 *Pst*, 12 *Pt*, and 10 *Pgt* pathotypes. *Pst* tests showed 13 cultivars were susceptible to all pathotypes, indicating lack of genes for resistance to stripe rust. Arrays comprising *Pst* pathotypes indicated the presence of *Yr1*, *Yr1+*, *Yr4/Yr4*, *Yr6*, *Yr7*, *Yr9*, *Yr9+*, *Yr9+Yr27* and *Yr27*. Five cultivars were susceptible to all 11 *Pt* pathotypes. Among 25 cultivars, *Lr1*, *Lr3a*, *Lr3ka*, *Lr13*, *Lr14a*, *Lr16* and *Lr26* were postulated singly or in combination. The remaining two cultivars were postulated to carry *LrB*. The 12 *Pgt* pathotypes indicated that two cultivars were susceptible and the remainder carried *Sr5*, *Sr5+*, *Sr5+Sr7b*, *Sr5+Sr8b*, *Sr7b+Sr9b*, *Sr8*, *Sr9e*, *Sr11*, *Sr11+Sr9b*, *Sr17+*, *Sr31 and Sr31+*. In adult-plant tests, cultivars susceptible in seedling tests were resistant to stripe, leaf, and stem rust, indicating the presence of adult plant resistance genes in these cultivars. Further study is necessary to characterize the nature and diversity of adult plant resistances.

Study on resistance reaction of elite barley lines to *Puccinia Striiformis* f.sp. *hordei* in Ardabil

S.A. Safavi[1] and M. Torabi[2]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran; 2. Seed and Plant Improvement Research Institute, Karaj, Islamic Republic of Iran

Barley stripe rust (caused by *Puccinia striiformis* f.sp. *hordei*) is an important disease of cultivated barley in several parts of world, and can cause significant yield losses due to severe epidemics. In Iran, it is increasing on susceptible cultivars and lines in north-western and northern provinces. In order to prevent disease epidemics and minimize yield losses, use and production of resistant lines, particularly with durable resistance, will be the most effective method of control. For this purpose, 36 barley genotypes in Elite Barley Yield Trials were evaluated in 2004–2005 in Ardabil. Each line was sown as two 1-m long rows spaced 30 cm apart. A susceptible cultivar (Afzal or Zarjow) was planted among the experimental entries at 10-entry intervals and also as borders for the nursery, which was conducted under natural infection conditions. In addition, artificial inoculation of the nursery was done using a mixture of spores and talcum powder at dusk using a duster. Plants were in the pre-flag-leaf stage. To increase disease development, mist and flood irrigation were used. At the adult plant stage, infection type (IT) of each entry was evaluated based on the Roelfs *et al.* method when disease was well developed on the susceptible check (70-80S). The percentage leaf area affected (disease severity) was also scored using the modified Cobb's scale at the same time. Coefficients of Infection (CI) were then calculated by combining IT and disease severity. It was concluded that, for Ardabil entries, 44.4% of genotypes were resistant (CI = 0–2), 2.8% moderately resistant (CI = 3–4), 13.9% moderately susceptible (CI = 5–12) and 38.9% susceptible (CI >12). Finally, 61.1% of entries were selected that had CI <16. Resistant lines or cultivars were introduced to SPII so that another evaluation could be conducted in the future.

Study on distribution of and damage from barley yellow rust in Ardabil Province

S.A. Safavi[1] and M. Torabi[2]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran; 2. Seed and Plant Improvement Research Institute (SPII), Karaj, Islamic Republic of Iran

Stripe [yellow] rust of barley is primarily a disease of cool climates and confined to barley grown at high elevations or over the winter. During the last few years, yellow rust has been increasing in some parts of Iran, especially in Ardabil province. Because of high losses due to disease epidemics, understanding of disease area distribution and determining its loss level is very important. Therefore, in order to study the distribution of disease in this province, trials were planted in different parts of Ardabil in several growing seasons. The distribution of disease (infected areas) was determined by field observation using a modified Cobb's scale and percentage of infected plants was determined by a quadrat method. Results of the first study showed that disease severity was variable depending on culture type, cultivars, geographical location and growth stage. The highest infection of barley yellow rust was observed in Lahrood, Ghasabeh, (near Meshkinshahr), Firozabad (near Kosar) and near Nir and Namin. Infection Type in these areas was both moderately susceptible and susceptible, and infection percentage varied from 45% to 81%. Continuing the first investigation in the second year (2004), determining damage due to disease was studied by planting lines with different infection types. Results of this study indicated that lines with susceptible and moderately susceptible reactions in inoculated plots had significant differences from non-inoculated plots (control sprayed three times with propicanazole) at the *P*=1% level. These differences were in yield, thousand-kernel weight (TKW) and area under disease progress curve (AUDPC). Differences between two replications and between two inoculated stages (except lines no. 3, 4 and 6 in AUDPC and lines with 1 and 7 in TKW) were not significant. Study of virulence and virulence factors of the disease agent is also being done using differential cultivars.

Resistance of International Winter Wheat Improvement Programme (IWWIP) germplasm to yellow rust

Mira K. Djunusova,[1] A. Yahyaoui,[2] A. Morgounov[3] and Jyldyz Egemberdieva[4]

1. Kyrgyz Agriculture Co-operative "MIS", Kant, Kyrgyzstan; 2. ICARDA; 3. CIMMYT International; 4. Scientific and Production Centre for Plant Protection "Korgoo", Bishkek, Kyrgyzstan

Wheat is the main cereal crop grown in Kyrgyzstan. One of the factors limiting further cultivation of bread wheat is the increasing presence of yellow rust. It has spread to almost every region where wheat is grown, but especially in Issyk-Kul Basin and Chui Valley, and the foothill zones of Kyrgyzstan. Severe epidemics of yellow rust were recorded in 1939–1941, 1946 and 2002 in Kyrgyz Republic. Since 1999, Kyrgyz Agriculture Co-operative "MIS" breeders, Kyrgyz Research Institute and scientists from International Centers (CIMMYT and ICARDA) and Turkey have launched an active collaborative breeding programme for resistance to yellow rust. Breeding nurseries of winter and facultative winter wheat germplasm from IWWIP and ICARDA were evaluated in Kyrgyzstan. Promising varieties of Kyrgyz selection and the CWAYRTYN nursery were identified. The objective of this work was to evaluate international germplasm in order to identify yellow rust-resistant genotypes for use in the breeding programmes. Germplasm evaluation was conducted in Chui Valley on a station located at an altitude of 813 m with average precipitation of 350–450 mm. yellow rust incidence was scored twice, using percent severity and a reaction-type scale. Then the entries were classified according to their Coefficient of Infection (CI) values. CWAYRTN nursery evaluation has shown that some commercial cultivars and lines with known resistance genes, such as: Ani 326, Vilmorin, Moro, Cook, Suwon 92×Omar, Hybrid 46, Karakylchyk 2, Azametli 95, Seri 82, Corella, Super Kauz, Cham 4, Cham 6, Ulugbek 600, YR5/6 YR10, showed high levels of resistance to yellow rust at this site. Moderately resistant varieties were also identified, such as Kinaci 97, Turkmenbashi and Pastor. More than 50% of the genotypes were moderately susceptible to susceptible. Local variety Dostuk and cv. Morocco were highly susceptible. As a result of this study, resistant genotypes were selected and were used in the crossing programme with the aim to incorporate resistance in highly productive Kyrgyz and Kazakhstan varieties such as: Intensivnaya, Yujnaya 12, Krasnovodopadskaya 210, NISHI 1458, Bermet, Adyr, Kyal and Tylek.

Resistance of mutant winter wheat forms to *Puccinia striiformis*

R. Chumueva,[1] G. Bayalieva[1] and S. Dzhunusova[2]

1. Kyrgyz Agrarian University, Bishkek, Kyrgyzstan; 2. Scientific and Production Centre for Plant Protection "Korgoo", Bishkek, Kyrgyzstan

Breeding for resistance to diseases and pests generally receives priority by wheat breeders throughout the world. There are examples of mutagen-induced disease resistance in wheat, and much more research under carefully controlled (contamination-free) conditions is needed. The limiting factor for further growth of winter wheat productivity in the Kyrgyz Republic is the increasing severity of diseases such as yellow rust (*Puccinia striiformis* f.sp. *tritici*). It is widespread in all wheat cultivation regions, particularly the Issyk-Kul region and Chui Valley. Strong epiphytotics of yellow rust were recorded in Kyrgyzstan in 1939–1941, 1946 and 2002.

Released bread wheat cvs Erythrospermum 760 and Lutescens 42, together with 12 hybrids (F_2), were irradiated by γ-rays and ultraviolet rays. Their reaction to yellow rust was observed under natural infection in Chui Valley. The mutant forms revealed that the variety Erythrospermum 760 has a moderate reaction to yellow rust, and Lutescense 42 has a moderately susceptible reaction. Hybrid populations 762, 768, 771 and 1387 were moderately resistant to resistant to yellow rust, while hybrid populations 791, 775, 779 and 1383 were susceptible. The resistance of mutant forms to yellow rust is affected by the mutagen, irradiation and genotypes. For example, γ-ray-irradiated (20′) hybrid population 762 had R reaction type to YR; hybrid population 779 (γ-rays, 50′) was very susceptible. Ultraviolet rays (15′, 25′) gave a resistance reaction to hybrids 762 and 771. Moderately susceptible and susceptible reactions were observed on hybrids 779, 782, 791 and 1383 (UV-5′).

Researching the influence of antifungal characteristics of copper component on the wheat

H. H. Kushiev, U. Berdalieva and O. Yunusov

Gulistan State University of the Republic of Uzbekistan

The phytopathological situation has become aggravated because of epiphytological spreading of fungi (yellow and leaf rusts and tan spot) and others that cause considerable economic damage, reducing the harvest and quality of wheat grain in Central Asia in recent years. Wheat rust disease causes significant damage to wheat each year. This shows the necessity of intensifying scientific research to create new, highly efficient chemicals for control of this disease. Combating rust diseases has been accomplished by cultivating varieties with stable yields and using chemical means to control disease. It should be noted that there are very few stable varieties resistant to this disease among the cultivars grown. Currently there is considerable interest in developing chemical preparations that both stimulate increased plant phyto-immunity and have positive fungitoxic effect against the wheat rust. When we used a preparation containing copper, positive results were observed that included slowing the development of rust fungi, including rust disease of wheat. According to preliminary data, the preparations help not only to resist rust, but use of this preparation as a seed dressing at 0.01% dose level improved productivity and raised the quantity of grains in the spike. The crop yield increased. This shows that there is a need to develop the preparation for application during the wheat growing period.

Resistance evaluation of elite wheat lines to yellow rust in Ardabil

G. R. Aminzadeh and S.A. Safavi

Agricultural Research and Natural Resources Centre of Ardabil, Ardabil, Islamic Republic of Iran

Yellow rust or stripe rust (caused by *Puccinia striiformis* f.sp. *tritici*) is the most important disease of wheat in Iran, causing high yield losses in epidemic years. The use and production of resistant cultivars is the best controlling method for the disease. For this purpose, reaction evaluation of 15 genotypes (ERWYT-C-82 entries) to yellow rust was carried out under field conditions using mist irrigation in 2004 and 2005. In addition, artificial inoculation of the nursery was done by mixing of spores with talcum powder and using a duster at sunset time, and applied before flag leaf development. At the adult plant stage, infection type (IT) of each entry was evaluated based on Roelfs *et al.* method. The percentage leaf area affected (disease severity) was also scored using the modified Cobb's scale. Coefficients of Infection (CI) were calculated by combination of IT and disease severity. Results showed that for ERWYT entries, 26.6% of genotypes were resistant (CI = 0–2), 20% moderately resistant (CI = 3–4), 26.63% moderately susceptible (CI = 5–12), and 26.6% susceptible (CI >12). In this research we also concluded that lines such as C-82-1, C-82-12 and C-82-13 were moderately susceptible or susceptible because they had CI >16. Other lines, especially C-82-3, C-82-4, C-82-6, C-82-8, C-82-10 and C-82-15, were selected for their resistance reaction to yellow rust and other desirable characters.

Postulation of stripe [yellow] rust resistance genes in entries of the 35th International Bread Wheat Screening Nursery

N.A. Dadkhodaie,[1] R.F. Park[1, 2] and C.R. Wellings[1]

1. University of Sydney, Plant Breeding Institute Cobbitty, Camden, Australia; 2. Seconded from NSW Department of Primary Industries

The 35th International Bread Wheat Screening Nursery (IBWSN), distributed by the International Wheat and Maize Improvement Centre in Mexico (CIMMYT), was assessed for stripe [yellow] rust resistance using selected

Australian pathotypes of *Puccinia striiformis* f.sp. *tritici* (*Pst*). An initial greenhouse screen with leaf rust pathotypes 104-1,2,3,(6),(7),11 and 104-1,2,3,(6),(7),9,11, which differ in avirulence/virulence for *Lr26*, respectively, indicated that 290 out of a total of 500 lines (58%) probably carried *Lr26* and therefore also the 1BL/1RS translocation on which rust resistance genes *Lr26*, *Yr9* and *Sr31* are located. The leaf rust tests also provided evidence of the presence of *Sr2* in some lines, based on the presence of the *Sr2*-linked trait seedling chlorosis. Greenhouse seedling tests on the lines identified as carrying 1BL/1RS (*Yr9*) using three pathotypes of *Pst* provided evidence for the potential additional presence of gene *Yr27* in some of the lines. The 210 regarded as lacking *Yr9* were seedling tested with five pathotypes of *Pst*. Several lines appeared to carry *Yr9*, indicating an error in scoring leaf rust response. The remaining lines either lacked detectable seedling genes for resistance to *Pst*, or were postulated to carry *Yr1*, *Yr6*, *Yr27*, *YrA* or uncharacterized resistance.

Stripe [yellow] rust distribution, harmfulness and population structure in the North Caucasus Region of Russia

Galina Volkova

All-Russian Research Institute of Biological Plant Protection, Krasnodar, Russia

For a long time, until the 1960s, stripe [yellow] rust had no economic importance in the North Caucasus region of Russia. The immunological characteristics of the cultivars with horizontal resistance and absence of corresponding ecological resources did not allow the pathogen to spread out into the steppe locations, where the hot and dry summer was very unfavourable for fungal development. The main areas for stripe rust infection in North Caucasus include Dagestan, Ossetia, Ingushetia, Kabardino-Balkaria, and sub-montane districts in the Stavropol and Krasnodar Regions. Since 1991, the natural habitat of this pathogen has steadily extended. In the last decade there was an epidemic peak in 1997, when stripe rust was recorded in greater (up to 70%) or lesser (under 5%) amounts in the whole territory of the Krasnodar Region and adjacent districts of the Rostov and Stavropol Regions. Nearly all commercial and newly developed winter wheat cultivars were infected by stripe rust to a variable degree. Maximum severity of disease (60–70%) was observed in the cvs Rufa, Demetra, Ophelia, Novokubanka and Zimorodok. Cultivars such as Yuna and Soratnitsa were infected to a lesser degree. Based on approximate evaluations, direct yield losses on unprotected

fields reached 30 to 50%. The analyses show the major reasons for the stripe rust epidemics in North Caucasus were: (1) high susceptibility to stripe rust in commercial and newly-developed winter wheat cultivars; (2) intensive form-building processes in the fungus; and (3) favourable meteorological conditions. According to the long-term data, the most typical North Caucasus races, such as 4E0, 4E16, 5E0, 5E16, 6E0, 6E16, 7E0 and 7E16, were identified in the infection reservation locations. These races are able to infect wheat cultivars having juvenile resistance genes *Yr1, Yr5, Yr7* and *Yr8*. The genotypes identified had from 1 to 4 virulence alleles. The single-pustule isolates of the fungus identified with International and European sets of differential cultivars in 2004–2005 represented six races: 6E16, 2E16, 0E16, 4E16, 2E0 and 64E16. The dominant races included the race 6E16, which made up 47.6% of the pathogen population. The frequency of occurrence in the stripe rust population was 19.0% for 2E16, 14.3% for 0E16, 9.5% for 4E16, 4.8% for 2E0, and 4.8% for 64E16.

The phenotypes of the fungus containing 1 to 6 virulence alleles were identified. The genetic structure analysis for the stripe rust pathogen showed that it included 13 virulence alleles of the 20 studied. No fungal isolates with *pp* alleles 3c, 4c, 9, 10, 17, SP, Tr1+Tr2 were identified; the isolates with virulence alleles 3a and 4b had low frequencies of occurrence. Thus stripe rust is one of the most widespread and harmful wheat diseases in North Caucasus. The pathogen control strategy should be based on extensive knowledge of the pathogen biology, natural conditions of the agricultural region, as well as the host plant biology and cultivation techniques.. Effective resistance genes in adult wheat plants against leaf, stem and stripe rusts and mildew should be applied for wheat breeding in North Caucasus.

Evaluation of some synthetic hexaploid wheats and their durum parents for stripe [yellow] rust resistance in Pakistan

I. Ahmad,[1] Abdul Mujeeb Kazi,[2] S. Rizwan,[3] G.M. Sahi,[1] J.I. Mirza [1] and M. Ashraf[3]

1. Crop Disease Research Programme, NARC, Islamabad, Pakistan; 2. Foreign Faculty Professor HEC/NIBGE/QAU, Quaid-e-Azam University, Islamabad, Pakistan; 3. Quaid-e-Azam University, Islamabad, Pakistan

Stripe [yellow] rust of wheat (caused by *Puccinia striiformis* Westend) is an important cereal disease in wheat growing countries, and associated with cool and wet environmental conditions. Tremendous losses in wheat production from yellow rust epidemics are usually blamed on favourable environmental conditions that foster pathogen activity. Although application of fungicides

and cultural practices have been adopted effectively in controlling outbreaks of this disease, genetic resistance remains the most economical and environmentally safe approach. At present, 30 resistant genes have been catalogued; however, a large number of these genes are ineffective due to the presence of corresponding virulence. Changing virulence patterns in the recent past have rendered resistant cultivars susceptible in Pakistan. Identification of resistance sources against yellow rust is thus an important task. Synthetic hexaploid wheats are a potent source of biotic and abiotic stress resistances or tolerances, and provide novel genetic diversity options for wheat improvement. This germplasm could thus be a source of yellow rust resistance. In this study, 128 lines of synthetic hexaploid wheats (*Triticum turgidum* × *Aegilops tauschii* (2n=6x=42, AABBDD) and 51 lines of the durum (*T. turgidum*, 2n=4x=28, AABB) parents were evaluated for seedling resistance in the greenhouse and adult plant resistance in field and greenhouse over two years (2005 and 2006). Bulk inoculum collected from wheat growing areas of Pakistan during 2004 was used as the disease challenge to screen the material. The inoculum contained virulence for genes *Yr1, Yr3, YrSD, Yr4, Yr5, Yr6, Yr7, YrCV* and *YrSP*. Seedling resistance to stripe rust was present in both synthetic hexaploid wheats and the durum parents used in the synthetics, with 45 synthetic hexaploid lines (35%) and 12 durum lines (23%) showing good seedling resistance. Field and greenhouse adult plant resistances were evaluated by estimating the area under the disease progress curve (AUDPC), and 13 (10%) synthetic hexaploid lines and 8 (15%) durum cultivars had good adult plant resistance under both greenhouse and field conditions, with 30 (23%) synthetic hexaploids and 7 (13%) durums showing resistance at both evaluation stages. Resistance from *Ae. tauschii* (2n=2x=14, DD) was unequivocally inferred from those lines in which durum parent was susceptible in seedling and adult plant stages. Such synthetics form the basis of specific genetic (monosomic analysis) and marker studies based upon genome and chromosome-specific microsatellites. The lines found resistant in our study can be used to improve bread wheat in Pakistan, and possess unique genetic diversity that could contribute to stable (durable) production outputs.

Wheat yellow rust establishment, distribution and varietal resistance in North West Frontier Province (NWFP) of Pakistan

Syed Jawad Ahmad Shah,[1] Shaukat Hussain,[2] Tila Mohmmad,[1] Farhatullah,[2] Ihsanullah,[1] M. Ibrahim[1] and Sajid Ali[2].

1. Nuclear Institute for Food and Agriculture (NIFA), Tarnab, Peshawar, Pakistan; 2. NWFP Agricultural University, Peshawar, Pakistan

Wheat growing areas of North West Frontier Province (NWFP) of Pakistan were surveyed in March-April of the 2004/05 crop season in order to record the establishment of yellow rust, its distribution and varietal resistance. Yellow rust (*Puccinia striiformis*) was prevalent at all sites visited in three different wheat production zones of the province. Disease symptoms were observed during late February to early March. The central irrigated zone, comprising Peshawar, Nowshera, Charsadda and adjacent areas of NWFP Agricultural University had emerged as having maximum mean rust severity. Among different wheat genotypes, 28% were rated as disease free at the time of scoring. These included future candidate varieties (SD-66 and PR-83) and commercial cultivars (Tatara, Khyber 87, Kohsar 93 and Chakwal 86). Phenotypic diversity of infection types on these genotypes was found to be maximum in the areas adjacent to NWFP Agricultural University. The study was useful for developing an understanding regarding the current field rust situation and resistance levels of wheat genotypes grown in different areas, as an input to effective breeding to combat this disease in Pakistan. This work is part of the PhD Research work of the principal author, to be presented at the Third Yellow Rust Conference, in Kyrgyzstan 9–12 June 2006.

Development of a detached leaf assay for stripe [yellow] rust resistance screening

A. Loladze,[1] K. Garland Campbell,[2] X.M. Chen[2] and K. Kidwell[1]

1. Department of Crop and Soil Sciences, Washington State University, Pullman, WA, USA; 2. Wheat Genetics, Quality, Physiology and Disease Research Unit, USDA-ARS, WSU, Pullman, WA, USA

Stripe [yellow] rust caused by *Puccinia striiformis* Westend. f.sp. *tritici* Eriks. is a major disease of wheat (*Triticum aestivum* L. em Thell.) worldwide, causing significant yield and quality losses. Screening wheat germplasm for resistance to stripe rust is conducted using greenhouse and field-based trials in the seedling and adult stages of plant development, respectively. Because of their efficiency, detached leaf assays have been developed for screening cereal crops for resistance to several foliar pathogens; however, the long latent period of stripe rust complicates detached leaf assay development for resistance to this pathogen. The objective of this study was to develop an effective, efficient detached leaf assay for screening wheat germplasm for resistance to stripe rust.

Detached seedling leaves of seven wheat differential cultivars were placed on the artificial media, which consisted of 0.5% water-agar with the addition of 10 mg/L kinetin, a plant senescence retardant, and the pH of the media was adjusted to 7. Leaf segments were inoculated with three races of stripe rust using a fine paintbrush and placed in a dark growth chamber for 24 h at 10°C. After the 24-h incubation period, the photoperiod conditions were set to 16/8 hours (day/night) at a temperature of 15–17/11–13°C (day/night). Simultaneously, the same plant material was grown for 10–14 days and inoculated in the greenhouse with a mixture of stripe rust spores and talcum powder (1:20). The reactions of the wheat genotypes to stripe rust races were recorded as infection types on a 0 (no infection) to 9 (completely susceptible) scale. Infection types from the detached leaf assay matched those of the whole seedling assay for all cultivars. The detached leaf assay provides a new method for screening for stripe rust resistance that requires less space and time than seedling evaluation methods and eliminates the need for greenhouse space and dew chamber access.

Reaction of dryland advanced wheat lines and cultivars to yellow rust in Ardabil.

S. A. Safavi[1] and A. Malihipour[2]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran; 2. Seed and Plant Improvement Research Institute(SPII), Karaj, Islamic Republic of Iran

Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is undoubtedly the most important fungal disease of wheat, especially in central and western Asia, and causes significant annual yield losses. Its relative importance from area to area depends on climate and also the predominant cultivars. Although the disease was first reported in Iran in 1947, it did not caused significant economic losses until 1993. In 1993 and 1995, losses due to yellow rust epidemics were estimated to be 1.5 and 1 million tonne, respectively.

Use of resistant cultivars is the best method of control. For this purpose, study of the reaction type of 234 dryland wheat genotypes to yellow rust was carried out in Ardabil in the 2002 to 2004 cropping years. Each genotype was planted in two 1-m long rows (rod row design). The experiment was conducted under field conditions and mist irrigation. In addition, artificial inoculation of the nursery was done by mixing spores with talcum powder and using a duster before flag leaf emergence. At the adult plant stage, the infection type (IT) of each entry was evaluated based on Roelfs *et al*. method. The percentage leaf area affected (disease severity) was also scored using the modified Cobb's scale. Coefficients of Infection (CI) were calculated by combining IT and disease severity. Results showed that from 234 evaluated lines or cultivars, 44.6% of genotypes were resistant (CI = 0–2), 4.3% moderately resistant (CI = 3–4), 18.5% moderately susceptible (CI = 5–12) and 32.6% susceptible (CI >12). Finally, 67.4% of entries were selected, because they had CI <16. Resistant lines or cultivars were introduced to SPII for further experiments.

Virulence variation of *Puccinia striiformis* f.sp. *tritici* in Pakistan

M.G. Sahi,[1] I. Ahmad,[1] S. Rizwan,[2] J.I. Mirza,[1] A. Rehman[1] and M. Ashraf[2]

1. Crop Disease Research Programme, NARC, Islamabad, Pakistan;
2. Quaid-e-Azam University, Islamabad, Pakistan

Yellow (stripe) rust caused by *Puccinia striiformis* f.sp. *tritici* is one of the most important diseases of wheat (*Triticum aestivum* L.) in Pakistan, and use of genetic resistance is the most common control strategy. Effective breeding strategies depend on an understanding of the genetics and virulence variation of the pathogen. In this study, yellow rust populations in Pakistan were characterized for their virulence pathotypes and races and pathogenetic variation using seedling evaluation of differential genotypes under glasshouse conditions in Murree (2000 masl). The differential genotypes comprised a World set, European set, near-isogenic lines and the universally susceptible bread wheat cv. Morocco. The two-year study identified a total of 18 race groups. Of these 18 race groups, several (68E0, 64E0, 66E0, 70E0, 6E0, 71E0, 6E0, 67E0 and 68E16) had been found previously. The new race group 70E32 found had probably evolved as a mutation from the previously existing 70E16. Virulence frequencies of *Yr* resistance genes were also determined on near-isogenic lines. Highest virulence frequencies were found for *Yr7* (88%), *Yr9* (57%), *Yr18* (70%) and *Yr24* (69%). Virulence frequencies were low for *Yr1* (4%), *Yr5* (7%), *Yr10* (16%) and *Yr15* (4%). Our studies indicated that virulence existed for almost all *Yr* genes, necessitating regular monitoring of the yellow rust populations, coupled with intense efforts to identify new sources of resistance to this pathogen.

Yellow rust research in Iran: past, present and future

M. Torabi

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Yellow rust causes economic losses in wheat throughout the world and is the most important disease of wheat in Iran. Several epidemics of yellow rust have occurred in Iran during the last 30 years, causing huge yield losses as a result of breakdown of resistance in the cultivars in popular use. The 1993 epidemic

reduced the harvest by an estimated 1.5 million tonne. To overcome the disease problem, intensive research has been carried out in Iran during the decade, and epidemiology, genetic variability, resistance and control strategies for the disease studied comprehensively. Epidemiological studies indicate that disease epidemics occur endemically in most parts of the country. The causal organism survives in over-summering sites on wild grasses in high lands, and moves to the new crop during autumn to infect the seedlings in fields. Latent infections in seedlings remain until spring, when the climatic conditions become favourable for disease appearance. Thirteen grass species were identified as hosts of the causal agent in Iran. A virulence survey through yellow rust trap nurseries grown in different locations, coupled with testing the disease samples in greenhouse on differentials, showed that virulence factors for resistance genes *Yr6, Yr7* and *Yr9* exist in all regions, while genes *Yr2, Yr1* and *Yr17* are ineffective only in some locations. Virulence has been recently detected in Fars province in south Iran. Based on these results, 14 high yielding wheat cultivars with different sources of resistance, mostly with adult plant resistance, have been released. At the time of writing, most of them are still effective in the different locations. By using genetic resistance together with other control strategies, yellow rust epidemics have been controlled effectively in many parts of the country during the last decade, even in years when meteorological conditions were very suitable for epidemic development.

Study on resistance reaction of elite barley lines to *Puccinia striiformis* f.sp. *hordei* in Ardabil

S. A. Safavi[1] and M. Torabi[2]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran; 2. Seed and Plant Improvement Research Institute(SPII), Karaj Islamic Republic of Iran

Barley stripe rust (caused by *Puccinia striiformis* f.sp. *hordei*) is an important disease of cultivated barley in several parts of world, and it often causes significant yield losses due to severe epidemics. In Iran, it is increasing on susceptible cultivars and lines in some parts, such as north-western and northern provinces. In order to prevent disease epidemics and decrease yield losses, use and production of resistant lines, particularly durable resistance, will be the best control method. Hence 36 barley genotypes from Elite Barley Yield Trials were evaluated in the 2004/05 cropping year in Ardabil. Each line was sown in two 1-m long rows spaced 30 cm apart. A susceptible cultivar (Afzal or Zarjow) was planted among the experimental entries at 10-entry

intervals and also as the border of the nursery. The experiment was conducted under natural infection conditions. In addition, artificial inoculation of the nursery was done by mixing of spores with talcum powder and dusting at sunset, before flag leaf development. For disease development, mist and flooding irrigation were used. At the adult plant stage, infection type (IT) of each entry was evaluated based on the method of Roelfs *et al.* when disease developed well (70-80S) on the susceptible check. The percentage leaf area affected (disease severity) was scored using the modified Cobb's scale at the same time. Coefficients of Infection (CI) were then calculated by combining IT and disease severity. From this study it was concluded that for Ardabil entries, 44.4% of genotypes were resistant (CI = 0–2), 2.8% moderately resistant (CI = 3–4), 13.9% moderately susceptible (CI = 5–12) and 38.9% susceptible (CI >12). Finally, 61.1% of entries were selected that had CI <16. Resistant lines or cultivars were introduced to SPII so that other evaluations can be conducted in future.

An overview of the network for cereal diseases management research in Turkey

F. Dusunceli,[1] L. Cetin,[1] S. Albustan,[1] Z. Mert,[1] K. Akan,[1] N. Bolat,[2] A.F. Yıldırım,[2] R. Ünsal,[3] M.E. Bayram,[5] İ. Özseven,[5] N. Dinçer,[6] H. Kılıç,[7] H. Bayramoglu,[8] İ. Öztürk,[9] U. Kucukozdemir,[10] A. İlkhan[11] and J. Nicol[12]

1. Central Research Institute for Field Crops, Ulus, Ankara, Turkey; 2. Anatolian ARI, Eskisehir, Turkey; 3. Aegean ARI, Menemen, İzmir, Turkey; 4. Bahri Dagdas International ARI, Konya, Turkey; 5. Sakarya ARI, Adapazari, Turkey; 6. Cukurova ARI, Adana, Turkey; 7. South East Anatolia ARI, Diyarbakir, Turkey; 8. Black Sea ARI, Diyarbakir, Turkey; 9. Thrace ARI, Edirne, Turkey; 10. Eastern Anatolia ARI, Erzurum, Turkey; 11. GAP Research and Training Centre, Ş. Urfa, Turkey; 12. CIMMYT-Turkey, Emek-Ankara, Turkey

Wheat and barley are grown in diverse geographical regions in Turkey, and various diseases can cause significant yield and quality losses, depending on climatic conditions. The cereal diseases research network has been established to link disease-related research activities of the research institutes with the aim of improving productivity through integrated research efforts for the management of diseases. Several breeding programmes operate at the research institutes in winter and spring cereal growing areas of the country, and these need support for diseases research. The overall objective of this activity is to facilitate development of disease-resistant cultivars of bread and durum wheat and barley. Specific aims of the study include monitoring disease occurrence,

multilocational screening of joint germplasm against important diseases, and exchange of sources of resistance against different diseases among research institutes. Primary target diseases are stripe [yellow] rust (*Puccinia striiformis*), leaf rust (*Puccinia recondita*) and common bunt (*Tilletia caries, T. foetida*) for wheat; scald (*Rhynchosporium secalis*) and leaf stripe (*Pyrenophora graminea*) for barley; and root and foot rots, caused by *Fusarium* spp. and *Drechslera sorokiniana,* for both crops. Viral diseases are also included in the study where they occur naturally. In the network, a total of 15 wheat and 6 barley nurseries were established in 2005 with 1803 and 244 entries, respectively, with contributions from the 10 research institutes located in the various regions. Of these, 3 nurseries with 147 entries were durum wheat and 12 nurseries with 1656 entries were bread wheat. The nurseries were sown in 10 locations for screening against the target diseases. Disease development was promoted with appropriate measures, including irrigation and artificial inoculation in some locations for screening purposes. In 2005, leaf rust and powdery mildew occurred naturally in some coastal locations and yellow rust screening could be done efficiently under artificial inoculation in Ankara. Natural occurrence of Wheat Soil-Borne Mosaic Virus (WSBMV) in Eskişehir and Barley Yellow Dwarf Virus BYDV) in Samsun allowed identification of more resistant genotypes against them. The results of the activities of 2005 indicated that 689, 122, 79, 56 and 8 wheat genotypes were identified as having a good level of resistance to stripe rust, leaf rust, common bunt, mildew (*Erysiphe graminis*) and root and foot rots, respectively. Natural occurrence of viral diseases allowed identification of 68 (31%) lines with some resistance to WSBMV and 16 (15%) lines with some resistance to BYDV. Of the barley entries, 78 (32%) showed a good level of resistance to scald (*Rhynchosporium secalis*) and 125 (51.2%) to barley leaf stripe (*Pyrenophora graminea*). The study facilitated, in addition to multilocational testing of the germplasm in different environments, exchange of germplasm with disease resistance properties among the breeding programmes.

Virus-induced gene silencing in wheat

Mahinur S. Akkaya

Middle East Technical University, Ankara, Turkey

Using the powerful Virus-Induced Gene Silencing (VIGS) approach, it is now possible to silence wheat endogenous genes with Barley Stripe Mosaic Virus (BSMV). The successful use of VIGS in wheat could develop into a revolutionary method for wheat functional genomics. Using BSMV-mediated VIGS, it will be possible to better understand the compatible and incompatible yellow rust fungal interactions, relatively easier than by other silencing methods. In this powerful reverse genetic approach, upon infection with virus vectors carrying homologous plant gene fragments, sequence-specific RNA degradation occurs in the corresponding mRNA in the infected cells and spreads systemically throughout the leaves. VIGS is rapid, does not require development of stable transformants, allows characterization of phenotypes that might be lethal in stable lines and offers the potential to silence either individual or multiple members of a gene family. Here, we report the silencing of phytoene desaturase (PDS) gene, causing photo-bleaching in wheat, using the constructs prepared by Holzberg and colleagues.

The BSMV vectors were linearized with proper restriction enzymes and transcribed using Ambion T7 mMessage mMachine Kit. Following the purification of transcribed messages, RNA was suspended in FES solution and immediately applied onto the young leaves of 20-day-old wheat plants. GFP expression was observed in infected and newly growing leaves after 6–7 days of infection. Photo-bleaching was observed in newly growing leaves after 12–16 days. We are currently in the process of silencing the genes identified with DD-RT and performing microarray analyses to confirm their roles in relation to the other genes by both assessing level of silenced genes and their expressional affects on the other genes of interests by Real Time RT-PCR (qRT-PCR).

Results of testing winter wheat for yellow rust reaction

N. N. Pozdnaycova, V.V. Vasilchenco, N.G. Aubekerova and D.A. Ten

Kyrgyz National University, Bishkek, Kyrgyzstan

During the period 2001–2005, 32 samples of the world collection of winter wheat were screened for resistance to yellow rust disease. All the accessions were tested under natural infection. The local cv. Intensivnaya was used as standard check. The evaluation of the nursery is shown in the table below.

No.	Cultivar or line	Origin	YR infection level (%)
1	Intensivnaya	Kyrgyz SRI of agriculture	57.6
2	Lutestsens 46	KSRT of agriculture	12
3	Frunzenskaya 60	KSRT of agriculture	2
4	Krasnovodskaya 210	Russia	1.5
5	Albidium 20212	KSRT of agriculture	1.7
6	Lutestsens 42	KSRT of agriculture	2.5
7	Besostaya 1	Russia	3
8	Spartanka	Russia	4
9	Zuke	USA	1.2
10	WA 6099	USA	13.5
11	Arban	USA	10
12	Marins	France	17
13	Caton	France	19
14	Sareto	Italy	16.7
15	Saisach Martal	Austria	1.5
16	Pagent	England	11.4
17	Comtal	France	4.7
18	Topaz	France	12.5
19	Oasis	USA	14.8
20	Ca 725061	USA	16.9
21	Parker	USA	13
22	Arthur 71	USA	5.5
23	Jeff	USA	10.5
24	Sentinel	USA	18
25	Yosnaya Zaraya	Russia	12
26	Pricubanskaya	Russia	8.5
27	Alibidium 5	AS Kazak Republik	2.5
28	Mutant Kaz. 3	AS Kazak Republic	5.7
29	Eritrospectrum 7327	Kaz SRI of agriculture	1.3
30	Eritrospectrum 41	Kaz SRI of agriculture	4.7
31	Issyk-Kuleskaya	Kyr SRI of agriculture	12.5
32	Eritrospectrum 13	Kyr SRI of agriculture	3.2

Inheritance of resistance to yellow rust in some Iranian wheat genotypes

F. Afshari

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Stripe [yellow] rust in wheat, caused by the fungus *Puccinia striiformis* f.sp. *tritici,* is an important disease in Iran. The use of resistant cultivars is the most effective, economical and environmentally safe method to control the disease. Extensive research on stripe rust resistance in wheat has occurred over many years and has been successful in providing farmers with rust-resistant cultivars. Early studies on stripe rust provided the first evidence that a single gene controlled resistance to a pathogen. Most of the early genetic studies on the inheritance of rust resistance in wheat were done in conjunction with wheat breeding. A susceptible cultivar was usually crossed with a resistant parent, and the F_2 populations and F_3 families were studied in the field where they were exposed to natural epidemics. F_3 families were classified into three classes: homozygous resistant, segregating, or homozygous susceptible. The number of genes involved was estimated from the frequencies of families classified in each class. Pathotype 134E134A+ was used for this study, with virulence on *Yr2, Yr6, Yr7, Yr9* and *YrA* genes. The main objective of the study was to gain a better genetic understanding of resistance to stripe rust in ten Iranian wheat cultivars and advanced lines, included Chamran, Marvdasht, Shirodi, Pishtaz, Shiraz, Dez, N-75-16, N-75-15, C-78-7 and C-78-18, which were crossed with the susceptible parent Avocet "S". The results of F_3 from the cross Chamran×Avocet "S" and N-75-16×Avocet "S" suggested one gene for each and the crosses of Marvdasht, Shirodi, Pishtaz, Shiraz, Dez and C-78-7 with Avocet "S" segregated for 2 independent dominant genes. The results from the cross C-78-18×Avocet "S" suggested two complementary dominant genes, and the cross N-75-15×Avocet "S" segregated for 3 dominant genes. The ultimate objective of the work reported here would be to catalogue the different unknown genes for seedling and adult plant resistance (APR) by locating them on chromosomes using aneuploid analysis or suitable molecular marker systems.

Comparison of reactions of some wheat genotypes at adult plant stage to *Puccinia striiformis* f.sp. *tritici.*

F. Afshari,[1] M.R.J. Kamali[1] and S. Rajaei[2]

1. Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran;
2. Agricultural and Natural Resources Research Centers of Fars, Islamic Republic of Iran

In order to identify resistance in genotypes of wheat at the adult plant stage, a field experiment was carried out in Karaj and Zargan in the 2005/06 cropping season. All 56 genotypes together with a susceptible landrace (Bolani) were sown in two 1-m long rows 30 cm apart, under artificial inoculation with race 134E134A+ in Karaj and race 166E134A+SK+ on the Zargan experimental field station. The first pathotype has shown virulence on plants with *Yr2*, *Yr6*, *Yr7*, *Yr9* and *YrA*, and the second pathotype has recently become dominant in central Iran (Fars province), with virulence on plants with genes *Yr2*, *Yr6*, *Yr7*, *Yr9*, *YrA*, *YrSD* and *Yr27(SK)*. A susceptible wheat landrace, Bolani, was planted as spreader around the field experiment and among the rows. The response of plants was evaluated using a modified Cobb's Scale, at flag leaf appearance. In the field, 52 genotypes were resistant to pathotype 134E134A+. Only 18 genotypes showed resistance to both pathotypes. The remaining lines and cultivars were scored moderately susceptible to susceptible. These resistant lines will be either released as new cultivars or used as sources of resistance in the national wheat breeding programmes.

Microsatellite-based detection of stripe [yellow] rust resistance gene *Yr24* in cv. Arrivato

S. Bhavani,[1] R.A. Hare[2] and H. S. Bariana[1]

1. University of Sydney Plant Breeding Institute, Cobbitty, Camden, Australia;
2. New South Wales Department of Primary Industries, Agricultural Research Institute, Calala Lane, Tamworth, Australia

The durum cv. Arrivato exhibits high levels of stripe [yellow] rust resistance. Genetic analysis based on 198 F_3 families derived from a cross involving Arrivato and the susceptible parent Bansi indicated digenic segregation for stripe rust response in the seedling stage. Single-gene segregating populations,

generated from monogenically segregating F_3 families, were used for molecular mapping of stripe rust resistance. The chromosome 1B-located markers gwm11 and gwm273 were mapped 2.5 cM and 6.5 cM proximal to the stripe rust resistance locus, respectively, in two monogenically segregating mapping populations. Several genes conferring resistance to stripe rust are located on the chromosome arm 1BS, namely *Yr10, Yr15, Yr24, YrH52* and *Yr26.* Ma and colleagues showed close genetic association of markers gwm11 and gwm18 with *Yr26*. Zakeri and colleagues showed close association of the microsatellite marker gwm11 with *Yr24*. Both these genes were transferred to hexaploid wheat from durum wheat genotypes. Close associations of the marker gwm11 in both cases suggested that *Yr24* and *Yr26* are likely to be identical. We concluded that the resistance gene located in the chromosome arm 1BS of cv. Arrivato was *Yr24*. Studies are in progress to determine the genomic location of the second stripe rust resistance gene carried by Arrivato

Genetics of adult plant stripe [yellow] rust resistance in wheat cv. Jagger

N.J. Willey and H.S. Bariana

University of Sydney Plant Breeding Institute, Cobbitty Australia

Resistance to stripe [yellow] rust can be broadly classified into two categories: seedling resistance and adult plant resistance (APR). Seedling resistance is conditioned by genes with major effects and is often complete and shown to be short-lived. In contrast, commercially acceptable levels of APR to stripe rust have been reported to be based on combinations of genes with minor effects. Individual components of APR *per se* seldom provide an adequate level of resistance; however, combinations of four or more genes can provide very high levels of resistance. The North American cv. Jagger displayed high levels of APR to stripe rust. Cv. Jagger was crossed with the susceptible parent Avocet S and BC_1F_2 families were developed and screened against *Puccinia striiformis* f.sp. *tritici* pathotype 134 E16A+ during the 2004 crop season. Chi-squared analysis of segregation data (97 resistant : 11 susceptible; $\chi^2_{7:1} = 0.53$ and $\chi^2_{15:1} = 2.85$, non significant at $P = 0.05$ and 1 d.f.) indicated the involvement of three to four genetically independent genes for APR in Jagger. Up to 100 individual plants from families putatively segregating at a single locus were grown during summer. Single-plant progenies have been planted in the field to isolate single-gene stocks for genomic location studies and further characterization.

Wheat seedling and adult plant resistance to yellow rust

Rsaliyev Shynbolat,[1] Tileubayeva Zhanar[1] and A. Morgounov[2]

1. Scientific Research Agricultural Institute (SRAI), Gvardeiskiy, Kazakhstan;
2. CIMMYT International

Unlike other rust species, yellow rust manifests itself and develops intensively on wheat seedlings. As a result the yield losses from the disease in the seedling stage are greater in comparison with the disease that occurs in the adult plant stage. Because of its early manifestation, some investigators call yellow rust "a seedling disease". However, according to abundant data, yellow rust develops also on adult plants, affecting generative organs as well and causing wheat grain losses. One of possible causes of rust development in different stages of plant growth can be the effects of juvenile and adult resistance genes. Due to this effectiveness of *Yr* genes in phases of wheat, seedlings and adult plants were studied using isogenic *Yr* lines of cv. Avocet and USA differentiating varieties with resistance genes. Juvenile resistance was studied in the field, in the greenhouse and in the climate chamber; adult plant resistance was studied in the field.

Analysis of resistance of Avocet isogenic lines and of differentiating varieties allows determining some regularities of *Yr* genes effect in different phases of wheat growth. Some resistance genes (*Yr1*, *Yr7*, *Yr11*) are heavily affected both in the early and in the late phases of plant vegetation. Resistance genes *Yr8* and *Yr17* that are highly effective in the seedling stage are ineffective in the adult plant phase. The older the plants of cv. Stephens, the more effective are the *Yr3a, YrSt1* and *YrSt2* genes. Slow-rusting genes form a separate group, and the varieties possessing them are affected by the disease, but very slowly. The effect of these genes is often recorded in the USA differentiating varieties Moro (*Yr10*), Lee (*Yr7*, *Yr22*, *Yr23*), Tyer (*YrTye*), Tres (*YrTr1, YrTr2*), Express (High-temperature, adult-plant (HTAP) resistance), Clement (*Yr9*, *YrCle*) and Compair (*Yr8*, *Yr19*). Slow-rusting genes *Yr9*, *Yr12*, *Yr18*, *Yr24* and *YrSk* were noted also in plants of Avocet isogenic lines.

The genes studied for wheat resistance to Kazakhstan populations of yellow rust are classified as follows:

- effective in all stages of plant growth: *Yr5*, *Yr10*, *Yr15*, *YrSP*, Druchamp (*Yr3*a, *Dru1*, *Dru2*), Riebesel 47/51 (*Yr9*), Produra (*YrPr1, Pr2*) and Yamhi II (*Yr2*, *Yr4*a);
- effective in the seedling phase: *Yr8*, *Yr17*, Lemhi (*Yr21*), Fielder (*Yr6*, *YrFie*) and Hyar (*Yr17*, *YrTye*);
- effective in the adult plant phase: Stephens (*Yr3*a, *YrSt1, YrSt2*);

- slow-rusting genes: *Yr9*, *Yr12*, *Yr18*, *Yr24, YrSk*, Moro (*Yr10*), Lee (*Yr7*, *Yr22*, *Yr23*), Tyer (*YrTye*), Tres (*YrTr1, YrTr2*), Express (high-temperature, adult-plant (HTAP) resistance), Clement (*Yr9*, *YrCle*), Compair (*Yr8*, *Yr19*); and
- ineffective plant genes: *Yr7*, *Yr11*, Chinese 166 (*Yr1*).

Occurrence and distribution of wheat stem rust in Syria

S. Al-Chaabi and B. Mustafa

GCSAR, Douma, Syria

Field surveys conducted of stem rust (*Puccinia graminis* Pers f.sp. *tritici* Erikss. et Henn.) on wheat in Syria during 1992–2007 showed that disease occurrence was limited, depending on the susceptibility of cultivars, the season and location. The disease was absent in most wheat-growing locations. Limited infested fields were observed in the 1994/95 and 2000/01 seasons on some durum cultivars in irrigated areas and on bread wheat cultivars in temperate zones. Assessment of reaction of wheat cultivars and lines to stem rust in on-farm yield trials under natural infection conditions revealed that most durum and bread wheat cultivars or lines were disease free. Reaction type of some differential cultivars against presented stem rust virulences was varied. The majority of Syrian promising and commercially grown durum and bread wheat cultivars showed no stem rust symptoms under natural infection conditions, with the exception of durum cvs Cham 1, Cham 5, Douma 41003, H. 8950, Bohouth 7, H. 5948, H. 8879 and Haurani, which were moderately susceptible in Al-Ghab Agricultural Research Centre during the 2005/06 season. The environmental conditions were still limiting factors for development of stem rust. The predominance of drought and high temperature during the early spring in Syria prevents development of disease epiphytotics.

Wheat rust surveillance

A. Yahyaoui

ICARDA, Aleppo, Syria

Monitoring of the trans-boundary air-borne rust diseases in field surveys using biological trap nurseries, when complemented with epidemiological investigations of pathogen movement through DNA fingerprinting and race analysis in order to determine the origin of new pathotypes, will provide an early warning system for farmers growing potentially susceptible cultivars. Furthermore, the knowledge of effective resistance genes in the region though testing them at rust hot-spots will enable breeders to incorporate and accumulate these genes in wheat germplasm, thus contributing to the development of resistant cultivars that sustain resistance for longer. Monitoring the evolution and migration of Ug99 is a high priority because: (1) several currently grown cultivars carry race-specific resistance genes that have a short life span; (2) the same cultivars are being grown over large areas in more than one country; and (3) the same genes conferring resistance to several rusts are deployed in cultivars grown in different countries. Rust populations share similar pathotypes in different regions, but novel virulence when it occurs would rapidly build up a large inoculum load on the defeated varieties, which often occupy large areas, and would move across a wider region. The expected movement of Ug99 based on simulations of the pathway of yellow rust in the 1990s could deviate, with the potential for devastating impacts on wheat production. The imminent threat of Ug99 and the development of more complicated races of both stem and yellow rust can be avoided or reduced though a global monitoring system that would provide an early warning system that would help avoid tremendous crop losses.

Meeting the Challenge of Yellow Rust in Cereal Crops

Proceedings of the Fourth Regional Yellow Rust Conference in the Central and West Asia and North Africa (CWANA) Region

Antalya, Turkey
10–12 October 2009

Scientific editors
Amor Yahyaoui and Sanjaya Rajaram

Jointly organized by
Turkish Ministry of Agriculture and Rural Affairs (MARA)
International Center for Agricultural Research in the Dry Areas (ICARDA)
International Maize and Wheat Improvement Center (CIMMYT)
Food and Agriculture Organization of the United Nations (FAO)

Contents

Abstracts only

List of participants

Algeria

Dr Benbelkacem Abdelkader, Institut National de la Recherche Agronomique d'Algérie, El Khroub

Australia

Dr Colin Wellings, Plant Breeding Institute, The University of Sydney

Dr Alexander Loladze, Plant Breeding Institute, The University of Sydney

Azerbaijan

Dr Ehtibor Ibraqimov, Azerbaijan Research Institute of Agriculture, Baku Abdin

Dr Abidin Abdullayev, Azerbaijan Research Institute of Agriculture

Canada

Dr S. Hambleton, Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, Ontario

China

Dr Z. Kang, Northwest A&F University

Dr X. Wang, College of Plant Protection and Shaanxi Key Laboratory of Molecular Biology for Agriculture, Northwest A&F University

Denmark

Dr Mogen Hovmøller, GRC-AARHUS

Egypt

Dr Mostafa El-Shamy, Wheat Diseases Research Department, Plant Pathology Research Institute, ARC, Giza

Dr Mousa Mosaad, ICARDA-Egypt

France

Dr Claudine Pope, INRA

Georgia

Ms Ketino Natsarishvili, Institute of Plant Immunity, Kobuleti

Ms Zoia Sikharulidze

India

Dr Mohinder Prashar, Rust Laboratory, Directorate of Wheat Research, Flowerdale, Shimla

Dr M.S. Saharan, Directorate of Wheat Research, Karnal, Haryana

Islamic Republic of Iran

Mr Safar Ali Safavi, Agricultural Research Station, Ardabil

Dr Mohammad Reza Jalal Kamali, CIMMYT-Iran Office, Seed and Plant Improvement Campus

Dr Siroos Mahfoozi, Department of Cereal Research, Seed and Plant Improvement Institute (SPII)

Dr Farzad Afshari, Seed and Plant Improvement Institute (SPII)

Dr Alireza Razavi, Agricultural Research and Natural Resources Centre, Khorasan Razavi

Majid Taherian, Islamic Azad University of Sabzevar

A.R. Souhani Darban, Department Agriculture, Mashad branch of Azad University

FAO

Dr Wafa Khoury

Kazakhstan

Dr Gulzat Essenbekova, Institute of Plant Biology and Biotechnology, Almaty

Dr Alma Kokhmetova, Institute of Plant Biology and Biotechnology, Almaty

Dr Sarbayev Amangeldy, Kazakh Scientific Research Institute of Husbandry and Agronomy, Almaty

Dr Yuriy Zelenskiy, CIMMYT - Kazakhstan

Kyrgyzstan

Academician Dzhamin Akimaliev, Kyrgyz Agricultural Research Institute

Dr Mira Dzhunusova, Kyrgyz Agrarian University

Morocco

Dr Brahim Ezzahiri, Hassan II Institute of Agronomy and Veterinary Medicine, Rabat

Nepal

Ms Sarala Sharma, Nepal Agricultural Research Council, Plant Pathology Division

Pakistan

Dr Makhdoom Hussain, Wheat Research Institute

Atiq ur Rehman Rattu, Crop Diseases Research Programme, IPEP – NARC, Islamabad

Salman Ahmad, University college of Agriculture, University of Sargodha

Russia

Mr Uriy Shumilov, All-Russia Research Institute of Biological Plant Protection, Krasnodar

Dr Galina Volkova, All-Russia Research Institute of Biological Plant Protection, Krasnodar

Tajikistan

Prof. Dr Hafiz Muminjanov, Tajik Agrarian University

Mr Mahbubjon Rahmatov, Tajik Agrarian University

Mr Munira Otambekova, Seed Association of Tajikistan

Dr Arne Hede, Sida Seed Project in Tajikistan

Dr Zebunisso Eshonova, Tajik Farming Institute, Sharora Settlement

Mr Bakhromiddin Khusenov, Tajik Agrarian University

Mr Ahadkhon Ibragimov, Chilgazi Seed Farm, Jamoat Chilgazi

Mr Mirzoali Karimov, Latif Murodov Seed Farm, Jamoat Dekhkonobod

Prof. Firuza Nasyrova, Institute of Plant Physiology and Genetics, Tajik Academy of Sciences, Dushanbe

Tunisia

Dr Allagui Mohamed Bechir, INRAT

Turkey

Mr M. Emin Şahin, Turkish Republic Ministry of Agriculture and Rural Affairs, Plant Protection Department

Dr Riza Unsal, Aegean Agricultural Research Institute-Menemen-İzmir

Dr Alexey Morgounov, IWWIP, CIMMYT-Turkey

Dr Masum Burak, TAGEM

Dr Mesut Keser, ICARDA Turkey

Dr Beyhan Akın, CIMMYT-Turkey

Prof. Mahinur Akkaya, METU

Dr Vehbi Eser, TAGEM

Mr Zafer Mert, Central Research Institute for Field Crops, Ankara

Mr Lütfi Çetin, Central Research Institute for Field Crops, Ankara

Mr Kadir Akan, Central Research Institute for Field Crops, Ankara

Dr Necmettin Bolat, Anatolian Agricultural Research Institute, Eskisehir

Dr Emin Donmez, Central Research Institute for Field Crops, Ankara

Mr Yuksel Kaya, Bahri Dagdas International Agricultural Research Institute, Konya

Sudan

Dr Abdalla Kurmut, Agricultural Research Corporation, New Haifa Research Station

Syria

Ms Shoula Kharouf, ICARDA, Aleppo

Dr Maarten Van Ginkel, ICARDA, Aleppo

Dr Amor Yahyaoui, ICARDA, Aleppo

Dr Osman Abdalla, ICARDA, Aleppo

Dr Nachit Meloudi, ICARDA, Aleppo

Dr Kumarse Nazari, ICARDA, Aleppo

Mr Munzer Naimi, ICARDA, Aleppo

Ms Maha Al Ahmed, ICARDA, Aleppo

Ms Iman Maaz, ICARDA, Aleppo

Mr Ziad Alamdar, ICARDA, Aleppo

Ukraine

Dr Olga Babayants, Plant Breeding and Genetics Institute, National Centre of Seed and Cultivar Investigation, Odessa

United States of America

Dr Xianming Chen, WSU Pullman, WA

Dr Eugene Milus, Fayetteville, AR

Uzbekistan

Dr Kushiev Habib, Gulistan State University

Dr Khabibjon Kushiev, Gulistan State University

Dr Saidmurat Kimsanbaevich Baboev, Institute of Genetics and Plant Experimental Biology of AS Ruz, Uzbek Academy of Sciences, Kibray, Tashkent

Mr Khurshid Turakulov Sadullaevich, Yukori-yuz, Kibray district

Dr Ram Sharma, Tashkent

Dr Zakir Khalikulov, Tashkent

Mr Safar Alikulov, c/o ICARDA-CAC Regional Office

Dr Martius Christopher, c/o ICARDA-CAC Regional Office

Identification of effective and durable resistance to yellow rust in spring and facultative winter wheats

A. Yahyaoui,[1] O. Abdalla,[2] M. Mosaad,[2] A. Morgounov,[3] M. Naimi,[2] M. Al Ahmed,[2] N. Marrawi,[2] A. Yajorka[2] and B. Djumakhanov[4]

1. ICARDA-CIMMYT Wheat Improvement Programme, ICARDA, Aleppo, Syria
2. ICARDA, Aleppo, Syria
3. CIMMYT-Turkey
4. ICARDA-Uzbekistan

Abstract

Wheat rusts present a constant threat to wheat production for many countries in Central and Western Asia (CWA), including Lebanon, Iran, Iraq, Syria and Turkey in Western Asia, and Azerbaijan, Tajikistan, Uzbekistan, Kyrgyzstan and Kazakhstan in Central Asia. A wide range of virulent yellow rust (*Puccinia striiformis* f.sp. *tritici*), stem rust (*Puccinia graminis* f.sp. *tritici*) and leaf rust (*Puccinia triticina*) pathotypes are evolving in this region, causing the breakdown of widely utilized sources of resistance in wheat. Hence, knowledge of effective resistance genes in the region will enable breeders to target those useful genes and reduce rust epidemics and crop losses. Wheat cultivars grown in CWANA were resistant to the prevalent rust populations when initially released. Within a few years, the corresponding virulence emerged and the genes lost immunity. A good example is the rapid spread of the virulent yellow rust race that defeated the *Yr9* resistance gene in the 1980s and caused a widespread epidemic on bread wheat from East Africa all the way to Pakistan across Western Asia. Currently, most wheat cultivars grown in CWA are susceptible to yellow rust. The wide cultivation of susceptible cultivars in East Africa and CWANA region may have an important impact on rust inoculum development, virulence change, and consequent epidemics.

Introduction

Wheat rusts present a constant threat for wheat production in many countries in Central and Western Asia (CWA), including Lebanon, Iran, Iraq, Syria and Turkey in Western Asia, and Azerbaijan, Tajikistan, Uzbekistan, Kyrgyzstan and Kazakhstan in Central Asia. A wide range of virulent yellow rust (*Puccinia*

striiformis f.sp. *tritici*), stem rust (*Puccinia graminis* f.sp. *tritici*) and leaf rust (*Puccinia triticina*) pathotypes are evolving in this region, causing breakdown of widely utilized sources of resistance in wheat. Hence, knowledge of effective resistance genes in the region will enable breeders to target those useful genes in their breeding programmes and avoid eventual rust epidemics and consequent crop losses.

Wheat cultivars grown in CWANA were resistant to the prevalent rust populations when initially released. After a few years of cultivation, the corresponding virulence emerges and the resistance genes became less effective. A good example is the rapid spread of the virulent yellow rust race that defeated the *Yr9* resistance gene in the 1980s, which caused a widespread epidemic on bread wheat from East Africa all the way across Western Asia to Pakistan. Currently, most wheat cultivars grown in CWA are susceptible to yellow rust. The wide cultivation of susceptible cultivars in East Africa and CWANA region may have an important impact on rust inoculum development, virulence change, and consequent epidemics. To develop appropriate, practical and easy to handle methodologies for effective screening for different types of resistance, we tested the known resistance genes for yellow rust against various virulence types and at different rust hot-spots in CWANA.

Materials and methods

Known yellow rust resistance genes and commercial cultivars (Table 1), that have been used in the Cereal Rust Trap Nursery and tested at several locations in CWANA, were selected based on their differential responses to yellow rust isolates under artificial inoculation, as well as their reaction to natural infections at several locations in Azerbaijan, Ethiopia, Lebanon, Iran, Tajikistan, Turkey, Syria and Yemen.

Table 1. Yellow rust resistance genes and commercial cultivars

Resistance Genes	Source or Origin
Yr*A*, *Yr1*, *Yr6*, *Yr5*, *Yr3*N, *Yr3*V, *Yr7*, *Yr9*, *Yr10*, *Yr15*, *Yr17*, *Yr27*, *YrSP*	Avocet isolines
Yr6+	Heines Peko
Yr7+	Reichersberg 42
Yr8 +18	Compair
YrSD	Strubes Dickopf
YrSU	Suwon 92×Omar
YrCV	Carstens
Commercial Cultivars	
Yuna, Destluck, Tarragui, Zhetysu and Karakylchyk	Cultivated in Central Asia
Seri 82, Alamout, Attila, Shirodi, Darab, Cham 1 and Triticale	Cultivated in West Asia

For each resistant genotype (Table 1) we determined, under artificial inoculation, the Area under disease progress curve (AUDPC) using the average coefficient of infection (ACI). The Coefficient of Infection (CI) combines disease severity and host reaction in the form:

Coefficient of Infection (CI) = Severity × Value of host reaction

where: Severity values vary from 0 to 100

and: Values of host reaction are attributed as follows: 0.0 = Immune reaction; 0.2 = Resistant (R) reaction; 0.4 = Moderately Resistant (MR) reaction; 0.6 = Moderately Susceptible (MS) reaction; 0.8 = Susceptible (S) reaction; and 1.0 = Very Susceptible (VS) reaction.

AUDPC combines the Average CI and the duration of the observation in weeks. Infection type was recorded weekly. First measurements were taken 7 days after first appearance of symptoms (21 March 2005) on the universal susceptible check cv. Morocco. The disease recording dates were: 21 March = appearance of symptoms on universal susceptible check, then 28 March = Week 0, 16 May = Week 7, and 23 May = Week 8.

A modified Cobb scale was used that considers the actual percentage (0–100%) occupied by rust pustules and the rust severities (R, MR, MS, S and VS) of the modified Cobb scale (Peterson, Campbell and Hannah, 1948).

Results and discussion

Adult plant resistance (APR) could offer a possible means for control of yellow rust disease in wheat. Yellow rust suffers most damage at the adult growth stage. Rust spores blown by wind from within an area or the region can rapidly infect susceptible plants and produce more inoculum for subsequent infection, particularly in the facultative winter wheat area, where the vegetative period of wheat extends for up to six to seven months. Effective adult plant resistance would reduce the inoculum intensity and hence reduce spread of yellow rust spores, in addition to the direct protection it provide for the wheat cultivars. In order to determine effectiveness of APR, known resistance genes were assessed singly and in combination. Sixteen yellow rust resistance genes from the Avocet isogenic lines, and three gene combinations among differential cultivars were evaluated under artificial inoculation at the Tel Hadya station of ICARDA, and assessed at different location in Central, West Asia and Nile Valley regions (including Ethiopia). Commercial cultivars that are commonly grown in Central and West Asia and 200 advanced breeding lines were also assessed. The ACI combined repeated reading during the same period (week 0 to week 6) and those realized at different locations (Week 7). The disease recording extended over seven weeks. In that short time (23 March to 18 May 2005) it was possible to discriminate the different levels of

resistance at seedling and adult growth stages. ACI for the last recording date (Week 7; 18 May 2005) at Tel Hadya under artificial inoculation was combined with the long-term average of records at hot-spots from several locations in CWA. The three vertical arrows shown on Figures 1 to 4 correspond to the onset of adult plant resistance reaction type (first arrow on Week 2, i.e. 14 days after symptom appearance), the optimum expression of adult plant resistance (arrow 2 on Week 4), and to the final expression of the resistance gene (arrow 3 on Week 6, i.e. 42 days after symptom appearance). The horizontal arrow corresponds to a cut-off point (threshold) for risk assessment or economic yield loss. Points above the line (ACI >0.5) represent high risk; the corresponding gene will not give enough protection for the remaining duration of plant growth.

The resistance genes were divided into two classes: ineffective resistance genes (IR) or effective resistance genes (ER). Each class has several groups and each group has resistance genes that have similar reaction on host differential plants under artificial or natural infection. The different groups within each class were:

Ineffective Resistance (IR) Genes – IR1 were susceptible cultivars Morocco and Avocet "S"; IR2 were *Yr6*, *Yr7*; IR was *YrA*; IR4 was *Yr9*; IR5 were *Yr10*, *YrSP*, *Yr27*; and IR6 was *Yr17*. Effective Resistance (ER) Genes – ER1 were *Yr6+*, *Yr7+*; ER2 were *YrSD, YrSU*; ER3 was *Yr3V*; ER4 was *Yr8* and *Yr18* combined; ER5 was *Yr1*; and ER6 were *YrCV*, *Yr5*, *Yr3N* and *Yr15.*

Figure 1 shows the trends of disease progress of the ineffective resistance genes, such as the universal susceptible check cvs Morocco and Avocet S, labelled as IR1; similar trends are shown by IR2 (*Yr6*, *Yr7*), IR3 (*YrA*) and IR4 (*Yr9*). IR5 (*Yr10*, *YrSP*, *Yr27*) shows a stable high reaction type with a high ACI of 0.8. IR6 (*Yr17*) shows a misleading trend, as in the case of many cultivated wheat varieties (Figure 3). This gene could be very effective in areas where yellow rust is sporadic, such as North Africa, where yellow rust occurs once every 5–8 years. This gene provides adequate protection at the onset of infection, then the resistance become ineffective towards the end of the season, which could be of no problem in a warm climate and on early maturing spring wheat varieties in wheat growing areas such those in Egypt, Sudan and parts of North Africa. However, it would be high risk to use the *Yr17* resistance gene in association with winter or facultative and winter wheat varieties, or under cool humid conditions in areas such as the Caspian Sea.

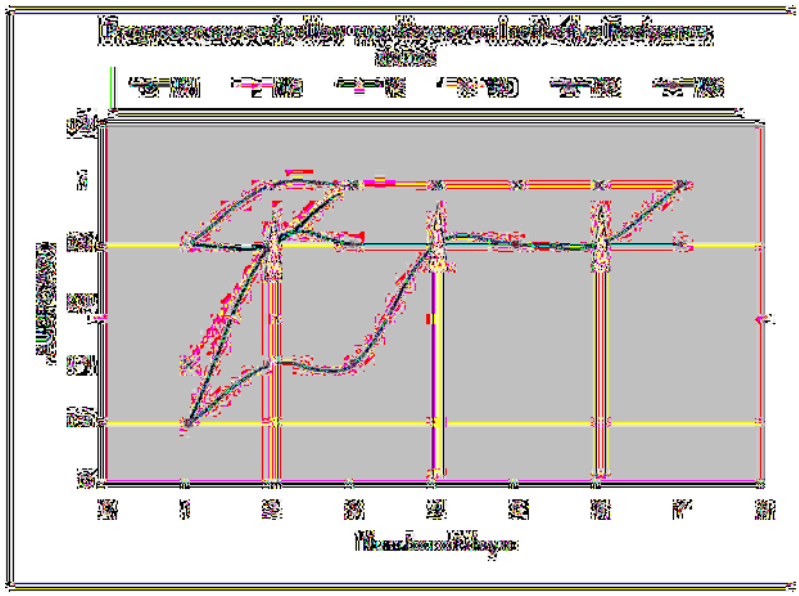


Figure 1. AUDPC of ineffective resistance genes for yellow rust disease

Effective resistance genes, under field conditions, that confer good protection at adult growth stages (Figure 2) show a low risk (ACI <4) all through the growing season, hence only minor yield loss would be expected. Genes such as *Yr6*+ and *Yr7*+ (ER1) show a susceptible reaction at early growth stages, and a similar trend is shown by ER2 (*YrSD, YrSU*). ER3 (*Yr3V*), ER4 (combined *Yr8* and *Yr18*) and ER6 (*YrCV*, *Yr5*, *Yr3N* and *Yr15*) show consistent good resistance levels and would provide adequate protection to wheat varieties grown in rust-prone areas; these genes could become more effective and ensure a sustainable protection if used in combination. Effective resistance genes should be carefully monitored to avoid surprises due rapid break down of resistance. ER5 (*Yr1*) is a good example: an increase in infection type was observed in Tajikistan, whence it slowly spread to Kyrgyzstan, Kazakhstan and Uzbekistan, and has recently been observed in Syria and Lebanon. ACI values that combined those under artificial inoculation and average values from other sites show a rapid increase on the final reaction type. This poses a high risk for late maturing varieties, as well as the facultative and winter wheat; the late epidemics in Central Asia are certainly associated with the breakdown of this resistance gene.

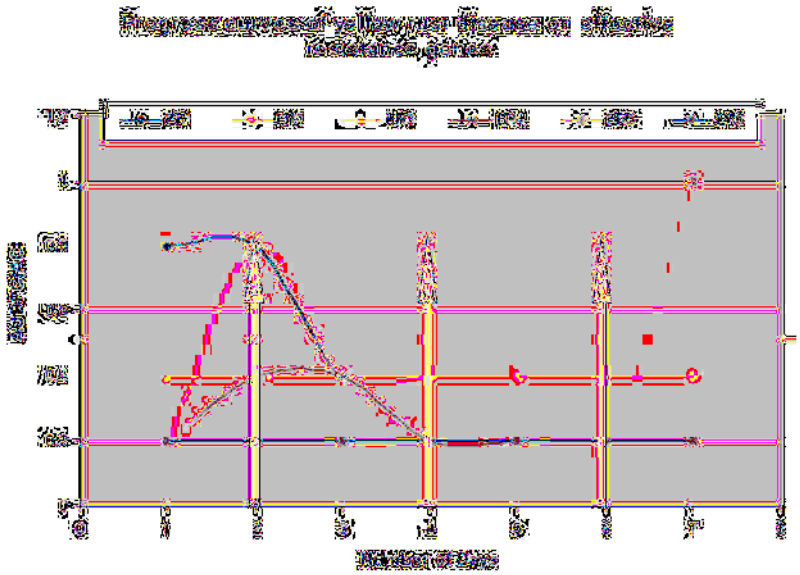


Figure 2. AUDPC of effective resistance genes for yellow rust disease

The characterization of resistance genes is tedious and time consuming, hence exploitation and monitoring of their reaction type over time and against various pathotypes (races) would allow better understanding of the evolution of virulence factors in the rust disease pathogen. The AUPDPC using ACI values tested on known resistance genes allowed discrimination of the resistance levels of commercial cultivars and elite lines. Figure 3 shows the disease development on susceptible cultivars (Yuna, Destluck, Seri82, Tarragui and Zhetysu), all of which were positioned in the high-risk area. A triticale line was used for comparative purposes, as triticale usually show adult plant resistance towards the end of the season. The triticale line showed a high infection type at the beginning, then a progressive drop after Week 4. This trend is highly desirable in Central Asia and the Caucasus. This type of reaction was selected for in newly released cultivars (Figure 4). The Iranian cv. Alamout shows a susceptible reaction type at the beginning of the season and tapers off sharply to stabilize at an ACI of 0.4, which is a low-risk value; the same is shown by cv. Karakylchyk selected in Azerbaijan. As discussed earlier for the case of *Yr1* (ER5; Figure 2), the line Attila shows the same trend, and most likely cv. Shirodi (a derivative of Attila) will follow the same trend in coming years.

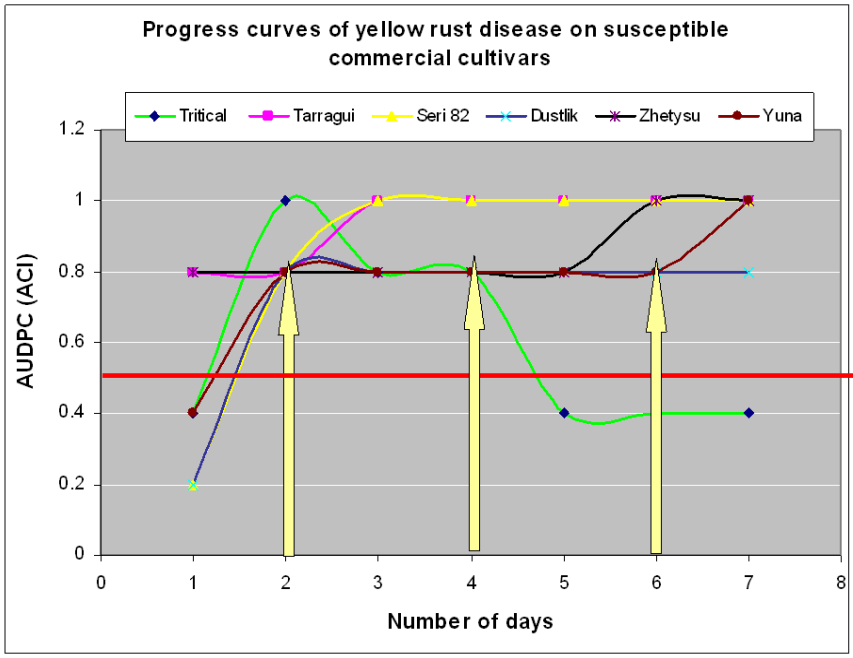


Figure 3. AUDPC of susceptible wheat cultivars for yellow rust disease

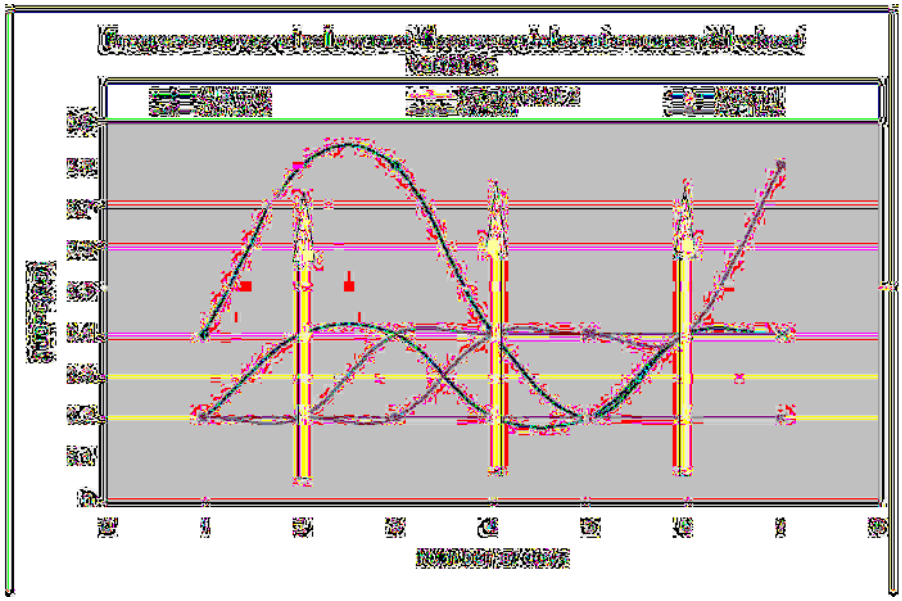


Figure 4. AUDPC of tolerant/resistant wheat cultivars for yellow rust disease

ACI values for AUDPC were used to characterize a large number of cultivars and elite lines under artificial inoculation in screening for yellow, stem and leaf rusts. Selected lines will be further tested under natural infection challenge at hot-spots for yellow rust (Azerbaijan, Ethiopia, Lebanon, Iran, Tajikistan and Yemen), leaf rust (Ethiopia, Lebanon, Kazakhstan and Morocco) and stem rust (Egypt, Ethiopia, Kenya, Morocco and Tunisia).

Among 200 bread wheats tested, three accessions showed complete resistance and 28 showed adequate adult plant resistance to the three rusts. About 71 accessions showed combined resistance to two rusts (Figure 5). Over 70 accessions showing resistance to a single rust disease (Table 2) or combinations of the rusts will be further evaluated for resistance to stem rust at hot-spots in East Africa.

Table 2. Distribution of 200 wheat lines according to their levels of reaction to rust diseases under artificial inoculation at Tel Hadya, Aleppo

Resistance level	3 Rusts	YR-LR	YR-SR	LR-SR	YR	SR	LR	Susceptible to 3 rusts
Complete resistances (R-type)	3	0	14	9	33	18	0	
Adult plant resistance	28	7	40	5	20	1	1	
Total number of lines	31	7	54	14	53	19	1	21

NOTES: Rust diseases: YR = yellow rust; LR = leaf rust; SR = stem rust. Adult plant resistance is measured as discussed for known resistance genes

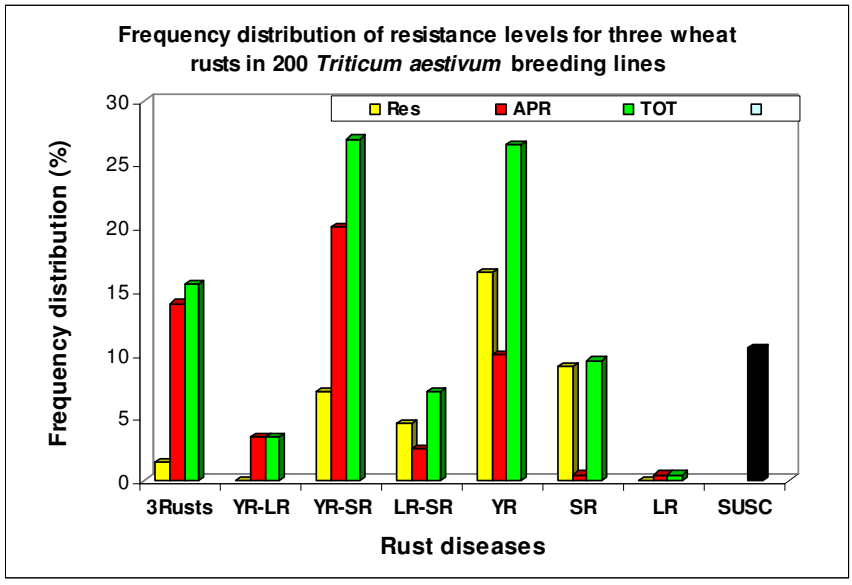


Figure 5. Frequency distribution of resistance levels among a collection of bread wheat breeding lines and varieties

Among the wheat lines tested, 51% conferred adult plant resistance, among which 14% combined resistance to the three rusts and 26% to two of the rusts. All the accessions showed adult plant resistance to a single rust.

Reference

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Wheat yellow rust epidemics in Uzbekistan in 2009

R.C. Sharma,[1] A. Amanov,[2] Z. Khalikulov,[1] C. Martius,[1] Z. Ziyaev[3]and S. Alikulov[3]

1. ICARDA, Central Asia and the Caucasus Regional Programme, Tashkent, Uzbekistan
2. Principal Consultant to the President's Office, Uzbekistan
3. Uzbek Research Institute of Plant Industry, Tashkent, Uzbekistan

Abstract

Severe wheat yellow rust epidemics occurred in many parts of Uzbekistan in April and May 2009. This yellow rust outbreak was experienced from the mid-southern region bordering Afghanistan and Turkmenistan to the north-east region of Fergana valley adjoining Kyrgyzstan and Tajikistan. The southern region of Uzbekistan experienced early, more severe epidemics than the northern part. The epidemics spread from irrigated to some of the traditionally rainfed wheat areas that had not experienced yellow rust problems for a long time. All released and candidate wheat cultivars planted in the epidemic zones showed susceptibility to yellow rust; a few showed severe infection for the first time. Late winter and spring weather conditions were unusually wet, creating favourable environments for development of yellow rust epidemics. Fungicides were sprayed to control the disease; however, frequent rains reduced the effectiveness of the chemicals. Estimates of grain yield reductions would depend upon cultivar, level of epidemics and effectiveness of fungicides. The older wheat cultivars showed up to 100S, whereas more recent cultivars showed up to 80S reaction to yellow rust. The most widely cultivated wheat cultivar in Uzbekistan, Kroska, showed high levels of susceptibility to yellow rust. There could be substantial economic losses, considering that Uzbekistan annually produces over 6 million tonne of wheat. The susceptibility on a few cultivars for the first time raises suspicion of new yellow rust virulence in Uzbekistan, which needs to be confirmed. Despite these severe epidemics, several advanced lines from the International Winter Wheat Improvement Programme (IWWIP) and other sources have shown resistance to yellow rust, underscoring the value of germplasm exchange. Identification of advanced breeding lines of winter wheat resistant to yellow rust in the severe epidemics in 2009 could be useful not only for Uzbekistan but also for other wheat improvement programmes in Central Asia, as well for the IWWIP to target for developing yellow rust-resistant wheat.

Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal, directly linked to food security and rural livelihood in central Asia, including Uzbekistan. There are many biotic and abiotic constraints to successful wheat cultivation in the region. Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici,* is the most important disease of wheat managed under irrigated conditions. This is clearly reflected by the frequent outbreaks of yellow rust in the region. For example, four (1999, 2001, 2005 and 2009) yellow rust epidemics have occurred in the past 11 years in Uzbekistan. Other countries in the region, such as Iran and Afghanistan, have also experienced frequent outbreaks of yellow rust, and hence pose a threat to wheat cultivation in Uzbekistan. A recent study has shown similarity among yellow rust strains from Central Asia, West Asia and South Europe (Hovmøller, Yahyaoui and Milus, 2008). Hence, a regional strategy is needed to manage trans-boundary wheat yellow rust in Central and West Asia.

The wheat farmers in Uzbekistan grow a number of wheat varieties developed by the breeding station in Krasnodar, Russia. Prior to 1999, the wheat crop in Uzbekistan often experienced epidemics of leaf rust. In the mid-1990s, Uzbekistan started large-scale cultivation of winter wheat cultivars developed by Krasnodar. Consequently, leaf rust damage to the wheat crop in Uzbekistan was considerably reduced. However, the wheat varieties developed by Krasnodar that were grown in Uzbekistan in the 1990s were not resistant to yellow rust. This resulted in the first epidemic of yellow rust in Uzbekistan, in 1999. The yellow rust epidemic of 1999 caused substantial economic loss to wheat farmers of Uzbekistan, because a popular wheat cv. Yuna, that had been cultivated on 70% of the wheat-growing area in the country, proved highly susceptible. In order to avoid large-scale damage to the wheat crop in following years, the Government of Uzbekistan made a strategic decision that each region of the country must grow at least seven wheat varieties. However, yellow rust continues to plague wheat crops in Uzbekistan at regular intervals, which is primarily controlled through fungicide sprays.

Once again there was a serious outbreak of yellow rust in Uzbekistan, in 2009, at a level not seen during previous epidemics. This caused substantial damage to the wheat crop. This study summarizes the development of yellow rust epidemics and disease severity on leading commercial wheat cultivars in Uzbekistan during the yellow rust epidemic of 2009.

Weather conditions and development of epidemic

The winter and spring seasons in 2009 in Uzbekistan were unusually moist, as precipitation up to 125% of the norm was experienced in several parts of the country. The winter temperatures were above normal, and thus conducive to yellow rust infection in several part of the country. Consequently, the first symptoms of yellow rust were observed in commercial fields in the central

southern part of Uzbekistan in February, when the wheat crop in that region was in the pre-booting stage. The temperatures in adjoining regions rose to a range suitable for yellow rust development, and rust symptoms were observed in March in new areas. By the end of March, the disease outbreak has spread over several other regions and continued through April and the first half of May. Because of persistent rain in March and April, the temperatures remain cool enough to allow disease spread. By the end of April, the disease had spread from the central southern part (bordering Afghanistan and Turkmenistan) to the north-east, reaching the Fergana Valley. The most severe disease epidemics were experienced in Samarkand, Jijjax, Syrdarya and Tashkent provinces.

Varietal responses

There were 22 winter wheat varieties commercially planted in different regions of Uzbekistan during 2008–2009. Their name, origin and year of release in Uzbekistan are presented in Table 1. All these varieties were grown in one or more regions of Uzbekistan where yellow rust epidemics occurred in 2009. Of the 22 varieties listed in Table 1, 20 showed susceptibility to yellow rust, but the level of disease severity differed, as 13 varieties showing >60% severity could be considered highly susceptible, and 7 varieties showing 20–40% severity could be considered moderately susceptible. Only two varieties were resistant. Cv. Kroshka, released in 2000 and occupying >20% of the wheat area in 2009 in Uzbekistan, was highly susceptible.

Upon observing initial yellow rust symptoms, farmers sprayed fungicide to limit the spread of disease and slow down the pace of infection. However, frequent rains, sometimes occurring soon after completing a spray, washed fungicide off the foliage and making chemicals less effective than expected. This compelled the farmers to apply multiple sprays of the fungicide on the same wheat fields. Achieving only partial control of the disease despite multiple sprays of the fungicide reduced grain yield, and also added to the cost cultivation, hence reducing the profit margin to the wheat growers.

The causes of the wheat yellow rust epidemics in Uzbekistan in 2009 are not fully understood. The unusually wet weather during winter and less harsh winter meant temperatures were suitable for yellow rust infection, and decidedly helped in fast spread of the disease. However, many varieties, including a few recently released ones, becoming susceptible in one year raises suspicion of a new race. Though these wheat varieties have not been tested before, limited previous information suggests that central Asian wheat possess *Yr1* and *Yr9* resistance genes.

Sources of resistance

Through the International Winter Wheat Improvement Programme (IWWIP)—a cooperative breeding project between the Ministry of Agriculture and Rural Affairs of Turkey, CIMMYT and ICARDA (see www.iwwip.org)—166 winter

wheat germplasm lines from were tested in the yellow rust epidemic zone in Uzbekistan in 2008/09. A large number (60%) of these winter wheat lines showed resistance to yellow rust (disease severity <20%). The detailed results of this study have been reported by Alikulov *et al.* (2009). These results suggest that apart from economic losses caused by the disease, the epidemic provided an excellent opportunity to identify many resistant lines, which could go a long way towards developing yellow rust-resistant wheat for Central Asia by including them in crossing programmes in the region.

Table 1. Yellow rust infection on commercial winter wheat cultivars in Uzbekistan, 2009

Wheat Variety	Origin	Year of release	Yellow rust severity (%)
Polovchanka	Russia	1999	100 S
Kroshka	Russia	2000	100 S
Umanka	Russia	2000	60 S
Chillaki	Russia	2002	80 S
Andijon 2	Uzbekistan	2003	60 S
Saidaziz	Uzbekistan	2004	20 S
Starshina	Russia	2004	30 S
Zamin 1	Uzbekistan	2004	0
Dustlik	Turkey	2005	40 S
Bobur	Uzbekistan	2006	60 S
Krassnodar 99	Russia	2006	60 S
Kuma	Russia	2006	60 S
Pamyat	Russia	2006	100 S
Tanya	Russia	2006	60 S
Fortuna	Russia	2007	100 S
Moskvich	Russia	2007	60 S
Nota	Russia	2007	40 S
Turkistan	Russia	2007	30 S
Vostorg	Russia	2007	40 S
Andijon 1	Uzbekistan	2008	80 S
Essaul	Russia	—	0
Karshi 1	Uzbekistan	—	40 S

Conclusions

Severe wheat yellow rust epidemics occurred in many parts of Uzbekistan in 2009. Late winter and spring weather conditions were unusually wet and temperatures suitable for yellow rust epidemics from February to May.

Fungicides were sprayed to control the disease, but frequent rains reduced the effectiveness of the chemicals. Estimates of grain yield reductions depended upon cultivar, level of epidemics and effectiveness of fungicides. The older wheat cultivars showed up to 100S, whereas the recent cultivars showed up to 80S reaction for yellow rust. This yellow rust epidemic was different from previous ones because of the large number of varieties succumbing to the disease. A regional strategy is needed for Central Asia and adjoining countries in West Asia to manage yellow rust in the region. Despite these severe epidemics, several advanced lines from IWWIP and other sources showed resistance to yellow rust, underscoring the importance of germplasm exchange. Identification of advanced breeding lines of winter wheat resistant to yellow rust under severe epidemics in 2009 could be useful not only for Uzbekistan but also for other wheat improvement programmes in Central and West Asia, as well for IWWIP in developing yellow rust-resistant wheat.

References

Alikulov, S., Amanov, A., Ziyaev, Z., Khalikulov, Z. & Sharma, R.C. 2009. Study of diverse winter wheat germplasm for resistance to yellow rust under severe epidemics in Uzbekistan. Paper presented at the 4th Regional Yellow Rust Conference, 10–12 October 2009, Antalya, Turkey. This volume.

Hovmøller, M.S., Yahyaoui, A.H. & Milus, E.A. 2008. Rapid global spread of aggressive strains of a wheat rust fungus. *Molecular Ecology*, 17: 3818–3826.

An analysis of the 2009 epidemic of yellow rust on wheat in Morocco

B. Ezzahiri,[1] A. Yahyaoui[2] and M. Hovmøller[3]

1. Hassan II Institute of Agronomy & Veterinary Medicine, Rabat, Morocco
2. Coordinator ICARDA-CYMMYT Wheat Program
3. Faculty of Agricultural Sciences, University of Aarhus, Denmark

Abstract

Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, caused substantial losses of bread wheat production in some major wheat growing areas of Morocco in 2009. This is primarily a disease of cool climates. However, outbreaks of yellow rust have been reported in the past in the neighbouring countries in the western Mediterranean region (Portugal, Spain, Italy, Tunisia and Algeria). The outbreak of yellow rust in Morocco in 2009 could be attributed to favourable climatic conditions for disease onset, widespread cultivation of susceptible cultivars, and the presence of virulent pathotypes. In this presentation, we evaluate the development of the yellow rust epidemic and its impact on wheat production. The first foci of yellow rust were observed in mid-February in the plains and the plateaus located near the Middle Atlas. The disease spread rapidly in these areas during March–mid-April. Later, the epidemic moved to wheat fields located in the middle Atlas at higher elevations. The analysis of the climatic conditions of the growing season 2008/09, compared with the long-term averages, indicated that temperatures were normal for the season. However, precipitation was more regular and more abundant than in a normal season. The epidemic was also favoured by the genetic uniformity of cultivars grown, in terms of susceptibility. Thus, the susceptible cultivars covered about 70% of the area planted to bread wheat. One cultivar, Achtar was 45% of the total bread wheat crop. This cultivar, previously resistant, succumbed due to the occurrence of a new pathotype of yellow rust in Morocco. In this respect, the samples of yellow rust collected in 2009 were found to belong exclusively to this pathotype. Its spectrum of virulence includes *Yr6, Yr7, Yr8, Yr9* and *Yr27*. The epidemic caused by this pathotype resulted in an estimated loss of US$ 60 million in rainfed areas and an additional expenditure of US$ 1 million on fungicides in an irrigated area where yellow rust was present.

Introduction

Yellow rust (*Puccinia striiformis* f.sp. *tritici*) caused substantial losses of wheat production in some major wheat growing areas of Morocco in 2009, due to rapid systemic infection of affected plants resulting in defoliation and shrived kernels. This is primarily a disease of cool climates. In Morocco, it had occurred in continental areas, without causing major losses. However, outbreaks of yellow rust have been reported in the past in the neighbouring countries in western Mediterranean. Thus, serious attacks of the disease occurred in Portugal in 1957 and 1960 (Zadoks, 1965), in Spain in 1957, 1960 and 1978 (Zadoks, 1965; Nagarajan *et al.*, 1984), and in Italy, Tunisia and eastern Algeria in 1977 (Ghodbane, 1977; Vallega and Zitelli, 1979). A recent epidemic of yellow rust was reported in Algeria in 2004, but not documented.

The outbreak of yellow rust could be attributed to favourable climatic conditions for disease onset and spread, to the widespread adoption of susceptible cultivars and the presence of virulent pathotypes (Zadoks and Bouwman, 1985). The objective of this paper is to analyse the components of the epidemic (climate, host and pathogen) that had occurred in the growing season 2008/09 in yellow rust-prone areas and to assess its impact on wheat production.

Materials and methods

Disease survey

Field trips were organized to locate yellow rust foci and to assess the subsequent disease development. There were four surveys: 12–13 March, 27–28 April, 15 May and 13 June. The areas surveyed were the Sais plains and the Middle Atlas Mountains. Stops were made each 20 to 30 km. At each stop we recorded the location (using GPS), the cultivar, the growth stage and disease severity (percentage of leaf area infected). An estimate was made each time on the potential yield and predicted yield loss.

Experimental yield loss estimation

A fungicide trial was conducted to determine potential yield loss caused by yellow rust. We compared one and two fungicide applications in addition to the control. The plot size was 50×12 m. The widely grown susceptible cv. Achtar was used. The fungicide was applied when the first yellow rust foci were observed on a neighbouring field, and the wheat was at the two-node growth stage. Opus (epoxiconazole) was sprayed at the rate of 1 L/ha on 26 February 2009. The second fungicide application took place four weeks later, at heading stage. Disease severity data were recorded each week after the first fungicide application. Yield components were determined at harvest in May.

Overall yield loss estimation

A general estimate of the overall yield loss was made by gathering the information collected during field surveys (disease severity and growth stage) and data on bread wheat area and varieties planted.

Race identification

Yellow rust samples were collected during field surveys. Leaves with single lesions were collected and put in Petri dishes containing agar and benzimidazole. Pathotype determination was by standard procedures.

Meteorological data analysis

Meteorological data for the 2008/09 season and the 30-year average were compiled for two stations: Rabat station, located on the Atlantic coast, with sporadic yellow rust; and Meknes station, representing the region where yellow rust was severe. The data used were monthly average of daily minimum, maximum and mean temperatures, and monthly rainfall. Disease severity varied from trace to 90% (Table 1), with 48.5% of the surveyed fields showing disease severities between 50 and 90%.

Table 1. Frequency (%) of classes of yellow rust severities in surveyed bread wheat fields

Severity class	Bread wheat fields	
	Number	Percent
Trace	07	08
5 – 10	22	26
20 – 40	15	17.5
50 – 70	25	29.5
80 – 90	16	19

Results and discussion

Disease survey

The survey covered 85 bread wheat fields, with 74.5% of the fields at a growth stage between 59 and 71 (Table 2)

Table 2. Growth stages of the bread wheat fields surveyed for yellow rust

Growth stage[(1)]	Description	Bread wheat fields	
		No.	Percent
39	Flag leaf visible	06	07
49	First awns visible	09	10.5
59	Emergence of inflorescence complete	16	19
69	Anthesis completed	25	29.5
71	Caryopsis watery ripe	22	26
75	Medium milk	07	08

NOTES: Growth stage using decimal scale of Zadoks, Chang and Konzak, 1974.

Experimental yield loss estimate

The yield component most affected by yellow rust was the kernel weight. A loss of 41% was recorded in the experiment.

Overall yield loss estimate

The area planted to the susceptible cv. Achtar was about 45% of the total bread wheat area. The potential average yield of the surveyed fields was estimated to be 3.5 t/ha. The estimated mean loss was 0.5 t/ha. Thus, total yield loss on cv. Achtar is estimated to be 100 000 tonne, worth ca US$ 30 million. (Table 3)

Table 3. Estimated yield loss of bread wheat due to yellow rust in the Sais region and the Middle Atlas mountains

Area planted to bread wheat	280 000 ha
Area planted to susceptible cv. Achtar	196 000 ha
Potential average yield (surveyed fields)	3.5 t/ha
Estimated mean loss (surveyed fields)	0.5 t/ha
Total production of cv. Achtar	700 000 t
Predicted production loss of cv. Achtar	100 000 t
Monetary loss	US$ 30 million

Race identification

The isolates of yellow rust collected from Morocco were of the same race. They were identical to the race pattern of the aggressive strain spreading in east Africa (Ethiopia/Eritrea) and West and Central Asia, i.e. virulence for *Yr2, Yr6, Yr7, Yr8, Yr9, Yr27* and *YrSD*.

Meteorological data analysis

The season 200/09 was in general cooler than the 30-year long-term average for most of the months, starting from October, as shown for the two locations of Rabat and Meknes (Tables 4a and 4b). The rainfall in this season was abundant, early and regular. The amount of rainfall was about 30% more than an average year (Tables 5a and 5b). Climatic conditions were therefore favourable for yellow rust onset and its epidemic spread. We note that yellow rust was becoming more prevalent in Morocco in the last few years. Thus, the carry over of inoculum has become important, increasing the chances of the pathogen surviving the summer. The prevailing summer weather conditions were reported to have a profound influence on the yellow rust epidemic in the following winter, spring and summer (Rapilly, 1979). If mean air temperatures are above 30°C for long periods, the urediniospores and the fungus in the lesions are inactivated. Thus, little inoculum carries over into the autumn-winter period to infect volunteer plants. Mild or moist summers favour the pathogen and inoculum is readily carried through for the next season. This is the case for the mountains in Morocco, where occasional rain showers occur in the summer.

Table 4a. Monthly mean temperature (°C) for the season 2008/09 compared with 30-year average for Meknes

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
30 years average	18.6	14	11	9.8	11.2	13.4	14.7
Season 2008-2009	16.6	11.6	9.1	9	11.3	14.5	14.2
Deviation from long term	-2.0	-3.4	-1.9	-0.8	+0.1	+1.1	-0.5

Table 4b. Monthly mean temperature (°C) for the season 2008/09 compared with 30-year average for Rabat

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
30-year average	21.7	15.7	13.2	11.9	12.9	14.6	15.7
Season 2008/09	18	13.5	11.7	10.2	9.4	15.2	14.6
Deviation from long term	-3.7	-2.2	-1.5	-1.7	-3.5	-0.6	-1.1

Table 5a. Monthly rainfall (mm) for the season 2008/09 compared with 30-year average for Meknes

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
30-year average	46	49	64.4	53.7	51	52	48
Season 2008-2009	68	106	126	124	84	59	11.4
Deviation from long term	+22	+57	+61.6	+70.3	+33	+07	-36.6
Percent deviation	+19%	+37%	+32%	+39%	+24.4%	+6%	—
Average deviation = +28%							

Table 5b. Monthly rainfall (mm) for the season 2008/09 compared with 30-year average for Rabat

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
30-year average	41.6	68.5	83.4	78	51.3	59.6	44.6
Season 2008-2009	73.4	200	142	107	118	105	74
Deviation from long term	31.8	131.5	58.6	29	66.7	45.4	29.4
Percent deviation	20%	49%	26%	15.6%	39.4%	27.6%	24.8%
Average deviation = +29%							

Conclusion

The outbreak of yellow rust in Morocco in the season 2008/09 was the consequence of favourable climatic conditions, the widespread cultivation of a susceptible cultivar and the presence of a virulent pathotype of the pathogen.

The weather was favourable from the beginning of the season, allowing the rust enough time to spread and develop. The presence of an aggressive pathotype of the pathogen aggravated the situation.

The area planted to bread wheat is increasing in Morocco, and that of durum wheat is decreasing. This will probably favour yellow rust becoming an established disease and be economically damaging to the wheat crop. Thus it is necessary to start a yellow rust research programme in Morocco that includes epidemiological studies, virulence surveys, screening and breeding for resistance.

References

Ghodbane, A. 1977. Stripe Rust on wheat. *FAO Plant Protection Bulletin,* 25: 212.

Nagarajan, S., Kranz, J., Saari, E.E., Seiboldt, G., Stubbs, R.W. & Zadoks, J.C. 1984. An analysis of the 1978 epidemic of yellow rust on wheat in Andalucia, Spain. *Phytopathologische Zeitschrift/Journal Of Phytopathology,* 91: 159–170.

Rapilly, F. 1979. Yellow rust epidemiology. *Annual Review of Phytopathology*, 61: 59–73.

Vallega, V. & Zitelli, G. 1979. Epidemics of yellow rust on wheat in Italy. *Cereal Rusts Bulletin,* 6: 17–22.

Zadoks, J.C. 1965. Epidemiology of wheat rusts in Europe. *FAO Plant Protection Bulletin,* 13: 97–108.

Zadoks, J.C. & Bouwman, J.J. 1985. Epidemiology in Europe. pp. 329–369, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Zadoks, J.C., Chang, T.T. & Konzak, C.F. 1974. A decimal code for the growth stages of cereals. *Weed Research*, 14: 415–421.

Further studies on *Yr9* virulent pathotypes of *Puccinia striiformis* f.sp. *tritici* in India and their management

M. Prashar, S.C. Bhardwaj, S.K. Jain and Y.P. Sharma

Directorate of Wheat Research, Flowerdale, Shimla-171002, H.P., India

Abstract

The area under cultivation of Veery-derived lines (carrying *Yr9/L26/Sr31*) increased at a rapid rate due to their adaptability in diverse agro-climatic regions. In India, the cultivation of cv. Attila (PBW 343) increased and now occupies about 8 million hectare. A *Yr*9-virulent pathotype was identified in 1991 in north-western India. This variant that arose due to change in the local pathotype started to build up in this region of the country. Due to the presence of additional resistance (*Yr27*) in cv. Attila, the large-scale spread of yellow rust was, however, curtailed. This resistance protected the crop for four years, until another variant, named as 78S84, was detected in this region in 2001. Studies of this pathotype revealed that its virulence was distinct and it was probably yet another case of foreign introduction in the country. At present this pathotype is building up rapidly and it is feared that it could cause heavy losses if the crop season is favourable. Our studies have identified genotypes that can match the yield levels of PBW 343 and have better resistance, and should now be cultivated.

Introduction

Yellow rust of wheat, caused by *Puccinia striiformis* West., causes severe economic losses in cooler areas of the world. In India, this disease is a major biotic factor in wheat production and has been known as an endemic disease in the north-western plains zone (NWPZ), north hills zone and south hills zone. These zones cultivate 40% of the total area under wheat in India. Prior to release of cultivars possessing *Yr9*, the prevalent pathotypes were primarily virulent on *Yr2, YrA, Yr6* and *Yr7*. Some pathotypes were also virulent on *Yr4b* (Hybrid 46), *Yr25* (Strubes Dickopf) and Heines VII (*Yr25+)*. However, *Yr9* was effective up to 1990. Following the registration of Veery #5-derived cultivars (HS 240, DWR 162, HUW 206, Macs 2496), the first virulence on *Yr9* was

detected. The spread of this virulence reduced the large-scale cultivation of these cultivars. Subsequently, PBW 343 (Attila) was registered as resistant to yellow rust for cultivation in 1996. This cultivar not only carried the additional gene *Yr27* (Prashar *et al.,* 2004) that protected it against yellow rust but also had a yield advantage that made it popular amongst farmers of this region. Due to these advantages, it spread very quickly, leading to a very strong selection pressure that led to the emergence of a virulent pathotype designated as 78S84 in 2005 in Punjab (NWPZ). Gradually, this pathotype started to increase in frequency. At present, only two *Yr9*-virulent pathotypes are prevalent in the country. The present study analyses the data of prevalence (percentage frequency) of both these pathotypes over the yellow rust-prone zones and their impact on wheat production in the country. Further studies on the evaluation of the popular cultivars of this region were also conducted to identify sources of resistance.

Materials and methods

Rust-infected leaves from experimental and commercial fields were collected, shade-dried and transferred to the laboratory. These leaves were then plated on 2% water agar in Petri dishes and kept at 10°C overnight. Later, the leaves were scraped using a sterile lancet needle and the scraping was applied on one-week-old seedlings of Agra Local (a local tall wheat that is being used as a susceptible control in India) to increase the inoculum. For each sample, a single pot (11 cm diameter) of Agra Local containing 6–7 leaves was used. These inoculated seedlings were then sprayed with a fine mist of water and kept in a dew chamber overnight at 10°C. These pots were then placed in a greenhouse maintained at 16–18°C. Uredia developed on leaves of Agra Local after 12–15 days. The multiplied single-leaf-origin uredospores were then collected by shaking the infected leaves over butter paper (non-hygroscopic paper). The uredospores thus collected were then used for further inoculation.

For identifying the pathotypes, a set of 21 lines was used, comprising old European and World set differentials along with a few supplementary differentials (Nagarajan, Nayar and Bahadur, 1983). This inoculated set was subjected to same of incubation conditions as above. The infection types, developed after 12–14 days, were recorded as per Stakman, Stewart and Loegering (1962). Infection types of 3 or 3+ were classified as susceptible, with 0, 1 or 2 rated as resistant.

Prevalence of a pathotype was determined as percent frequency of total number of isolates analysed during the year. Following the determination of the most predominant pathotypes, these were then multiplied in bulk for use in screening adult plants. A set of the most popular 43 wheat varieties currently cultivated in different agro-climatic zones of the of the country was evaluated against the most predominant pathotypes. For adult plant

evaluation, these varieties were hand sown as clumps (7–8 seeds) in one-metre rows. Each row accommodated eight entries and a susceptible check was planted after every 6th row. These studies were conducted in a polyhouse. Inoculations were done by atomising uredospores, suspended in Soltrol 70, on these plants at flag leaf or flag-1 leaf stage. These studies were conducted consecutively for three years (2006, 2007 and 2008 crop seasons). The infection response was recorded as suggested by Peterson, Campbell and Hannah (1948): first after 20–22 days when the rust had fully developed, followed by a second reading taken 8–10 days later. The highest rust response of all the observations was then taken into consideration for deciding resistance vs susceptibility of a cultivar.

Results and discussion

During the period from 2001 to 2008, more than 2500 samples were analysed. The data were classified broadly into two pathotype categories, i.e. *Yr9*-avirulent or *Yr9*-virulent. *Yr9*-avirulent pathotypes were identified in 38% and the *Yr9*-virulent pathotypes in 55% in 2000/01 (Figure 1). By 2005, *Yr9*-avirulent pathotypes had decreased in frequency to 3%, while *Yr9*-virulent pathotypes increased to more than 65%.

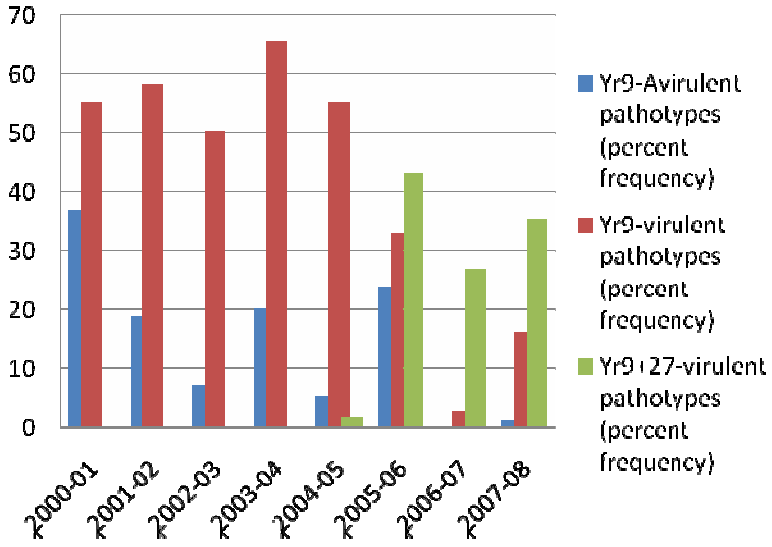


Figure 1. Frequency of wheat yellow rust pathotypes in India from 2000 to 2008.

The frequency of these pathotypes had been on the rise ever since first detection of *Yr9*-virulent pathotypes in 1996. The population of *Yr9* pathotypes started to decline by 2005/06. Later, another pathotype combining virulence for both *Yr9* and *Yr27* emerged in this region. The decline in population of *Yr9*-virulent pathotypes had followed the release of PBW 343, which carried an additional gene *Yr27*. The resistance of *Yr27* protected this wheat against *Yr9*-

virulent pathotypes. Since detection, *Yr9+27* pathotypes steadily increased due to increase in area under PBW 343. For the last two seasons (2006/07 and 2007/08), this pathotypes was the most prevalent and the only one to predominate in the entire NWPZ region. Last year, its build up caused damage to wheat yields of this region. Adult plant evaluation of cultivated wheat revealed that few of these cultivars had a vertical resistance gene. For example, HD 2329, HD 2733, HP 1633, Sonalika, VL 61 and HS 240 expressed resistance against *Yr9+27* pathotypes, indicating that these wheats carry a vertical resistance gene(s) (Table 1). Multi-pathotyping tests of these cultivars have indicated the presence of a cv. Avocet gene that is responsible for adult plant resistance. Both PBW 343 and PBW 373 exhibited seedling resistance against *Yr9+27* pathotypes, which is due to *Yr27* postulated in these cultivars. WH 1021 carried an unknown gene that is imparting seedling resistance. Further studies are needed to identify this resistance. Five wheats, namely HS 277, DL 803-3, DWR 162, Macs 2496 and VL 738, were susceptible at seedling and adult plant stage, indicating lack of a resistance gene in these cultivars. The remaining wheats were found susceptible at the seedling stage and showed resistance at the adult plant stage. It is evident that these carry adult plant resistance gene(s). We suggest that the resistance of these lines be used to minimize wheat yield losses in this region. Both DBW 17 and PBW 550 have been registered and suggested as replacements for PBW 343. The gradual replacement of PBW 343 with these resistant varieties will certainly reduce severity and incidence of yellow rust in the region.

References

Nagarajan, S., Nayar, S.K. & Bahadur, P. 1983. The proposed brown rust of wheat (*Puccinia recondita* f.sp. *tritici*) virulence monitoring system. *Current Science,* 52: 413–416.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Prashar, M., Bhardwaj, S.C., Jain, S.K. & Datta, D. 2007. Pathotypic evolution in *Puccinia striiformis* in India during 1995-2004. *Australian Journal of Agricultural Research,* 58: 602–604.

Stakman, E.C., Stewart, D.M. & Loegering, W.Q. 1962. Identification of physiological races of *Puccinia graminis tritici* . *USDA Agricultural Research Service,* E-617. 53 p.

Table 1. Genotype response to pathotypes at seedling and adult plant stage

No.	Line	Adult Plant Response		Seedling Response	
		Yr9-virulent	*Yr9+27*-virulent	*Yr9*-virulent	*Yr9+27*-virulent
1	HD 2329	40MR-MS	Tr-R	S	MR
2	HD 2733	60S	5MR-MS	S	R
3	HP 1633	40MR-MS	10MR-MS	S	R
4	HS 240	40MS	5MR	S	R
5	PBW 396	20MR-MS	5R	S	R
6	Sonalika	40MR-MS	Tr-R	S	R
7	VL 616	40MS	Tr-R	S	R
8	PBW 343	Tr-R-S	40MS	R	S
9	PBW 373	T-R-S	40MS	R	S
10	WH 1021	5R	10MR	MR	MR
11	HS 277	40MS	40MS	S	S
12	DL 803-3	60MS	40MS	S	S
13	DWR 162	60MS	60S	S	S
14	MACS 2496	40MS	60MS	S	S
15	VL 738	60MS	60MS	S	S
16	C 306	Tr-R	Tr-R	S	S
17	DBW 14	Tr-R	Tr-R	MS	S
18	DBW 16	Tr-R	Tr-R	S	S
19	DBW 17	Tr-R	Tr-R	S	S
20	DL 788-2	5R	60MS	S	S
21	HD 2189	60MS	10MR	S	S
22	HD 2204	Tr-R	5MR	S	S
23	HD 2285	40MR-MS	5RS	S	S
24	HD 2687	40MS	20MR-MS	S	S
25	HD 2888	Tr-R	Tr-R	S	S
26	HPW 251	Tr-R	Tr-R	S	S
27	HS 295	Tr-R	60MS	S	S
28	HS 420	Tr-R	40MS	S	S
29	HUW 234	40MR-MS	5R	S	S
30	HUW 468	5MR	40MS	S	S
31	Kalyansona	40S	40S	S	S
32	Lal bahadur	60S	5R	S	S
33	LOK-1	40MR	40MR	S	S
34	PBW 175	40MS	5MR	S	S
35	PBW 502	5R	10MR-MS	MS	S
36	PBW 550	Tr-R	Tr-R	S	S
37	RAJ 1482	20MR-MS	5R	S	S
38	RAJ 3765	Tr-R	Tr-R	S	S
39	UP 2425	Tr-R	Tr-R	S	S
40	UP 262	40MR-MS	Tr-R	S	S
41	VL 804	20MR-MS	5MR	S	S
42	WH 147	40MR-MS	Tr-R	S	S
43	WH 542	Tr-R	Tr-R	S	S

Virulence pattern of *Puccinia striiformis* in Pakistan

A.R. Rattu,[1] M. Fayyaz,[1] I. Ahmad,[2], Y. Ahmad[3] and K.A. Khanzada[3]

1. Crop Diseases Research Programme, National Agricultural Research Centre, Islamabad, Pakistan
2. National Agricultural Research Centre, Islamabad, Pakistan
3. Crop Diseases Research Institute, Karachi University, Karachi, Pakistan

Abstract

Wheat stripe rust (yellow rust) caused by the fungus *Puccinia striiformis* f.sp. *tritici* is a major problem in wheat production in most parts of Pakistan and appears in the country every year. Monitoring of the pathogen virulence factors and their changes provides basic information for the development of an early warning system for breeders and researchers. To monitor the regular virulence changes every year, isogenic lines for yellow rust resistance were planted at four locations in Northern Punjab and NWFP in five consecutive years, 2004–2009. Trap nurseries comprised 24 yellow rust isogenic lines from ICARDA and 12 of the most popular Pakistani commercial bread wheat varieties. The 3rd YRTN, comprising 85 entries received from ICARDA, was planted at three locations. When the infection and severity under natural infection on susceptible cv. Morocco, the susceptible check, was high then the response of each line was assessed using a modified Cobbs scale. In five years of study, the lines showed similar behaviour at all the test locations. Results revealed that no virulence was observed on yellow rust resistance genes *Yr5, Yr10, Yr15, YrSP* and *YrCV* at all locations. Virulence on genes for yellow rust resistance *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17, Yr18, Yr24, Yr26, Yr27, Yr28, Yr29* and *Yr31* was common during the study at almost all locations. The 3rd YRTN result revealed that *YrSP* in different backgrounds behave differently. In an Avocet background it was resistant, while in others it was susceptible. Among commercial varieties, GA-2002 and Tatara were the only two varieties found resistant against all the races prevailing in the country. The rest of the varieties were susceptible at all locations.

Introduction

Wheat rusts historically are considered major biotic production constraints globally (Singh and Rajaram, 1991), and yellow rust, caused by *Puccinia striiformis* Westend f.sp. *tritici,* is one of the most important diseases of wheat in the world (Roelfs, Singh and Saari, 1992). Severe epiphytotics of the disease

may result in losses of up to 70% in commercial fields (McIntosh, Wellings and Park, 1995). Severe epidemics of the disease have been reported in Central and West Asia (Braun and Saari, 1992; Mamluk and El-Naimi, 1992; Torabi *et al*., 1995). Losses caused by epidemics of yellow rust in 1993 and 1995 in Iran were estimated at 1.5 and 1.0 million tonne, respectively (Nazari and Torabi, 2000). The severe leaf rust epidemics in Pakistan resulted in an estimated national loss of US$ 86 million due to a 10% yield loss (Hussain, Hassan and Karmani, 1980). Ahmad *et al.* (1991) reported an estimated US$ 8 million revenue loss in just three districts of Balochistan in Pakistan.

Only a few attempts have been made previously to use field tests rather than seedling tests to evaluate virulence in rust populations (McIntosh, Wellings and Park, 1995). Pathogenicity surveys are necessary for delimiting the distribution of current pathotypes and virulence factors of obligate pathogens. The result of these surveys can be used for early detection of new virulence combinations of the pathogen, for screening and for cultivar recommendation (Wellings, McIntosh and Mamluk, 1996).

The yellow rust pathogen exists as range of pathogenic variants. These pathotypes are capable of overcoming current resistance and are considered the primary limiting factor in developing resistance in cultivars (Nazari and Torabi, 2000). Growing cultivars with resistance has no cost to farmers and provides cost-effective benefits to growers. A yellow rust trap nursery was used under field conditions for the first time to determine the geographical distribution of yellow rust in Europe (Zadoks, 1961).

The objective of this study was to identify the prevailing virulences of yellow rust in nature by planting yellow rust trap nurseries at different hot-spots within the country. The trap nursery comprised isogenic lines and commercial varieties and was planted in hot-spots to assess the virulence pattern. The principal and practical purpose for studying the rust population is to identify effective genes. The use of race-specific resistance to control yellow rust requires continued monitoring for virulence shifts in the rust population. It has been continuously done in most of wheat producing countries. A yellow rust trap nursery (YRTN) was planted at three locations (hot-spots) in the country during the study period to identify the prevailing yellow rust virulence.

Materials and methods

A trap nursery specially designed for yellow rust and consisting of 24 yellow rust isogenic lines from ICARDA and 12 of the most popular commercial bread wheat varieties were planted in different parts of the country (Table 1). The 3rd YRTN, comprising 85 entries, was received from ICARDA in 2008/09 and was also planted at three locations during the study period (Table 2). The domestic nursery was evaluated for five consecutive years (2004–2009). The locations

represented different agro-ecological zones and hot-spots where the conditions are favourable for yellow rust development. Each entry of the nursery was planted as a non- replicated single 1-m long row, 30 cm apart. Two rows of susceptible spreader (cv. Morocco) were planted around the nursery. Observations recorded included natural occurrence and first appearance of rust infection on the susceptible check. Observations at all locations on response of yellow rust were recorded according to Loegering (1959) and severity as percent of rust infection on the plants according to the modified Cobb's Scale (Peterson, Campbell and Hannah, 1948).

Results and Discussion

The role of resistance genes in protection of wheat against rusts depends on the virulence changes of pathogens. Results revealed that no virulence was observed on yellow rust-resistance genes *Yr5, Yr10, Yr15, YrSP* and *YrCV* at all locations in the field . Virulence on yellow rust-resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17, Yr18, Yr24, Yr26, Yr27, Yr28, Yr29* and *Yr31* was common during the five years of study at almost all locations. The 3rd YRTN result revealed that *YrSP* behaves differently in different backgrounds. In an Avocet background it was resistant, while susceptible in others. Among commercial varieties, GA-2002 and Tatara were found resistant against all races prevailing in the country. The rest of the varieties showed susceptibility at all locations.

Northern and central parts of Pakistan are considered hot-spots for yellow rust. The major wheat varieties in these areas are Inqilab 91, Bhaktawar 2002, Sehar 2006, Shafaq 2006, Tatatar, Fakhr-e-Srahad and Saleem 2000. The wheat varieties showed erratics. Inqilab 91, which is the most popular commercial variety in Pakistan and occupied a large area under cultivation, showed susceptibility at all locations, which suggests the complete breakdown of *Yr27*. The epidemics of 2005 (Unpublished data) on Inqilab 91 was an alarming situation in Pakistan. Bakhtawar 92 has yellow rust resistance genes *Yr+9* and showed partial virulence during the study period. *Yr9* has virulence, but due to presence of a minor gene in Bakhtawar 92 it showed only partial virulence. *Yr9* is genetically linked with *Lr26* and *Sr31*. *Yr9* and *Lr26* are ineffective genes in Pakistan for yellow and leaf rusts. Fakhr-e-Sarhad is widely grown in northern areas of Pakistan. Susceptibility of this variety occurred at almost all the locations. Sarsabz and Tandojam 83 are grown in the plains of Sindh province and have yellow rust resistance genes *Yr7* and *Yr6+*. Although these varieties are not grown in yellow rust-prone areas of Pakistan, susceptibility for these varieties was present at all three locations. Auqab and AS-2002 showed a moderate-type reaction at all locations. The varieties Tatara and GA-2002 were found effective at all the tested locations. GA-2002 is for rainfed areas of Pakistan and has the *Yr3* resistance gene that is an effective gene in the field

Table 1A. Wheat yellow rust scenario at different parts of the country. Part A – results at UAP and NIFA

Gene or line	UAP				NIFA			
	2004/05	2005/06	2006/07	2008/09	2004/05	2005/06	2006/07	2008/09
Yr1	40MS-S	0	5S	20S	40MS-S	50MS-S	10S	–
Yr2	–	–	30S	30S	–	–	20S	–
Yr5	0	0	0	0	0	0	0	–
Yr6	40S	5S	30S	80S	70S	80S	40S	–
Yr7	40S	20S	60S	90S	70S	80S	30S	–
Yr8	30MS-S	0	0	0	30MS-S	50S	20S	–
Yr9	30S	0	20S	70S	50S	80S	40MS-S	–
Yr10	0	0	0	0	0	0	0	–
Yr15	0	0	0	0	0	0	0	–
Yr17	40MS-S	10S	20S	70S	60S	80S	40S	–
Yr18	30MS-S	5S	5S	30S	40MS-S	60S	20S	–
Yr24	Tr-MR-MS	0	0	30S		50MR-MS	20MR-MS	–
Yr26	5R-MR	0	0	5MR-MS	Tr-R	40MS-S	20MR-MS	–
Yr27	20MS-S	0	5S	90S	30MS-S	50MS-S	20S	–
YrSP	0	0	0	0	0	0	0	–
YrCV	–	–	0	0	–	–	0	–
Yr28	–	–	5S	30S	–	–	20MS-S	–
Yr29	–	–	5S	50S	–	–	10S	–
Yr31	–	–	0	40S	–	–	30S	–
Carstens V	–	–	0	–	–	–	0	–
Avocet -*YrA*	30S	5S	40S	80S	50S	80S	50S	–
Avocet +*YrA*	60S	0	5S	70S	20MS-S	80S	40S	–
Jupateco R (*Yr18*)	30MS-S	0	5S	20S	40MS-S	60S	–	–
Jupateco S	60S	5S	40S	90S	70S	80S	–	–
Inqilab 91	10MS-S	5S	40S	70S	40R-MR	60S	40S	–
Bhakkar-2002	20MS-S	0	0	20S	10MR-MS	0	5R	–
Bakhtawar 93	5MS-S	0	5MS-S	10MS	10MS-S	60MS-S	Tr-S	–
Tatara	0	0	0	0	0	0	0	–
Fakhr-e-Sarhad	20MS-S	5S	0	0	0	30MS-S	5S	–
Tandojam 83	30MS-S	30S	20S	40S	70S	60S	20S	–
Saasabz	10MS-S	5S	0	40S	20MR-MS	60S	30SD	–
Marvi-2000	Tr-R	10S	0	0		70S	0	–
Auqab	Tr-R	5MR-MS	0	0	Tr-R	50MS-S	5MR-MS	–
GA-2002	5MR-MS	0	0	0	Tr-R	Tr-R	Tr-R	–
AS-2002	5S	0	0	0	Tr-R	0	20MS-S	–
Morocco	70S	80S	70S	90S	80S	90S	90S	–

Table 1B. Wheat yellow rust scenario at different parts of the country. Part B – results at CCRI and NARC

Gene or line	CCRI				NARC			
	2004/05	2005/06	2006/07	2008/09	2004/05	2005/06	2006/07	2008/09
Yr1	40MS-S	30S	50S	70S	0	10S	50S	70S
Yr2	—	—	60S	80S	—	—	60S	70S
Yr5	0	0	0	0	0	0	0	0
Yr6	80S	70S	50S	80S	60MS-S	80S	70S	80S
Yr7	80S	70S	80S	80S	80S	90S	70S	70S
Yr8	40MS-S	10S	5S	0	70MS-S	90S	80S	0
Yr9	40S	30MS-S	80S	70S	Tr-MS	60S	80S	70S
Yr10	0	0	0	0	0	0	0	0
Yr15	0	0	0	0	0	0	0	0
Yr17	60S	70S	40S	80S	10MS-S	90S	40S	70S
Yr18	40MS-S	50S	20S	40S	10MS-S	60S	50S	30S
Yr24	30MR-MS	70MR-MS	30R-MR	20S	Tr-R	20MR-MS	20MR-MS	20S
Yr26	10R-MR	0	20R-MR	Tr-R	0	0	5R-MR	30S
Yr27	40MS-S	40MS-S	50S	60S	30MS-S	80S	60S	80S
YrSP	0	0	0	0	0	0	0	0
YrCV	—	0	0	0	—	5S	0	0
Yr28	—	80S	10S	20S	—	80S	40S	70S
Yr29	—	70S	20S	70S	—	80S	60S	80S
Yr31	—	50S	50S	70S	—	30S	50S	70S
Carstens V	—	10MR-MS	0	—	—	0	10S	20S
Avocet -*YrA*	80S	70S	60S	70S	80S	60S	50S	80S
Avocet +*YrA*	70S	70S	80S	70S	10MS-S	40S	50S	70S
Jupateco R (*Yr18*)	60MS-S	70S	—	80S	60S	50S	—	80S
Jupateco S	70S	80S	—	90S	80S	90S	—	60S
Inqilab 91	70MR-MS	30S	60S	30S	90S	70S	70S	90S
Bhakkar-2002	Tr-R-MR	0	5MR-MS	70S	70S	80S	20MR-MS	70S
Bakhtawar 93	40MS-S	0	5S	10MS-S	20S	80MR-MS	56S	10MS
Tatara	0	0	0	0	0	Tr-R	0	0
Fakhr-e-Sarhad	60MS-S	20MS-S	10S	0	0	0	5S	0
Tandojam 83	80S	60S	60S	90S	80S	80S	60S	80S
Saasabz	40MS	40S	60S	40S	80S	60S	60S	70S
Marvi-2000	40MS	70S	0	5S	0	0	0	0
Auqab	5MS	10MR-MS	0	5MS	10MR-MS	20MR	5MR	0
GA-2002	Tr-R	20R-MR	0	0	0	0	0	0
AS-2002	30MS-S	0	5S	0	20MS-S	0	10S	0
Morocco	70S	90S	80S	90S	100S	100S	90S	90S

Table 1C. Wheat yellow rust scenario at different parts of the country. Part C – results at UAF

No.	Gene/line	UAF			
		2004/05	2005/06	2006/07	2008/09
1	*Yr1*	0	0	0	20S
2	*Yr2*	—	—	5S	30S
3	*Yr5*	0	0	0	0
4	*Yr6*	0	Tr-MS	5S	80S
5	*Yr7*	60S	50S	50S	90S
6	*Yr8*	0	0	0	0
7	*Yr9*	5S	10S	20S	70S
8	*Yr10*	0	0	0	0
9	*Yr15*	0	0	0	0
10	*Yr17*	0	Tr-S	10S	70S
11	*Yr18*	0	0	0	30S
12	*Yr24*	0	0	0	30S
13	*Yr26*	0	0	0	5MR-MS
14	*Yr27*	0	0	5S	90S
15	*YrSP*	0	0	0	0
16	*YrCV*	—	0	0	0
17	*Yr28*	—	30MR-MS	5MS	30S
18	*Yr29*	—	—	0	50S
19	*Yr31*	—	—	0	40S
20	Carstens V	—	—	0	5MS
21	Avocet -*YrA*	10S	5S	20S	0
22	Avocet +*YrA*	0	5S	50S	0
23	Jupateco R (*Yr18*)	0	0	—	80S
24	Jupateco S	5S	20S	70S	90S
25	Inqilab 91	0	40MS-S	70S	10S
26	Bhakkar-2002	20MR-MS	5MS-S	5R	5MS
27	Bakhtawar 93	0	0	0	0
28	Tatara	0	0	0	0
29	Fakhr-e-Sarhad	0	0	0	0
30	Tandojam 83	0	Tr-MR-MS	20S	5S
31	Saasabz	0	0	5S	5MR-MS
32	Marvi-2000	0	0	0	5MS
33	Auqab	0	0	0	0
34	GA-2002	0	0	0	0
35	AS-2002	0	0	0	0
36	Morocco	20S	40S	80S	70S

Table 2. Response of tester lines included in 3rd YRTN

No.	Cultivar/*Yr* genes	Yellow rust Response		
		F.JANG	**NARC**	**CCRI**
1	Morocco (check)	90S	70S	90S
2	Pollmer—2.1.1 (*Triticale*)	0	0	0
3	Gobusten	0	0	0
4	Azametli 95	70S	60S	60S
5	Sardari	50MS-S	70S	70S
6	Alamout	80S	90S	80S
7	Cham 4	0	0	0
8	Cham 6	40S	60S	50S
9	Cham 8	10MS-S	10R	40MS-S
10	Morocco (check)	90S	100S	90S
11	Bohouth 6	50S	70S	80S
12	Gereck 79	0	0	0
13	Kinaci 97	0	0	20MS-S
14	Gun 91	60S	90S	90S
15	Ak bugday	80S	90S	90S
16	Dustlik	0	0	0
17	OPATA 85, *Yr27*+*Yr18*	70S	80S	90S
18	SUPER KAUZ, *Yr9*,*Yr27*,*Yr18*	70S	50S	40S
19	PASTOR, *Yr31*+APR	5S	0	0
20	Morocco (check)	80S	100S	90S
21	ATTILA M85836-50Y-0M-0Y-3M-0Y, *Yr27*+?	70S	80S	80S
22	Chinese 166 (W;*Yr1*)	0	MISSING	0
23	Lee (S;*Yr7*)	60S	60S	50S
24	Heines Kolben (S'*Yr6*+1)	50MS	50S	50S
25	Vilmorin 23 (w;*Yr3*a,4a+other)	0	0	0
26	Moro (w; *Yr10*)	0	0	0
27	Strubes Dickopf (w; 2-more?)	0	0	0
28	Suwon 92×Omar(W)	0	0	10S
29	Clemet (W; *Yr9*+*Yr2*+?)	0	0	0
30	Morocco (check)	80S	90S	80S
31	Hybrid46(W; *Yr4*)	0	0	0
32	Reichersberg 42(W; *Yr7*+?	5MR	0	0
33	Heines Peko(S; *Yr6*+?)	10MR	0	0
34	Nord Desprez (w; YrND)	30MS	0	0
35	Compair (S; *Yr8*)	0	0	0
36	Carstens V (W; *Yr32*)	0	0	0
37	Spaldings Prolific (w; *YrSP*)	10MR-MS	0	0
38	Heines VII (W; *Yr2*+?)	0	0	0
39	Federation	70S	90S	90S
40	Morocco (check)	80S	80S	90S
41	Fed.4/Kavkaz(*Yr9*)	60S	70S	80S
42	*Triticum spelta* (Inter, *Yr5*)	0	0	0
43	Kalyansona (S)	70S	50S	70S
44	TATARA CM85836-50Y-0M-0Y-2M- 0Y-0PAK	0	0	5S
45	Anza	0	0	5S

No.	Cultivar/*Yr* genes	Yellow rust Response		
		F.JANG	NARC	CCRI
46	Cham 1	0	0	0
47	Cook (S)	5MR	0	5S
48	Jupateco 'R' (S)	70S	60S	60S
49	Jupateco 'S'	80S	80S	80S
50	Morocco (check)	90S	90S	80S
51	Avocet S	90S	80S	80S
52	Avocet R	30S	90S	60S
53	*Yr1*/6 * Avocet S	50S	70S	60S
54	*Yr5*/6 * Avocet S	0	0	0
55	*Yr6*/6 * Avocet S	60S	90S	70S
56	*Yr7*/6 * Avocet S	80S	80S	80S
57	*Yr8*/6 * Avocet S	40MR-MS	0	50MR-MS
58	*Yr9*/6 * Avocet S	80S	90S	70S
59	*Yr10*/6 * Avocet S	0	0	0
60	Morocco (check)	90S	70S	80S
61	*Yr15*/6 * Avocet S	0	0	0
62	*Yr17*/*6**AOC	70S	70S	60S
63	*Yr18*/*3**Avocet S	40MS-S	60S	60S
64	*Yr27*/*6**AOC	60S	80S	70S
65	*Yr28*, AVOCET-YRA*3/3/ALTAR 84/A.E.SQ//OPATA CGSS00Y00204T-099M-20Y	30S	70S	30S
66	*Yr31* AVOCET-YRA*3/PASTOR CGSS00Y00207T-099M-1Y	60S	0	70S
67	*YrSP*/6* Avocet S	0	0	0
68	*YrCV*/6*AOC	0	20S	5S
69	*Yr26*	0	0	0
70	Morocco (check)	90S	90S	80S
71	*Yr24*	70S	80S	50S
72	*Yr26*	60S	30S	30S
73	*Yr27*	60S	70S	20S
74	*YrSP*	60S	70S	30S
75	Tres/6* AVS	0	0	0
76	TP981	60S	60S	40S
77	TP1295	70S	70S	50S
78	Ciano 79	10MR-MS	40S	40S
79	Lal Bahadur/Pavon 1B L	70S	80S	60S
80	Morocco (check)	80S	100S	80S
81	INIA 66	30S	70S	20MS-S
82	Lee	50S	70S	30S
83	fielder	40S	50S	50S
84	Lemhi	30S	0	40S
85	Thatcher	60S	70S	30S

NOTES: APR = adult plant resistance

The 3rd YRTN result revealed that *YrSP* in different backgrounds behaves differently. In the Avocet background it was resistant, while susceptible in others. Cvs Opata, Superkauz and Attila showed susceptibility at all three locations, while cvs Pastor, Tatara and Anza showed occasional susceptibility. Most of the varieties and wheat yellow rust differentials were found effective at all the tested locations.

Yr5, Yr10, Yr15, YrSP and *YrCV.* were resistant at all locations in Pakistan. Hence these effective resistance genes can be recommended as resistance sources for incorporation in breeding programmes. The protection strategy for protection of wheat against rusts could be enhanced by gene pyramiding in breeding programmes.

References

Ahmad, I., Mirza, J.I., Rattu, A.R. & Akhtar, M.A. 2000. Report on trap nursery 1999–2000. CDRI, NARC, PARC, Islamabad, Pakistan.

Ahmad, S., Rodriguez, A., Sabir, F., Khan, G.R. & Pannah, M. 1991. Economic losses of wheat crops infested with yellow rust in highland Baluchistan. MART/AZR Project Research, Report # 67. ICARDA, Quetta. 15 p.

Braun, H.J. & Saari, E.E. 1992. An assessment of the potential of *Puccinia striiformis* f.sp. *tritici* to cause yield losses in wheat on the Anatolian Plateau of Turkey. pp. 121–123, *in:* F.J. Zeller and G. Fishbeck (editors). Proceedings of the 8th European and Mediterranean Cereal Rust and Powdery Mildews conference, 8–10 September 1992, Weihenstephan, Germany.

Hussain, M., Hassan, S.F. & Karmani, M.A.S. 1980. Virulence in *Puccinia recondita* Rob. ex. Dsem. f.sp. *tritici* in Pakistan during 1978 and 1979. pp. 179–184, *in:* Proceeding of the Fifth European and Mediterranean Cereal Rust Conference, Bari, Italy.

Loegering, W.Q. 1959. Methods for recording cereal rust data. USDA International Spring Wheat Rust Nursery.

Mamluk, O.F. & El-Naimi, M. 1992. Occurrence and virulence of wheat yellow rust in Syria. pp. 115–117, *in:* F.J. Zeller and G. Fischbeck (editors). Proceedings of the 8th European and Mediterranean Cereal Rusts and Mildews Conference, 8–11 September 1992. Weihenstephan, Germany.

McIntosh, R.A., Wellings, C.R. & R.F. Park. 1995. *Wheat rust – An Atlas of Resistance Genes.* Kluwer Academic Publishers, Dordrecht, The Netherlands.

Nazari, K. & Torabi, M. 2000. Distribution of yellow rust resistance genes. Proceeding of the 10th Cereal Rusts and Powdery Mildews Conference, Budapest, Hungary, 28 August–1 September 2000. *Phytopathologia et Entomologica Hungarica,* 35: 121–131.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P., Singh. R.P. & Saari, E.E. 1992. Rust diseases of wheat. Concepts and methods of disease management. CIMMYT, Mexico.

Singh, R.P. & Rajaram, S. 1991. Resistance to *Puccinia recondite* f.sp. *tritici* in 50 Mexican bread wheat cultivars. *Crop Science*, 31: 1472–1479.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A. R., Ramai, A. M., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildew Bulletin,* 23: 9–13.

Wellings, C.R., McIntosh, R.A. & Mamluk, O.F. 1996. Near-isogenic lines for the assessment of pathogenic variation of the wheat stripe rust pathogen. Proceeding of the 5th international Wheat Conference. 10–14 June 1996, Ankara, Turkey.

Zadoks, J.C. 1961. yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

Pathotyping of wheat stripe [yellow] rust over the last three years in Iran

F. Afshari

Seed and Plant Improvement Institute, P.O. Box 4119, Karaj, Islamic Republic of Iran

Introduction

The occurrence of pathogenic variability in rust fungi led to considerable confusion and disagreement among early researchers of rust diseases. For example, Rudorf (1929; cited in Wellings, 1986) noted that some cultivars resistant in the USA were susceptible in Germany. This was due presumably to variation in pathogenic attributes between geographical regions. Wheat is a host for many groups of parasitic fungi, bacteria, viruses and insects. Major threats to wheat production on a worldwide basis come from one or more of the three rust diseases. Yellow rust caused by *Puccinia striiformis* West. f.sp. *tritici* (*Pst*) is the most important rust disease in Iran. The annual cost due to stripe [yellow] rust in Australia in terms of yield lost and control costs was estimated to be $AUS 139 million (Brennan and Murray, 1988). In 1994, an estimated 15% (1.5 million tonne) of the national wheat yield was lost in Iran due to yellow rust (Torabi *et al.*, 1995).

The wheat stripe rust pathogen oversummers on volunteer wheat and possibly certain species of *Aegilops, Agropyron, Bromus* and *Elymus* in Europe (Stubbs, 1985). Stripe rust uredospores can be wind-borne in a viable state for more than 800 km (Zadoks, 1961). O'Brien *et al*. (1980) reported the introduction of wheat stripe rust to Australia, which was probably aided by man. In 1980, the pathotype first found in Australia appeared in New Zealand, presumably having been air-borne from Australia, a distance of approximately 2000 km (Beresford, 1982). In Iran, yellow rust epidemics were recorded in 1993 and 1995 (Torabi *et al*., 1995), and crop losses were estimated at 1.5 and 1 million tonne, respectively. In Yemen and Ethiopia, early yellow rust epidemics have been recorded since 1988 (Mamluk, EL-Naimi and Hakim, 1996). Torabi *et al.* (2002) noted that the majority of Iranian yellow rust pathotypes had virulence on plant with genes *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23* and *YrA.* Surveys of *Pst* pathotypes and the genetic variation within the pathotypes are important and valuable information for the breeding programme. This study reports on the prevailing *Pst* pathotypes in Iran.

Materials and methods

This study was carried out on Karaj station with 53 isolates of stripe rust collected from different parts of Iran. Spores of each isolate, after multiplication, were inoculated on an international standard yellow rust differential set of wheat lines in the greenhouse. A set of the World (8 genotypes) and European (8 genotypes) wheat yellow rust differentials, as proposed by Johnson *et al.* (1972), was used in the study, in addition to 10 supplementary genotypes, namely Federation*4/Kavkas (*Yr9*), Anza (*YrA*), Avocet R (*YrA*), Kalyansona (*Yr2*), *Triticum spelta* var. *album* (*Yr5*), TP 981 (*Yr25*), Meering 24 (*Yr24*), Bolani (susceptible check), Avocet S and TP 1295.

For inoculation, uredospores were mixed with talcum powder (1:4). After each inoculation, spray equipment was thoroughly washed in water and dried in an oven at 60°C to avoid contamination when successively inoculating with different pathotypes. After inoculation the seedlings were placed in trays and covered with plastic hoods. Trays were placed in an incubation room at 10°C, where the differential temperatures between the water and room temperature resulted in dew formation. Seedlings were held for 24 h at 10°C and 100% RH in the dark. Following incubation, plants were moved to the greenhouse and maintained at 18–19°C. Infection types were recorded 16–19 days after inoculation, depending upon the disease and temperature. The objective was to record reactions when the difference between the controls and the test lines were at their maximum. Infection types were recorded using the scale (0–9) described by McNeal *et al*. (1971).

Results and Discussion

Stripe rust is the most serious disease of wheat in CWANA, including Iran. The development of resistant cultivars is the most effective, safe and economical method of control. However, stripe rust pathogenic variation remains the underlying reason for elusive rust resistance. Genetic variation in the stripe rust pathogen is continuously evolving in CWANA.

In greenhouse tests, among 53 Iranian collections, 28 pathotypes were determined (Table 1). The stripe rust population in the region consists of a number of pathotypes that differ in their pathogenicity on the host plant. According to the results, virulence on plants with gene(s) *Yr2, Yr6, Yr7, Yr8, Yr9, Yr24, Yr25, Yr27, YrSD, YrSP, Yr3N, Yr2+, Yr6+, Yr9+, Yr7+, Yr32+* and *YrA* was detected. The majority of isolates showed virulence on plant with *Yr2, Yr6, Yr7, Yr9, YrA* and *Yr24* genes. No virulence was detected on plants with *Yr1, Yr3V, Yr4, Yr5, Yr10* or *YrSU*. Torabi *et al*. (2002) noted that virulence was not detected for plant with genes *Yr1, Yr4, Yr5* and *Yr10,* and virulence on plant with genes *Yr2, Yr6, Yr7, Yr9, Yr22, Yr23* and *YrA* was common in Iran. Of these virulences, pathotypes possessing the combination of virulence

against *Yr7* and *Yr9* were particularly implicated in the epidemics on cv. Falat in 1993.

Table 1. Locations and yellow rust pathotypes (races) identified in Iran

No.	Location	Race	No.	Location	Race
1	Gonbad	4E0A+	15	Karaj Ahvza.3 Ahvza.4 Lar.1 Mogan.2	6E142A+
2	Joyem Lar	4E4A+	16	Bye Kola	6E148A+
3	Maneh.1	4E8A+	17	Mogan.3	6E150A+
4	Sari	6E0A+	18	Mogan.4 Mogan.5	6E158A+
5	Islam Abad.1	6E2A+	19	Garakhil.3	6E174A+
6	Garakhil.1	6E4A+	20	Bojnord.2	38E66A+
7	Garakhil.2 , Malayer Araghimahaleh Darab.1	6E6A+	21	Bojnord.3	134E4A+
8	Hamadan Zargan	6E22A+	22	Mashhad	134E6A+
9	Darab.2	6E44A+	23	Yazd.1 Yazd.2	134E130A+
10	Gorgan	6E78A+	24	Yazd.3 Torogh	134E142A+
11	Islam Abad.2	6E128A+	25	Maneh.2	134E150A+
12	Gazvin.1, Gazvin.2	6E130A+	26	Gachsaran	166E30A+
13	Ahvza.1, Dezful.1, Bojnord.1 Dezful.2 Ahvza.2	6E134A+	27	Lar.2	166E134A+
14	Mogan.1	6E138A+	28	Sari	230E142A+, *Yr27*+

Hakim *et al*. (2002) reported that the Iranian stripe rust pathotypes do not differ in their pathogenicity from those found in Syria and Lebanon. Yahyaoui *et al*. (2002) reported seven pathotypes, 6E0, 20E148, 38E134, 166E150, 6E20, 134E150 and 230E150, in Syria and Lebanon between 1993 and 1994. Pathotype 134E150 was also detected in Iran. The pattern of virulence factors of Syrian and Lebanese pathotypes with virulence on plant with *Yr2, Yr6, Yr7, Yr9* and *YrA* is similar to that of the Iranian pathotypes. In addition, more diverse pathotypes could be identified that include compatibility with *Yr1, Yr3V, Yr5, Yr10* and *YrSU* genes that have not been deployed in Iran. In the greenhouse population, frequency of virulence to wheat genotypes with *Yr32+, Yr27*, *YrSP* and *YrSD* gene was less than 7%, while virulence to the other wheat genotypes was between 19 and 100%.

The most recently deployed resistance genes (*Yr18* and *Yr27*) in several bread wheat cultivars cultivated in CWANA are become ineffective against prevalent stripe rust pathotypes (Singh, Duveiller and Huerta-Espino, 2004). For example, pathotype 230E142A with virulence on plants with *Yr27* was detected in Sari in 2007. Bread wheat cvs Seri 82, Mexipak and Gereck were resistant to the prevalent stripe rust populations when initially released. Within a few years the corresponding stripe rust virulence genes increased and the resistance genes such as *Yr9*, associated with the above cultivars, became

ineffective (Yahyaoui *et al*., 2004). Therefore, the monitoring of stripe rust pathotypes and its changes can be an important consideration for breeding programmes in Iran.

References

Beresford, R.M. 1982. Stripe Rust (*Puccinia striiformis*), a new disease of wheat in New Zealand. *Cereal Rusts Bulletin*, 10: 35–41.

Brennan, J.P. & Murray, G.M. 1988. Australian wheat diseases: assessing their economic importance. *Agricultural Science (New Series),* 1: 26–35.

Hakim, M.S., Yahyaoui, A., El-Naimi, M. and Maas, I. 2002. Wheat yellow rust pathotypes in Western Asia. pp. 55–61, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Johnson, R., Stubbs, R.W., Fuchs, E. & Chamberlaine, N.H. 1972. Nomenclature for physiological races of *Puccinia striiformis* infecting wheat. *Transactions of the British Mycological Society,* 58: 475–480.

Mamluk, O.F., EL-Naimi, M. & Hakim, M.S. 1996. Host preference in *Puccinia striiformis* f.sp. *tritici*. pp. 86–88, *in:* Proceedings of the 9th European and Mediterranean Cereal Rusts and Powdery Mildews Conference, 2–6 September 1996, Lunteren, The Netherlands.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

O'Brien, L., Brown, J.S., Young, R.M. & Pascoe, T. 1980. Occurrence and distribution of wheat stripe rust in Victoria and susceptibility of commercial wheat cultivars. *Australasian Plant Pathology Society Newsletter*, 9: 14.

Singh, R.P., Duveiller, E. & Huerta-Espino, J. 2004. Virulence to yellow rust resistance gene *Yr27*: A new threat to stable wheat productions in Asia. *In:* 2nd Regional Yellow Rust conference for Central and West Asia and North Africa, 22–26 March, Islamabad, Pakistan. [This volume.] ICARDA Publisher.

Stubbs, R.W. 1985. Stripe Rust. pp. 61–101, *in:* A.P. Roelfs and W.R. Bushnell (editors). *The Cereal Rusts*, Vol. II. *Diseases, Distribution, Epidemiology and Control*. Academic Press, Orlando, USA.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildew Bulletin*, 23: 9–12.

Torabi, M., Nazari, K., Afshari, F., Mardoukhi, V. & Malihipour, A. 2002. Seven-year pathotype survey of *Puccinia striiformis* f.sp. *tritici* in Iran. p. 69, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Wellings, C.R. 1986. Host : Pathogen studies of wheat stripe rust in Australia. PhD Thesis. University of Sydney, Australia. 237 p.

Yahyaoui, A., Wellings, C.R., Torabi, M., Nazari, K., Ketata, H. & Cetin, L. 2002. Effective resistance genes to yellow rust of wheat in Central and Western Asia. p. 53, *in:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Yahyaoui, A., Singh R.P., Wellings C.R. 2004. Yellow Rust in CWANA: Status, approaches, and management. *In:* 2nd Regional Yellow Rust conference for Central and West Asia and North Africa, 22–26 March 2004, Islamabad, Pakistan. [This volume.] ICARDA Publisher.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

Combining high yield potential and durable rust resistance against yellow rust in bread wheat

Mak. Hussain,[1] Muh. Hussain,[1] Mu. Hussain,[2] A. Rehman,[1] F. Muhammad,[1] J. Anwar[1] and N. Ahmad[1]

1. Wheat Research Institute, Faisalabad, Pakistan
2. Plant Pathology Research Institute, Faisalabad, Pakistan

Abstract

A programme was initiated to breed for yellow rust (*Puccinia striiformis*) resistance at Wheat Research Institute, Faisalabad, Pakistan, during 1992/93. The aim of this programme was the development of wheat varieties having minor-gene-based resistance against yellow rust. Wheat germplasm was screened for yellow rust resistance under natural and high stress inoculation conditions with diversified inoculum at multiple locations. The rust development pattern was observed and data recorded for yellow rust for two years. Accessions carrying minor genes were identified based on slow-rusting behaviour and low terminal rust reaction. Auqab 2000, Kohistan 97, Pb 96, Shalimar 88, HD 2179, Luan and Weaver showed moderate levels of resistance against yellow rust at natural hot-spot areas and under artificial inoculation conditions. The locally adapted varieties like Lu 26, Pak 81, MH 97, Inqilab 91, Chenab 2000 and V-87094 (Wattan) have a history of high yield potential. These lines were crossed for pyramiding minor genes for rust resistance and high yield potential. Segregating material was evaluated under artificial rust inoculation and natural conditions using a selected-bulk-method approach. The homozygous lines having high yield potential and better resistance than the parents and the existing wheat varieties were selected in the F_7 generation for evaluation in station yield trials for two years. In different ecological zones of Pakistan, these lines were also tested for yield (1 crop season) and rust reactions (2 crop seasons). The most promising crosses were Lu26/HD2179/2* Inqilab 91 (V-00183), Shalimar-88/Weaver (V-02156), Shalimar-88/Wattan//MH 97 (V-02192), Luan/Kohistan (V-03138), Shalimar-88/V-90A204//MH 97 (V-04178), Pb-96/Wattan//MH 97 (V-04179), Chenab-2000/Inqilab 91 (V-05082), Lu-26/HD-2179//Chill'S' (V-06018), Shalimar-88/Pak 81//MH 97(V-06068), Auqab-2000/Milan (V-06096), Oasis/5*Angra//Inqilab 91 (V-06117) and Lu26/HD2179(V-87094). Two

genotypes, Shafaq 06 in 2006, and Lasani 08 in 2008, have been released for general cultivation. Some other lines having better resistance than the parents are in the pipeline. Shafaq 06 and Lasani 08 have high yield potential and resistance to yellow rust.

Introduction

Wheat (*Triticum aestivum* L.) is a crop cultivated worldwide. The world production of wheat is 607 million tonne, making it the third most-produced cereal after maize (784 million tonne) and rice (651 million tonne) (FAO, 2007). In Pakistan, wheat is the major staple food of the people and is cultivated on an area of 8.61 million hectare with annual production of ca 25 million tonne (Anon., 2009). Many factors, such as rusts, drought, heat, sunlight, salinity and irrigation water, are limiting the achievement of potential yields of cultivars. But rusts are a persistent threat and caused a 10% reduction in national yield during the 1978 leaf rust epidemic. During 1995, a yellow rust epidemic in NWFP caused a 20% yield loss. Similarly, huge yield losses occurred during 2005 because of a bad yellow rust epidemic in NWFP and northern districts of the Punjab.

Yellow rust can reduce wheat yields by as much as 84% (Murray, Ellison and Watson, 1995). It is therefore of considerable economic importance to control this disease. In recent decades, around 40 race-specific yellow rust resistance genes have been identified in wheat and deployed in wheat breeding programmes (McIntosh, Wellings and Park, 1995). This type of resistance, however, can be overcome by changes in virulence of the *P. striiformis* pathogen. Virulences have evolved against major genes *Yr1*, *Yr2*, *Yr3*a, *Yr4*a, *Yr6*, *Yr7*, *Yr9*, *Yr17*, *Yr27* and *Yr28* (Kisana, Mujahid and Mustafa, 2003). As a result, major wheat varieties of Pakistan, including Pak 81, Pirsabak 85, Inqilab 91 and MH 97, became susceptible to stripe rust.

The breeding strategy of relying on major genes as a source of yellow rust resistance is rapidly becoming superseded. Therefore, pathologists and breeders sought resistance mechanisms based on either minor genes that are potentially durable, or on adult plant resistance (Broers, 1989; Singh and Rajaram, 1992; Singh, Huerta-Espino and Rajaram, 2000). This type of rust resistance mechanism is more effective against multiple races and is long lasting (Hussain *et al.*, 1998, 1999; Bariana *et al.*, 2001). A high level of resistance to yellow rust could be achieved by accumulating 4 or 5 minor genes in a variety (Singh, Huerta-Espino and William, 2005). However, a moderate level of resistance can be achieved by accumulating 2 or 3 minor genes in a line (Singh, Huerta-Espino and William, 2005). Parents having partial resistance are crossed to pyramid genes for rust resistance and yield. This has resulted in many wheat lines that were better in yield and disease resistance than their parents (Hussain *et al.*, 2007).

Breeding for yellow rust-resistant varieties should be regarded as the only long-term remedy to protect the crop from the disease. The objective of the programme reported here was to develop and screen wheat germplasm against yellow rust under natural and high-stress inoculation conditions, to monitor the lines that might have minor-gene-based resistance, and to transfer that resistance to susceptible but high yielding, adapted varieties through conventional hybridization, for the development of wheat varieties having minor-gene-based resistance against yellow rust.

Materials and methods

A programme for breeding for yellow rust resistance was initiated at the Wheat Research Institute, Faisalabad, Pakistan, during 1992/93. Wheat germplasm comprising 140 lines were screened for yellow rust resistance under natural conditions at Islamabad, Pirsabak, Peshawar and Kaghan, and under artificial inoculated conditions with diversified inoculum at Faisalabad. All the entries were sown in two 2-m long rows at 30 cm intervals with a susceptible check, cv. Morocco, after each ten entries. The material was planted on two sowing dates one month apart at Faisalabad to provide a maximum period of exposure under rust conditions for all growth stages. The nursery was inoculated with yellow rust races in the second week of January. Rust reaction was recorded when the susceptible check was 100S. The lines showing a slow-rusting tendency with a 20–40% terminal rust rating were marked for the crossing programme on the assumption that these might have minor-gene resistance. These parents were crossed with local adapted high yielding varieties. Twenty single crosses were developed in 1994–95, while in the next season 30 three-way crosses were developed by crossing the F_1 with either of the recurrent parents or a third parent. The material was advanced by using the selected-bulk approach (Singh, Huerta-Espino and William, 2005) and disease pressure in segregating populations was created by inoculating the susceptible border rows with diverse races of yellow rust. Plants having rust reactions up to 30MR were tagged from each cross in the F_2 to F_5 generations. From the F_5 generation, single-head rows were raised from desirable selected plants having 90–110 cm plant height, 10–30 tillers/plant, compact head, 50–90 grains/head and with amber grain colour. Similarly, from the F_6 head rows, selections were again made based on the same criteria together with low terminal rust rating. The selected F_6 rows were harvested and allotted entry numbers and were put in preliminary yield testing trials. The best were tested in micro-yield trials and national uniform yield trials in different agro-ecological regions of the country. These entries were also tested in disease screening nurseries in hot-spot areas for yellow rusts (Islamabad, Pirsabak-Nowshera, Peshawar and Kaghan). The data for disease resistance were recorded following Roelfs, Singh and Saari (1992).

Results and discussion

Germplasm was evaluated for disease reaction when the susceptible check cv. Morocco became fully diseased. Disease reactions of all the entries were recorded and six local varieties and lines known for high yield potential and having moderate levels of resistance, along with two exotic lines from CIMMYT with moderate levels of resistance and medium yield potential, were selected for gene pyramiding studies (Table 1). The varieties and lines having high yield potential are presented in Table 2. However, their resistance had been broken down due to the ineffectiveness of yellow rust major genes, such as *Yr9, Yr27* and *Yr29* (Hussain *et al.*, 2006). For combining high yield potential with minor gene-based resistance against yellow rust, single crosses, backcrosses and top crosses were developed and evaluated in the field. From these crosses, 140 lines were selected when they had achieved a desirable level of homozygosis, and were tested in yield trials for two years. The best performing lines selected from station yield trials were promoted to Micro Wheat Yield Trials and National Uniform Wheat Yield Trials.

Table 1. Disease reactions of the selected slow-rusting parents

Variety or line	Disease reactions to yellow rust					Average yield (kg/ha)
	1992/93	1993/94	2004/05	2005/06	2008/09	
Auqab-2000	30M	30M	20MR-MS	30MR-MS	10MR	4250
Kohistan-97	10MR	20MR	20MR	10MR	0	3750
Luan	5MR	10MR	10MR	5MR	0	3250
Shalimar-88	10MR	20MR	20R-MR	30MR-MS	0	4000
Punjab 96	10R-MR	10MR	30MR-MS	30MR-MS	0	4250
Weaver	10M	10MR	10MR	5MR	0	3000-3500
HD-2179	5MR-MS	5MR-MS	5MR-MS	5MR-MS	5MS	3000-3500
Morocco (check)	100S	100S	100S	100S	100S	—

Table 2. Disease reactions of the selected high yielding parents

Variety or line	Disease reactions to yellow rust					Average yield (kg/ha)
	1992/93	1993/94	2004/05	2005/06	2008/09	
Inqilab 91	30M	30M	100S	30MR-MS	60S	4250
V-87094(Wattan)	40M	30MR	40MS	30MS	20MR-MS	3750
M.H-97	30MR-MS	30MR-MS	80S	40MS-S	60S	4000
Lu 26	10MR	20MR	80S	70S	40S	4000
Pak 81	10R-MR	10MR	100S	90S	100S	4250
Chenab 2000	10M	10MR	60S	50S	60S	3000
Morocco (check)	100S	100S	100S	100S	80S	—

It is evident from Table 3 that Lu26/HD2179/2* Inqilab 91 (V-00183R), Shalimar-88/Weaver (V-02156), Shalimar-88/Wattan//MH 97 (V-02192), Luan/Kohistan (V-03138), Shalimar-88/V-90A204//MH 97 (V-04178), Pb-96/Wattan//MH 97 (V-04179), Chenab-2000/Inqilab 91 (V-05082), Lu-26/HD-2179//Chill'S' (V-06018), Shalimar-88/Pak 81//MH 97(V-06068), Auqab-2000/Milan (V-06096) and Oasis/5*Angra//Inqilab 91 (V-06117) were the best crosses, having moderate levels of yellow rust resistance. These crosses produced lines superior in yield and disease resistance to Inqilab 91 and Seher 06. Among the best crosses, Wattan, Shalimar 88 and MH 97 were common parents in four crosses each. These were therefore the best parents for the breeding programmes aiming at development of high yielding varieties having good rust resistance. Luan, the important parent, which has an alien species in its parentage, might also carry minor genes for yellow rust resistance.

Table 3. Yield performance of selected durable rust-resistant elite lines

Line	Parentage	Cross type	Trials	Years tested	Av. yield (kg/ha)	Check yield(1)	Diff.(2)
V-00183R (Shafaq 06)	Lu26/HD2179//2* Inq-91	Back	120	5	4139	4031*	+2.70%
V-02192	SH88/V87094//MH97	Top	124	5	4049	3970*	+2.44%
V-02156	SH-88/Weaver	Single	50	4	4236	4046*	+4.50%
V -03138 (Lasani 08)	Luan/Koh.97	Single	125	3	4141	3983*	+ 3.96%
V-04178	SH88/90204//MH97	Top	120	5	4098	4198**	+2.38%
V-04179	Pb96/V87094//MH97	Top	50	3	5267	5255*	+4.70%
V-05082	CHENAB2000/INQ91	Single	24	4	4296	4198**	+2.33%
V-06018	LU26/HD2179//CHILL'S'	Top	24	3	4752	4532**	+4.85%
V-06068	SH88/PAK81//MH97	Top	24	3	4454	4532**	+2.91%
V-06096	UQAB2000/MILAN	Single	24	3	4822	4532**	+6.40%
V-06117	OASIS/5*ANGRA//INQ91	Double	24	3	4736	4532**	+4.50%

NOTES: (1) Check cvs for yield: * = Inqilab 91; ** = Seher 06. (2) % increase or decrease compared with check.

The advanced lines listed in Table 3 were tested in a series of replicated trials at various locations across the country and were compared with high yielding variety Inqilab 91. The line V-00183RR was tested in 120 trials and it yielded 2.70% more than Inqilab 91. Line V-03138 was tested in 125 trials and was found to yield 3.96% more than Inqilab 91. Line V-02192 had 2.44% higher yield than Inqilab 91. The other lines—V-02156, V-04178, V-04179, V-05082, V-06018, V-06068, V-06096 and V-06117—out-yielded the check, cv. Seher 06 (Table 3). These selected lines had higher yields than Inqilab 91 and Seher 06 as a result of the accumulation of genes in these lines, which improved their

pathogen resistance and hence yield potential. The development of high yielding wheat varieties by using single cross, backcross or top cross approaches have been advocated by many researchers (Hussain *et al.,* 2007; Singh, Huerta-Espino and William, 2005).

The basic objective of the study was the accumulation of minor genes for yellow rust resistance, as by crossing partially resistance parents, more minor genes can be accumulated in the lines. Singh and Rajaram (1992), Singh, Huerta-Espino and Rajaram (2000) and Hussain *et al.* (2006) have successfully accumulated minor genes for rust resistance by crossing partially resistant parents. Singh, Huerta-Espino and William (2005) showed that accumulating 4 to 5 minor genes may produce relative immunity. The selected elite lines were tested for yellow rust in disease screening nurseries in hot-spot areas of Pakistan (Table 4). The lines V-02192, V-04178, V-05082 and V-06117 have shown rust reactions near to immunity for yellow rust, which is an indication of the presence of 3 to 4 minor genes that confer resistance to yellow rust. Moreover these lines are high tillering, with more yield potential than other existing wheat varieties in Pakistan. V-03138 (Lasani 08) also showed rust reactions near immunity for yellow rust (Table 3). The rust reactions of the other entries, i.e. V-00183R, V-02156, V-04179, V-06018 and V-06068, is attributed to the presence of 2 or 3 minor genes for resistance against yellow rust. However, assessment of the minor genes accumulated in these lines should be confirmed by genetic studies.

These lines were also tested for grain quality parameters (Table 5). All the selected lines had better 1000-grain weights, ranging from 44 g to 55 g. Lines V-00183R and V-06117 showed most 1000-grain weight, i.e. 55 g. Line V-00183R showed good 1000-grain weight (55 g) and protein percentage (13%), and its bread (chapatti) quality was very good. Similarly, V-03138 also showed good 1000-grain weight (44 g) and protein level (12.5%), with very good bread (chapatti) quality.

Line V-00183RR was released in 2006 as Shafaq 06 for general cultivation and is gaining popularity among the farming community due to its higher yield and very good chapatti quality characters. Similarly V-03138 was released as Lasani 08 in 2008.

Table 4. Rust reactions in hot-spots of elite lines finally selected

Line	Parentage	Yellow rust				
		Faisalabad	Bahwalpur	Peshawar	Islamabad	Pirsabak
V-00183R (Shafaq-06)	V87094/2* Inq-91	0	0	10MR-MS	20MR-MS	30MR-MS
V-02192	SH88/V87094//MH97	0	0	0	10R	5R-MR
V-02156	SH-88/Weaver				10R-MR	20R-MR
V-04178	SH88/90A204//MH97	0	0	0	Tr-MR-MS	Tr-MR-MS
V-04179	Pb96/V87094//MH97	0	0	0	10R	40R-MR
V -03138 (Lasani-08)	Luan/Koh.97	0	0	0	5R	15MR
V-05082	CHENAB2000/INQ91	0	0	0	Tr-MR	Tr-MR
V-06018	LU26/HD2179//CHILL'S	0	0	0	20MR-MS	5MR
V-06068	SH88/PAK81//MH97	0	0	0	20MS	5MR
V-06096	UQAB2000/MILAN	0	0	10MR-MS	20MR-MS	10MS
V-06117	OASIS/5*ANGRA//INQ91	0	0	Tr-MR-MS	Tr-MR-MS	5MS
Inqilab 91	WL711/CROW	30MR-MS	0	40MR-MS	60S	80S
Morocco (check)		30MR-MS	0	90S	100S	100SN

Table 5. Quality parameters of the new lines

Line	1000-grain weight (g)	Chapatti quality	Protein (%)
V-00183R (Shafaq-06)	55	Very good	13.0
V-02192	45	Fairly good	11.0
V-02156	48	Good	12.5
V-04178	49	Good	—
V-04179	48	Good	13.0
V -03138 (Lasani-08)	44	Very good	12.5
V-05082	45	Good	13.60
V-06018	45	Good	13.10
V-06068	50	Good	13.23
V-06096	45	Good	13.23
V-06117	55	Good	13.30
Inqilab 91	45	Good	12.5

References

Anon[ymous]. 2009. Second estimate of crop reporting service. MIFALL, Pakistan.

Bariana, H.S., Hayden, M.J., Ahmad, N.U., Bell, J.A., Sharp, P.J. & McIntosh, R.A. 2001.Mapping of durable adult plant and seedling resistance to stripe [yellow] rust and stem rust diseases in wheat. *Australian Journal of Agricultural Research,* 52: 1247–1255.

Broers, L.H.M. 1989. Partial resistance to wheat leaf rust in 18 spring wheat cultivars. *Euphytica,* 44: 247–258.

FAO [Food and Agriculture Organization of the United Nations]. 2007. Data from the FAOSTAT Web site.

Hussain, M., Chaudhary, M.H., Shah, J.A., Hussain, M. & Younis, M. 1998. Genetic diversity to *Puccinia recondita* f.sp. *tritici* in 59 wheat lines. *Pakistan Journal of Phytopathology,* 10: 113–121.

Hussain, M., Chaudhary, M.H., Rehman, A. & Anwar, J. 1999. Development of durable rust resistance in wheat. *Pakistan Journal of Phytopathology,* 11: 130-139

Hussain, M., Ayub, N., Khan, S.M., Khan, M.A., Muhammad, F., Hussain, M. & Ahmad, N. 2006. Pyramiding rust resistance and high yield in bread wheat. *Pakistan Journal of Phytopathology,* 18: 11–21.

Hussain, M., Rehman, A., Hussain, M., Muhammad, F., Younis, M., Malukra, A.Q. & Zulkiffal, M. 2007. A new high yielding durable rust resistance variety – Shafaq 06. *Pakistan Journal of Phytopathology,* 19 (12):238-142.

Kisana, S.N., Mujahid, Y.M. & Mustafa, Z.S. 2003. Wheat production and productivity 2002–2003.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* Kluwer Academic Publishers, Dordrecht, The Netherlands.

Murray, G.M., Ellison, P.J. & Watson, A. 1995. Effects of stripe rust on the wheat plant. *Australasian Plant Pathology,* 24(4): 261–270.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. Rust diseases of wheat: Concepts and methods of disease management. CIMMYT, Mexico.

Singh, R.P & Rajaram, S. 1992. Genetics of adult plant resistance to leaf rust in Frontana and three CIMMYT wheats. *Genome*, 35: 24–31.

Singh R.P., Huerta-Espino, J. & Rajaram S. 2000. Achieving near-immunity to leaf and stripe rusts in wheat by combining slow-rusting resistance genes. *Acta Phytopathologica et Entomologica Hungarica,* 35: 131–139.

Singh, R.P., Huerta-Espino, J. & William, H.M. 2005. Genetics and breeding for durable resistance to leaf and stripe rusts in wheat. Turkish Journal of Agriculture, 29: 1–7.

Evaluation of Indian wheat genotypes for slow-rusting resistance to stripe [yellow] rust under artificially inoculated conditions

M.S. Saharan, A.K. Sharma, M. Singh and S.S. Singh

Directorate of Wheat Research, Carnal, Haryana, India

Abstract

Wheat rust diseases—stripe or yellow rust; leaf or brown rust; stem or black rust—are common fungal foliar diseases in many regions of the world, including India. Yellow rust of wheat, caused by *Puccinia striiformis* West. f.sp. *tritici*, inflicts heavy yield losses in northern parts of India if cool and humid weather prevails between December and March. Use of genetic host resistance is the most effective, economical and eco-friendly approach for rust control. Resistance breeding resulted in the release of several rust-resistant varieties during the post-Green Revolution period in India. However, evolution of new pathotypes in rusts always posed challenges in wheat rusts management in India. Slow-rusting is a form of resistance where a susceptible host reaction is observed but the rate of disease development is slower than in susceptible cultivars. In trials, 114 wheat genotypes (41 advanced entries, 73 checks) of advanced varietal trial (AVT)-2nd year and 126 entries of AVT-1st year were inoculated with prevalent pathotypes of yellow rust (67S8, 47S102, 46S103, 70S69, 46S119, 78S84) at Karnal during the 2008/09 crop season.

Rust intensities recorded at equal intervals were analysed using the Area Under Disease Progress Curve (AUDPC) technique and genotypes were categorized into distinct groups. Group I included 127 genotypes (69 entries + 58 checks) that exhibited AUDPC values <1% of the susceptible check variety A-9-30-1 (AUDPC value 1300) for yellow rust. Genotypes exhibiting AUDPC values for stripe [yellow] rust in the ranges of 1–100, 101–200 and 201–500 were placed in Group II (15 genotypes), Group III (25 genotypes) or Group IV (32 genotypes), respectively.

Group III (HPW 251, PDW 313, PDW 314, PBW 175, HUW 612, HUW 616, HUW 324, HUW 468, HD 2932, MP 1203, MP 4010, HI 8680, MACS 6273, HW 5207, KRL 213, HS 490, SWL 19, K 0708, PBW 618, PBW 620, PDW 316, PDW 317, DBW 52, MP 1218 and PBW 623) and Group IV (HS 295, HS 375, HS 420,

VL 738, PBW 343, PBW 396, K 0607, K 0616, K 0617, NW 2036, HD 4719, DL 738-2, GW 322, HD 2864, HW 2004, MACS 6222, UAS 304, UAS 305, HD 2189, VL 616, MACS 2971, HI 8694, K 0707, GW 1250, HI 8690, HI 8691, HI 8693, HI 8693, MPO 1220, GW 1251, MACS 2988 and MACS 2998) genotypes were characterized as partially resistant, as these genotypes exhibited AUDPC values <50% of the checks.

Introduction

With the Green Revolution in the mid-1960s, India achieved remarkable increases in production and productivity of wheat. India is now the second largest producer of wheat in the world and wheat production reached a record 78.4×10^6 t for the 2007/08 cropping season (Anon., 2008). This achievement in wheat production has been perhaps the most important and unparalleled in the history of India. At the same time, India is also the second-largest wheat consumer after China (FAO, 2004). The rusts of wheat attract most attention because wheat is one of the two most important food crops for mankind. India, in particular, has not faced any rust epidemic in the last 35 years because of proper deployment of rust resistance genes in wheat breeding programmes.

Wheat rusts pose a constant threat to sustainable wheat production and thus India's food security. Stripe rust or yellow rust (*Puccinia striiformis* Westend f.sp. *tritici)* of wheat (*Triticum aestivum* L.) is an important disease of wheat globally, including India, especially in areas with cool and wet environmental conditions (Roelfs, Singh and Saari, 1992). Stripe rust could affect wheat production on approximately 43×10^6 ha in Asia and 9.4×10^6 ha in India (Singh, 2004). Stripe rust is very important in the North Western Plains Zone (NWPZ), as well as Northern Hill Zone (NHZ), and poses a potential threat to the main wheat belt of India if cool and humid weather persists from December to March. Sometimes the disease also inflicts yield losses in other, cooler, parts of the country. Cultivation of resistant varieties is the most effective, eco-friendly and economically viable method of managing wheat rusts. However, resistant cultivars typically become susceptible due to evolution of new pathotypic variation. Indian variety PBW 343 has become vulnerable to stripe rust pathotype 78S84. During the 2008/09 crop season stripe rust also appeared in severe form at a few locations in Jammu and Kashmir, Punjab and Haryana. Resistance conditioned by major genes is short lived when used commercially because this form of resistance can be easily overcome by mutation and selection pressure for virulence in rust pathogens. Slow rusting is a form of resistance where a susceptible host reaction is observed but the rate of disease development is slower than in fully susceptible cultivars. The delay in progress of epiphytotic development is attributed to several factors, including latent period, number of uredosori per unit area, size of uredosori, and rate of sporulation. Studying these

components individually is quite laborious and time consuming, particularly in the case of trials with many entries. A convenient option is use of the Area Under the Disease Progress Curve (AUDPC) technique, which takes into account all the factors collectively leading to manifestation of slow-rusting in a genotype. The aim of the present study was to identify slow-rusting genotypes for stripe rust among advanced breeding material and popular cultivars grown in different agro-climatic zones, as sources for minimizing the occurrence of new virulence.

Materials and methods

A trial with 114 wheat genotypes (37 advanced lines of *T. aestivum*, 5 advanced lines of *T. durum*, and 72 checks, including 62 *T. aestivum*, 9 *T. durum* and 1 *T. dicoccum*) from advance varietal trial (AVT)-2nd year and 122 entries (103 lines of *T. aestivum*, 2 lines of triticale, 15 lines of *T. durum* and 2 lines of *T. dicoccum*) from AVT-1st year were sown in as 1-m long rows with a spreader row of a susceptible check (A-9-30-1) every 20th row at Karnal during crop season 2007/08. All lines were planted as 2-m rows at 23 cm intervals in the 2008/09 crop season. Three spreader rows (row to row gap of 15 cm) of a mixture of susceptible cultivars (A-9-30-1, Bijaga Yellow, Sonalika) were planted on the four edges of the plot and between the test material after every 10 rows. The crop was fertilized at a rate of 120 kg N/ha (split equally between seedling and stem elongation stages), 60 kg P/ha and 40 kg K/ha. Irrigation was provided at crown root initiation, stem elongation, flowering and grain formation stages of crop growth. A stripe rust epidemic was initiated by inoculating 3-week-old plants of the spreader rows with urediniospore-water-Tween 20 suspension having equal proportions of predominant stripe rust pathotypes (67S8, 47S102, 46S103, 70S69, 46S119, 78S84) collected from actively sporulating plants of susceptible varieties maintained in isolation in a polyhouse. Hypodermic syringes and sprays were used to inoculate the spreader rows to ensure timely establishment of stripe rust in the field. High humidity was maintained for rust development. The infection types (Tr-R, R, Tr-MS, MS, Tr-S and S) were recorded by following McNeal *et al.* (1971). Stripe Rust scores were recorded, combining the disease severity based on the modified Cobb's scale and the infection type(s) of Peterson, Campbell and Hannah (1948). The rust intensities were recorded at 10-day intervals and a Coefficient of Infection (CI) was calculated. AUDPC values were calculated using a computer package developed at CIMMYT, Mexico (CIMMYT, 1988). Wheat genotypes were grouped based on AUDPC value ranges 0, 1–100, 101–200, 201–500, 501–1000 and >1000.

Results and discussion

The 114 wheat genotypes from AVT-2nd year and 122 entries from AVT-1st year were evaluated for yellow rust under artificially inoculated conditions at Karnal (Haryana) during the 2008/09 crop season to identifying slow rusting lines based on AUDPC values. Among the AVT-2nd year genotypes, Group I included 48 genotypes (19 entries + 29 checks) with AUDPC values <1% of the susceptible check variety A-9-30-1. Genotypes exhibiting AUDPC values for stripe rust in the ranges of 1–100, 101–200 and 201–500 were placed in Group II (11 genotypes), Group III (15 genotypes) and Group IV (20 genotypes), respectively. The remainder had AUDPC values in the range of 501–1000 (10 genotypes) or >1000 (10 genotypes).

Among AVT-1st year entries, 88 genotypes (79 *T. aestivum*, 2 triticale, 7 *T. durum*) were completely free from disease, with 5 genotypes in Group II (AUDPC 1–100), 8 in Group III (AUDPC 101–200), 10 in Group IV (AUDPC 201–500), 8 in Group V (AUDPC 501–1000) and 3 genotypes in group VI (AUDPC >1000).

Grouping based on AUDPC values is shown in Tables 1 and 2. By combining the results of AVT-1st year and 2nd year entries and popular cultivars used as checks, Group III (HPW 251, PDW 313, PDW 314, PBW 175, HUW 612, HUW 616, HUW 324, HUW 468, HD 2932, MP 1203, MP 4010, HI 8680, MACS 6273, HW 5207, KRL 213, HS 490, K 0708, PBW 618, PBW 620, PDW 316, PDW 317, DBW 52, MP 1218 and PBW 623) and Group IV genotypes (HS 295, HS 375, HS 420, VL 616, VL 738, PBW 343, PBW 396, K 0607, K 0616, K 0617, NW 2036, HD 4719 (d), DL 738-2, GW 322, HD 2864, HW 2004, MACS 6222, UAS 304, UAS 305, HD 2189, MACS 2971, HI 8694, K 0707, GW 1250 (d), HI 8690 (d), HI 8691 (d), HI 8693 (d), MPO 1220 (d), GW 1251 (d), MACS 2988 and MACS 2998) were characterized as partially resistant, as these genotypes exhibited AUDPC values <50% of the checks. In recent years, wheat researchers have emphasized the importance of developing and deploying cultivars that carry durable or slow-rusting resistance based on quantitatively inherited genes (Caldwell, 1968; Johnson and Law, 1975; Knott, 1989; Parlevliet, 1975; Rajaram, Singh and Torres, 1988).

The slower progress of rust does not affect the yield potential of host genotype adversely and chances of new variants or pathotypes are also minimized due to reduced selection pressure. The entries possessing slow-rusting traits offer durable field resistance. Therefore slow rusting lines identified in the present study can be considered as important genetic stocks for providing durable resistance to stripe rust in breeding programmes.

Table 1. Grouping of AVT-2nd year entries and released varieties based on stripe rust AUDPC under artificially inoculated conditions at Karnal, India, during 2008/09 crop season

AUDPC Value (Group)	Zone	Genotype
0 (Group I)	NHZ	HS 502*, HS 490, TL 2942 , VL 804 and VL 892
	NWPZ	DDW 12 (d)*, HD 2967*, HD 2985*, HI 8681*, PBW 610*, PBW 612*, PBW 613*, WH 1061*, WH 1062*, C-306, DBW 16, PBW 550, PDW 233 (d) and WH 896
1–100 (Group II)	NHZ	VL 907* and VL 829
	NWPZ	PDW 311 (d)*, UAS 419*, WH 1063*, DBW 17, PBW 373, PBW 590 and PDW 291 (d)
101–200 (Group III)	NHZ	HPW 251
	NWPZ	PDW 313 (d)*, PDW 314 (d)* and PBW 175
201–500 (Group IV)	NHZ	HS 295, HS 375, HS 420, VL 616 and VL 738
	NWPZ	PBW 343 and PBW 396
501–1000 (Group V)	NHZ	Sonalika
>1000 (Group V)	NHZ	HS 240 and HS 277

NOTES: NWPZ = North Western Plains Zone; NHZ = Northern Hill Zone. *indicates wheat entries. Entries without *are released varieties. (d) = durum

Table 2. Grouping of AVT-1st year entries based on stripe rust AUDPC calculated during 2008/09 crop season under artificially inoculated conditions at Karnal, India

AUDPC Value (Group)	Zone	Wheat genotype
0 (Group I)	NHZ	HPW 289, HPW 296, HPW 297, HPW 309, HPW 315, HS 505, HS 507, HS 508, HS 512, HS 513, HS 521, HS 522, HS 523, TL 2963, TL 2966, UP 2771, UP 2772, VL 914, VL 916, VL 920, VL 921, VL 924, VL 925, VL 926, VL 933, VL 934 and VL 935
	NWPZ	DBW 49, DBW 50, DBW 51, HD 3002, HD 3003, HD 3007, HD 3012, HD 3013, HD 3014, HD 4720, HUW 625, HUW 626, PBW 617, PBW 621, PBW 624, PBW 628, PBW 629, UAS 315, UP 2744, UPD 85, WH 1073, WH 1076, WH 1080, WH 1081 and WHD 943
1–100 (Group II)	NHZ	HPW 3088
	NWPZ	HI 8692 and K 0716
101–200 (Group III)	NHZ	HS 490
	NWPZ	K 0708, PBW 618, PBW 620, PDW 316 and PDW 317
201–500 (Group IV)	NWPZ	HI 8694 and K 0707
501–1000 (Group V)	NWPZ	K 0711

NOTES: NWPZ = North Western Plains Zone; NHZ = Northern Hill Zone.

References

Anon[ymous]. 2008. Agricultural Statistics at a Glance. Advance estimates of production of food grains, oilseeds and other commercial crops during 2007-08. Ministry of Agriculture, New Delhi, India.

Caldwell, R.M. 1968. Breeding for general and/or specific plant disease resistance. pp. 263–272, *in:* K.W. Finlay and K.W. Shephard (editors), Proceedings of the Third International Wheat Genetics Symposium. Australian Academy of Sciences, Canberra, Australia.

CIMMYT. 1988. A software package program for calculation of AUDPC. CIMMYT, Mexico.

FAO [Food and Agriculture Organization of the United Nations]. 2004. Data from FAOSTAT statistical database. See: www.fao.org.

Johnson, R. & Law, C.N. 1975. Genetic control of durable resistance to stripe rust (*Puccinia striiformis*) in the wheat cultivar Hybride de Berse. *Annals of Applied Biology,* 81: 385–391.

Knott, D.R. 1989. *The Wheat Rusts – Breeding for Resistance.* Springer-Verlag, Berlin, Germany.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

Parlevliet, J.E. 1975. Partial resistance of barley to leaf rust, *Puccinia hordei*. Effect of cultivar and development stage on latent period. *Euphytica,* 24: 21–27.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Rajaram, S., Singh, R.P. & Torres, E. 1988. Current CIMMYT approaches in breeding for resistance to the rusts of Wheat. *In:* N.W. Simmonds and S. Rajaram (editors). [Proceedings of the conference on] Breeding Strategies for Resistance to the Rusts of Wheat, El Batan, Mexico, 29 June–1 July 1987. CIMMYT, Mexico.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. Rusts Diseases of Wheat: Concepts and Methods of Disease Management. CIMMYT, Mexico.

Singh, R.P. 2004. Wheat rust in Asia: meeting the challenges with old and new technologies. *In:* Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 September–1 October 2004.

Effective and ineffective resistance genes and resistance reaction of commercial cultivars to *Puccinia striiformis* f.sp. *hordei* in Iran

S.A. Safavi,[1] A. Babaei,[2] F. Afshari,[3] M. Arzanlou[2] and Sh. Ebrahimnejad[4]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran
2. Plant Pathology Department of Tabrize University, Tabrize, Islamic Republic of Iran
3. Seed and Plant Improvement Research Institute, Karaj, Islamic Republic of Iran
4. Research Centre of Agriculture and Natural Resources of Mazandaran, Sari, Islamic Republic of Iran

Abstract

Barley stripe rust (caused by *Puccinia striiformis* f.sp. *hordei*) is an important disease of cultivated barley in several parts of world and sometimes causes significant yield losses due to severe epidemics. In Iran, it is increasing on susceptible cultivars and lines in some parts (such as north-western and northern provinces). In order to prevent epidemics and reduce yield losses, identification of effective resistance genes, use and production of resistant cultivars and lines (particularly with durable resistance) will be the best control method. For this purpose, 29 barley genotypes (including differential sets and commercial cultivars) were evaluated in 2007–2009 crop years. The differential sets were planted in various parts of Iran (Ardabil, Sari, Mashhad), but commercial cultivars were evaluated in Ardabil by measuring AUDPC. Each line was sown as two 1-m long rows spaced 30 cm apart. Trials were conducted under natural infection condition and based on complete block designs with three replications. A susceptible cultivar (Afzal) was planted among the experimental entries (at 10-entry intervals) and also as the borders of the nursery. At adult plant stage, infection type (IT) of each entry was evaluated when disease developed on the susceptible check. The percentage leaf area affected (disease severity) was also scored using a modified Cobb's scale. The results of virulence and avirulence monitoring in Ardabil showed presence of virulence for *Rps2*, *Rps1.b*, *Rps3*, *RpsTr1*, *RpsTr2* and *RpsI5*, while in Mashhad virulence was observed for *Rps2*, *Rps1.b* and Bancroft. In this study it

was also concluded that *RpsEm1, RpsEm2, RpsHF, Rps4, Rps1.c, RpsVa1, RpsVa2* and *RpsAst* were effective resistance genes. Among commercial cultivars, only 6 entries had low infection; the remaining cultivars had a moderately susceptible or a susceptible reaction to barley stripe rust in Ardabil.

Introduction

Stripe rust of barley (*Hordeum vulgare* L.) caused by *Puccinia striiformis* West. f.sp. *hordei*, was first separated from other stripe rusts by Eriksson in 1894 (Erikson, 1894). Barley stripe rust has occurred in Europe and Asia for many years and severe epidemics of the disease have been reported in north-western and central European countries, India, Bangladesh, Nepal, China and Japan (Chen, Line and Leung, 1995). Since 1975, barley stripe rust has been a problem in several South American countries, with yield losses of 30 to 70% (Dubin and Stubbs, 1986).

Barley stripe rust was first reported in Iran in 1947 (Esfandiari, 1947), and it is increasing in some parts of Iran, such as northern and north-western provinces. The increase in disease incidence is probably due to cultivation of susceptible cultivars under conditions favourable for the pathogen.

Among the methods available for controlling stripe rust is that of growing resistant cultivars, which is the most efficient, economically viable and environmentally friendly approach to control (Line and Chen, 1995). Two types of resistance have been identified in this pathosystem: hypersensitive or qualitative, versus quantitative resistance. The use of quantitative resistance in breeding programme requires extensive field testing. This type of resistance is generally more difficult to breed for than qualitative resistance. The interest in quantitative resistance reflects its probable durability (Sandoval-Islas *et al.*, 1998; Castro *et al.*, 2002).

In view of the disease's importance and the damage it causes due to epidemics, investigation of resistance sources and study of virulence factors are very important. The ability to manage disease depends on understanding the composition of the pathogen population. Differentials with different resistance genes or new gene combinations provide the information necessary for selection of new sources of host resistance (Brown, Hill and Velasco, 2001). Genetic diversity varies in virulence in pathogenic fungal populations, and is usually expressed as virulence factors or virulence phenotypes (Brown, Hill and Velasco, 2001). Zadoks (1961) reported that physiological races of *P. striiformis* can be detected using trap nurseries in which differential cultivars are exposed to natural infection in locations where the pathogen frequently occurs. Quantitative resistance should be more effective and durable against pathogens with a highly variable population, such as yellow rust of barley. The manipulation of quantitative resistance in breeding programmes is more difficult than manipulation of specific resistance. If a correlation between

seedling resistance and adult plant resistance exists, the task becomes easier. Unfortunately, there is very low correlation between these two types of resistance. Because of very low correlation between them, field tests are also necessary to distinguish adult plant resistance genes.

The present study is about virulence factors of barley yellow rust and investigation of effectiveness of resistance genes in Iran. The objectives of this study are the determination of effective and ineffective resistance genes to barley yellow rust and the identification of cultivars with probably slow-rusting resistance.

Materials and methods

Differential sets

The twelve differential barley genotypes used in this study are listed in Table 1. This experiment was carried out under natural conditions in three regions of Iran (Ardabil, Sari, Mashhad) for the period 2007–2009. Each entry was planted in two 1-m long rows spaced at 30 cm. Plots were spaced at 65 cm. A susceptible spreader (cvs Afzal or Topper) row was sown around plot borders and at 10 entry intervals. Disease severity was estimated according to the modified Cobb scale (0% =immune, 100% = fully susceptible; Peterson, Campbell and Hannah, 1948) when disease was well developed (80S) at the flag leaf stage. The infection type of the disease was also recorded based on Roelfs *et al*. (1992). Effective and ineffective genes were distinguished based on studies of Chen and Line (2002).

Commercial cultivars

The 17 commercial cultivars used in this study are listed in Table 2. This experiment was conducted in Ardabil in 2009. Each entry was planted in two 1-m long rows spaced at 30 cm. Plots were spaced at 65 cm. The experimental design was a complete block design with three replications. A susceptible spreader (cvs Afzal or Topper) row was sown around the trial borders and at 10-entry intervals. Percentage severity was recorded based on the modified Cobb scale (Peterson, Campbell and Hannah, 1948) and reaction based on Roelfs, Singh and Saari (1992).

Results and discussion

Differentials assessment

The results in Ardabil showed the presence of virulence for *Rps2, Rps1.b, Rps3, RpsTr1, RpsTr2* and *RpsI5,* but in Mashhad virulence was observed for *Rps2, Rps1.b* and Bancroft. In Sari, no virulence was observed (except for cv. Topper).

from this study we concluded that *RpsEm1, RpsEm2, RpsHF, Rps4, Rps1.c, RpsVa1, RpsVa2* and *RpsAst* were effective resistance genes.

The weather conditions in 2007 and 2008 were not favourable for disease development. In 2009, barley stripe rust developed well at all sites. The results indicate that the Ardabil pathotype is more virulent than two other pathotypes.

Effectiveness of breeding is highly dependent on the relevance of information concerning the nature and extent of the pathogenic variation. In this study we concluded that cv. Bancroft is moderately susceptible. This cultivar has high-temperature adult plant resistance, which is a form of durable resistance (Line, 2002). Thus in breeding programmes we can use this cultivar, in combination with other cultivars that have desirable characteristics and other durable resistance genes.

Table 1. Results of survey on virulence factors of barley yellow rust pathogen in 2007–2009 in three areas of Iran

Differential sets	Resistance genes	2007	2008			2009		
		Ardabil	Ardabil	Sari	Mashhad	Ardabil	Sari	Mashhad
Topper	—	70S	50S	O		40S	30MS	40S
Helis Franken	*Rps4(Yr4),rpsHF*	O	O	O		10MR	O	O
Emir	*rpsEm1, rpsEm2*	O	O	O		O	O	O
Asterix	*Rps4(Yr4), rpsAst*	O	O	O		10MR	O	O
Hiproly	*rpsHi1, rpsHi2*	O	O	O		10MS	O	O
Varunda	*rpsVa1,rpsVa2*	O	O	O		0	O	O
Abed Binder	*rps2 (yr2)*	Tr-MR	40MS	O		40MS	O	30S
Trumpf	*rpsTr1,rpsTr2*	O	10MS	O		20MS	O	O
Mazurka	*rps1.c*	O	O	O		20MR	O	O
Bigo	*rps1.b (yr)*	O	10MS	O		20S	O	30MS
I5	*rps3 (yr3), rpsI5*	10MS	20MS	O		30MS-S	O	30MR
Bancroft	HTAP genes	10MS	O	O		30MS-S	O	40S
Afzal	—	70S	80S	50S		60S	40MS-S	90S

NOTES: HTAP = high-temperature, adult-plant [resistance].

Evaluation of commercial cultivars:

Among commercial cultivars, except entries 2, 3, 4, 7, 10, 11 (see Table 2) which had low infection, the cultivars had a moderately susceptible or susceptible reaction to barley stripe rust in Ardabil. The results indicated that Ardabil conditions were favourable for disease development, allowing an appropriate assessment of commercial cultivars.

The cultivars expressing an infection type MS or MR may carry durable resistance genes (Brown, Hill and Velasco, 2001; El-Naimi *et al*., 2001). Consequently, entries 2, 3, 4, 7, 10 and 11 (see Table 2) may have some form of durable resistance, such as high-temperature, adult-plant (HTAP) and slow rusting. This type of resistance is long lasting, because it is controlled by more than one gene, in other words, polygenic (Dehghani and Moghadam, 2004).

In consideration of the fact that the rust challenge is continuously changing due to mutation, migration over long distances and in response to selection pressure of cultivar genotypes on pathogen genotypes (Hovmøller, 2001; Ben Yehuda *et al*., 2004), researchers should deploy non-specific resistance instead of race-specific.

Table 2. Severity and infection type for commercial cultivars to barley yellow rust pathogen in 2009 in Ardabil, Iran

Entry no.	Cultivar	Infection type		
		Replicate 1	Replicate 2	Replicate 3
1	Walfajre	30M	30MR	30MS
2	Rihane	10MR	20MS-S	20MS
3	Makouee	5R	10MR	0
4	Kavir	30M	20MS	20MR
5	Karoon	70MS	60M	60M
6	Torkman	60MS	60M	60M
7	Dasht	10MS	10MS	20MS
8	Jonob	40MS	40MS-S	40MS
9	Gorgan-4	40MS	30MS	10MR
10	Zarjow	10MR	30MR	30M
11	Arass	20MR	20M	20MR
12	Goharjow	70S	60S	50S
13	Eram	100S	70S	50MS
14	Sina	50M	70MS-S	50MS
15	Shirin	60MR	60M	60M
16	Torsh	100S	100S	100S
17	CB-74-2	40MS-S	20MS	30MS
Check	Afzal	80S	70S	70S

References

Ben Yehuda, P., Eilam, T., Manisterski, J., Shimoni, A. & Akster, Y. 2004. Leaf rust on *Aegilops speltoides* caused by a new *forma specialis* of *Puccinia triticina*. *Phytopathology*, 94: 94–101.

Brown, W.M. Jr, Hill, J.P. & Velasco, V.R. 2001. Barley yellow rust in North America. *Annual Review of Phytopathology*, 39: 367–384.

Castro, A.J., Chen, X.M., Hayes, P.M., Knapp, S.J., Line, R.F., Toojinda, T. & Vivar, H. 2002. Coincident QTL which determine seedling and adult plant resistance to stripe rust in barley. *Crop Science*, 42(5): 1701–1708.

Chen, X.M. & Line, R.F. 2002. Identification of genes for resistance to Puccinia striiformis f.sp. *hordei* in 18 barley genotypes. *Euphytica*, 129: 127–145.

Chen, X.M., Line, R.F. & Leung, H. 1995. Virulence and polymorphic DNA relationships of *Puccinia striiformis* f.sp. *hordei* to other rusts. *Phytopathology*, 85: 1335–1342.

Dehghani, H. & Moghaddam, M. 2004. Genetic analysis of latent period of stripe rust in wheat seedlings. *Journal of Phytopathology*, 122: 325–330.

Dubin, H.J. & R.W. Stubbs. 1986. Epidemic spread of barley stripe rust in South America. *Plant Disease*, 70: 141–144.

El-Naimi, M., Yahyaoui, A., Ketata, H., Abdalah, O., Nachit, M. & Hakim, S. 2001. Screening for yellow rust resistance in bread and durum wheat. Abstract. *In:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Eriksson, J. 1894. Uber die Spezialisierung des Parasitismus bei den Getreiderostpilzen. *Ber. Dtsch. Bot. Ges.*, 12: 292–331.

Esfandiari, E. 1947. Les rouilles de cereales en Iran. *Entomology Phytopath. Appl.*, 4: 67–76.

Hovmøller, M.S. 2001. Disease severity and pathotype dynamics of *Puccinia striiformis* f.sp. *tritici* in Denmark. *Plant Pathology*, 50: 181–189.

Line, R.F. 2002. Stripe Rust of wheat and barley in North America: A retrospective historical review. *Annual Review of Phytopathology*, 40: 75–118.

Line, R.F. & Chen, X.M. 1995. Success in breeding for and managing durable resistance to wheat rusts. *Plant Disease*, 79: 1254–1255.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. Rusts Diseases of Wheat: Concepts and Methods of Disease Management. CIMMYT, Mexico.

Sandoval-Islas, J.S., Broers, L.H.M., Vivar, H. & Osada, K.S. 1998. Evaluation of quantitative resistance to yellow rust (*Puccinia striiformis* f.sp. *hordei)* in the ICARDA/CIMMYT barley breeding programme. *Plant Breeding*, 117: 127–130.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology]*, 67: 69–256.

New approaches in traditional resistance breeding

Kh.S. Turakulov and S.K. Baboev

Institute of Genetics and Plant Experimental Biology AS Ruz, Uzbek Academy of Sciences, Kibray, Tashkent, Uzbekistan

Abstract

The development of cultivars of wheat with resistance to destructive pathogens that reduce grain yield and quality constitute major wheat breeding objectives. To incorporate resistance in wheat varieties from different sources, crossing is still the principal procedure for breeding new varieties, utilizing genetic recombination and bringing together multigenic combinations. In this respect, an experiment was conducted to study the inheritance of yellow rust on bread wheat. We screened released and prospective varieties and selected lines of bread wheat from local, CIMMYT and ICARDA germplasm sources for yellow rust and leaf rust resistance. Among screened material, crosses were made between four groups. In the first group, the crosses were made among resistant lines and cultivars (resistant × resistant). In the second group, crosses were made between susceptible cultivars and lines (susceptible × susceptible). In the third group, crosses were conducted among resistant and susceptible material in a reciprocal manner (resistant × susceptible; susceptible × resistant). Finally, in the fourth group, we crossed moderately resistant and moderately susceptible cultivars and lines. Except in group one, the crosses were conducted among parents with different distinct morphological traits and disease reactions in order to identify eventual morphological markers for resistance. Plant colour analysis of progeny showed that resistance was more frequent in progenies which tend to have a greyer green colour rather than greener. There was no difference in disease reaction in plants having spikes with awns or without. Early heading was associated more with resistance than susceptibility. In late heading progenies, both resistance and susceptibility occurred equally. Progenies with tall plants were more resistant but lodged more easily. Almost in all groups, we obtained progenies with R, MR, MS and S types of reaction. In progenies of crosses involving moderately resistant and moderately susceptible parents, we obtained a range of reactions, including resistant, moderately resistant, moderately susceptible and susceptible plants. In some crosses, such as Superwheat 1659 × Djagir and F19 × Sanzar, we observed slow rusting in the progenies. These progenies expressed an increased latent period, decreased infection frequency and a reduced length of infection lesions (stripes). In the crosses between susceptible and resistant entries (e.g. Morocco × Ravi), it was found that some progenies were highly

resistant despite the high susceptibility of one of the parents. This high level of resistance was maintained until F_5. Usually in traditional resistance breeding, to get resistance, backcrossing is conducted with the resistant parent. Instead of this approach, we made backcrosses with susceptible parents. Interesting results were observed in this case when backcrossing with susceptible parent Sanzar 8. Thus, backcrossing of the progenies of the crosses Ravi × Sanzar 8 and CIMMYT-UZ × Sanzar 8, with Sanzar 8, has resulted in an increased number of resistant lines with durable resistance.

Introduction.

Stripe [yellow] rust, caused by *Puccinia striiformis* Westend. f.sp. *tritici* (*Pst*), is an important disease of wheat (*Triticum aestivum* L.) throughout the world. Growing resistant cultivars is the most-effective, economical and environmentally sound approach of controlling stripe rust (Line and Chen, 1995).

The development of cultivars of wheat with resistance to destructive disease pathogens that reduce grain yield and quality constitute major wheat breeding objectives. To gain resistance in wheat varieties from different sources of resistance, hybridization is the still principal plant breeding procedure of breeding new varieties used to obtain genetic recombination and to bring together multigenic combinations for improved performance of the whole plant.

Hybridological analyses of plant diseases are one of the main divisions of genetic analyses. Results of genetic analyses of plant diseases give an opportunity to predict successes of remote and intercrossing hybridizations, which is very important for efficiency in practical resistance breeding.

The inheritance of yellow rust, one of the most destructive diseases of bread wheat, was studied using the artificial infectious background of the experimental field of the Laboratory of Cereal Grains Genetics of Institute Genetics and Plant Experimental Biology of ASUz.

Materials and methods

The experiment screened samples of bread wheat from local (released, cultivated and prospective varieties and lines), and germplasm from nurseries from CIMMYT (ESWYT, HTWYT, SAWYT, YR/LR) and ICARDA (CWA-RTN), assessing yellow rust and leaf rust resistance. The infection background was created by mixing pathogen spores with powder at a ratio of 1:300, for 1 m^2 plots at +13–15°C and 80–90% RH. Hybridization was conducted at the end of April and beginning of May. Hybridization among screened samples involved four types of recombination: among resistant parent samples

(resistant × resistant); susceptible parent samples (susceptible × susceptible); among resistant and susceptible parent samples (reciprocal resistant × susceptible or susceptible × resistant); and moderately resistant × moderately susceptible parents. Except in group one, hybridizations were conducted among parents with distinct morphological traits with resistance or susceptibility to study correlation and give an opportunity for identifying morphological markers for resistance. Variances of the phenotypic classes in different combinations were determined by χ^2 (Ayala and Kayger, 1988).

Results and discussions

Plant colour analysis of the progeny shows that resistance was inherited more in hybrids tending to a greyer green colour rather than greener. Both spikes with awns or awnless inherited resistance and susceptibility almost equally. Early heading was associated more with resistance and moderate resistance. In late heading hybrids susceptibility occurred frequently.

In almost all groups, hybrids were obtained with R, MR, MS and S type reactions. Hybrids were obtained that were moderately resistant and moderately susceptible from parents appearing resistant, moderately resistant, moderately susceptible or susceptible. In some hybrids (Superwheat 1659 × Djagir; F19 × Sanzar) a group of plants were observed with slow rusting due to increased latent period and reduced infection frequency and length of infection lesions (stripes). In susceptible × resistant hybrids (e.g. Morocco × Ravi) both susceptible plants and highly resistant plants appeared, despite a highly susceptible parent, with this high level of resistance extending to the F_5 generations of the combination.

In the Morocco × Ravi (S × R) combination, high resistance was inherited at the same time as tall and normal height, but only with early heading and only with greyer colour. Moderate resistance occurred only with normal height and late heading. All moderately susceptible hybrids were late heading with normal height.

In the SP 1659 × Djaggir combination there were no tall plants, but dwarf hybrids appeared alongside normal height offspring. High resistance was inherited only with early heading and greyer colour. Moderate resistance was inherited with dwarf and normal heights, early and late heading (long spikes), although colour was greyer in hybrids with earlier heading and long spikes, and was greener in hybrids with dwarf and late heading. Here, among moderately resistant hybrids appeared hybrids with long spikes in earlier heading plants. Moderate susceptibility was inherited with earlier heading and dwarfism. Highly susceptible hybrids inherited earliest heading and normal height.

The segregation ratios of the hybrids varied according to parental genotype (Tables 1 and 2).

Table1. Segregation ratio in F_2 hybrids

Hybrid	Estimated no. of hybrids				Ratio	
	R	MR	MS	S	R:MR:MS:S	R:S
Ravi × Sanzar 8 (R/MS)	17	22	20	41	3:3:3:7	7:9
CIMMYTUZ × Sanzar 8 (R/MS)	5	30	45	20	1:6:6:3	7:9
Yr7 × Sanzar 8 (R/MS)	5	25	30	40	1:3:6:6	4:12
F19 × Sanzar 8 (R/MS)	14	3	5	78	2:1:1:12	3:13
F15 × Saykhun (R/R)	15	13	17	55	1:3:3:9	4:12
F34 × Saykhun (R/R)	6	27	30	37	1:3:6:6	4:12
F19 × Marjon (R/S)				100		

The yellow rust resistance screening included samples from different germplasm sources and nurseries. We made crosses between entries from various CIMMYT germplasm nurseries (ESWYT, HTWYT, SAWYT, YR/LR). These nurseries focus on different traits, such as high yield (ESWYT), resistance to high temperature (HTWYT), or resistance to yellow and leaf rusts. In Table 1, parents Ravi, CIMMYT UZ, *Yr7* are from the LR/LF nursery, and in combinations with Sanzar 8, Ravi×Sanzar 8 (R/MS), CIMMYT UZ×Sanzar 8 (R/MS), *Yr7*×Sanzar 8 (R/MS), segregation ratios were 7:9, 7:9 and 4:12, respectively. In combinations of Sanzar with parents from another nursery, the F19×Sanzar 8 (R/MS), F15×Saykhun (R/R), F34×Saykhun (R/R) ratios were 3:13, 4:12 and 4:12, respectively. From the F19×Marjon (R/S) cross all hybrids were susceptible, with the ratio of susceptible hybrids increased over combinations between Sanzar 8 and YR/LR nursery varieties. So, genotypes with certain traits inherited resistance traits with specificity according to their trait. Here, certain traits may influence resistance negatively or positively. We can conclude that in inheritance of yellow rust resistance the role of interaction between genes is significant.

Usually in traditional resistance breeding to get a resistant hybrid one backcrosses to the resistant parent. We tested this with susceptible parents.

Interesting results were observed after backcrossing hybrids with susceptible parent Sanzar 8. Resistant variety Ravi was used as a resistant parent. Backcrossing hybrids Ravi×Sanzar 8, CIMMYT UZ×Sanzar 8 again with Sanzar 8, the number of resistant hybrids with durable resistance increased instead of the expected susceptible hybrids. From Table 2 it appears that in combinations Ravi×Sanzar 8, CIMMYT UZ× Sanzar 8 and YR7×Sanzar 8, the ratio of the resistant and susceptible hybrids are 6:10, 7:9 and 4:12, respectively, and here the quantity of susceptible hybrids is almost

twice that of resistant ones. When we backcrossed these combinations again with Sanzar 8, instead of susceptible hybrids, the ratio of resistant hybrids increased to R/S 14:2, 13:3 and 13:3, respectively. In practical breeding to increase resistance levels in hybrids one usually makes a backcross to the resistant parent (Briggs and Noulze, 1972; Remeslo, 1978). If we consider the negative correlation between resistance and quality (flour, breadmaking) traits, by backcrossing again with the resistant parent, in most cases we get a resistant hybrid with inferior flour and breadmaking quality.

Table 2. Segregation ratios of F_2 hybrids with variety Sanzar 8 and backcrosses

Hybrids	**R**	**MR**	**MS**	**S**
Ravi/Sanzar 8 (R/S)	17	22	20	41
According to susceptibility level 3:3:3:7, R/S 6:10				
Sanzar 8/CIMMYTUZ (S/R)	5	30	45	20
According to susceptibility level 1:6:6:3, R/S 7:9				
Yr7/Sanzar 8 (R/S)	5	25	30	40
According to susceptibility level 1:3:6:6, R/S 4:12				
Backcrosses				
Ravi3//Sanzar 8/Sanzar 8	30	60	10	0
According to susceptibility level 4:9:1, R/S 14:2				
CIMMYTUZ//Sanzar 8/Sanzar 8	10	70	20	0
According to susceptibility level 1:12:3, R/S 13:3				
Yr7//Sanzar 8/Sanzar 8	10	70	20	0
According to susceptibility level 1:12:3, R/S 13:3				

So, in backcrossing for the purpose of getting resistant forms, instead of including only resistant parents we can use susceptible parents by screening varieties by backcrossing for this purpose. In that case we will have a good chance of combining a plant resistance trait with flour and breadmaking quality.

References

Ayala, F. & Kayger, D. 1988. pp. 261–265, *in: Modern genetics*. MIR, Moscow.

Briggs, F. & Noulze, F. 1972. *Scientific bases of plant breeding.* Spike. Moscow.

Line, R.F. & Chen, X.M. 1995. Success in breeding for and managing durable resistance to wheat rusts. *Plant Disease,* 79: 1254–1255.

Remeslo, V.N. 1978. Breeding and seed growing of cereal grains. pp. 23–24, *in*: *Yield*. Kiev.

Monitoring and evaluation of yellow rust for breeding resistant varieties of wheat in Tajikistan

M. Rahmatov,[1, 5] Z. Eshonova,[2] A. Ibrogimov,[3] M. Otambekova,[1] B. Khuseinov,[1, 5] H. Muminjanov,[1] A. Morgounov,[4] A. Merker[5] and A. Hede[6]

1. Tajik Agrarian University, Tajikistan
2. Farming Institute, Tajik Academy of Agricultural Sciences, Tajikistan
3. Breeding Station "Chilgazi", Isfara Rayon, Tajikistan
4. Turkey-CIMMYT-ICARDA, International Winter Wheat Improvement Programme, Turkey
5. Swedish Agricultural University of Science, Alnarp, Sweden
6. Sida Project "Support to Seed Industry Development in the Republic of Tajikistan", Dushanbe, Tajikistan

Abstract

Wheat is an important food crop in Tajikistan. It occupies a prominent position in the farming system of the country. To cope with increasing food demand due to population growth, there is a need to increase wheat productivity. Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is widespread in Tajikistan under irrigated and rainfed conditions and is considered the most damaging disease on the wheat crop. Yellow rust epidemics may totally destroy wheat plants and decrease wheat yield up to 60%. Since 2003, our research group has carried out monitoring and evaluation of rust diseases in breeding nurseries and farmer fields in different agro-climatic zones of Tajikistan. The results of the surveys and investigations showed the maximum yield loss was 60%, in 2003. In comparison with 2003, losses decreased to 5% in the period between 2004 and 2007. In 2008, yellow rust was not observed apart from sporadic occurrence of yellow rust recorded in all agro-ecological zones of Tajikistan. During this period, humidity was low, and the weather conditions in April and May were very dry. In the spring of 2009, the humidity was very high, but yellow rust infection was still low (about 10%) and the wheat crop was mainly damaged by leaf rust. The reduced occurrence of yellow rust might be due to the use of varieties and advanced lines that are resistant to yellow rust. Our results indicate that every year the percentage of wheat genotypes expressing resistance to yellow rust is increasing. Regional and International cooperation has been initiated with the Turkey-CIMMYT-ICARDA IWWIP, and winter and facultative wheat nurseries have been sown in Tajikistan. Cooperation in wheat breeding and germplasm exchange has also been established with Oklahoma State University, USA. In this respect, segregating F_2 population

nurseries from Oklahoma University are received for further selection in Tajikistan. A National Wheat Breeding Programme was initiated through the GTZ-CIMMYT Project "Regional Network on Wheat Variety Promotion and Seed Multiplication", and currently continues as Sida Project "Support to Seed Industry Development in Tajikistan". The germplasm used for the breeding programme of Tajikistan originated mainly from CIMMYT, ICARDA, Turkey, USA and Tajikistan. Several advanced lines have been selected by our research group and are annually tested in Preliminary Yield Trials, and the best advanced lines are submitted for official variety testing for release in Tajikistan. The advanced lines that have been selected for high yield, improved bread making quality and resistance to yellow rust and other diseases include: PRINA/STAR, SHARK/F4105W2.1, VORONA/KAUZ//1D13.1/MLT, CHEN/*Aegilops squarosa*/TAUS.RCN//3RAV and VORONA SNO79. Cvs Attila, Ziroat 70, Tacikar, Ormon, Sadokat, Iqbol, Oriyon, Chilgazi, Isfara, Yusufi and Vahdat, which were selected from IWWIP and ESWYT nurseries, are in official testing. Cvs Alex, Norman, Orman and Somoni were recently released.

Introduction

Tajikistan is an agrarian country in which agriculture contributes 20–22% to GDP. The total area of agricultural land is over 3.8 million hectare, most of which is open grazing pasture. The area of arable land is only 709 000 ha, of which 508 000 ha is irrigated. Every year, 500 000–600 000 t of seed-cotton, 900 000 t of wheat, 500 00–550 000 t of potato, 700 000–720 000 t of vegetables, 150 000–170 000 t of melons and water melons and 140 000–160 000 t of fruits are produced.

The transition to a market economy, organization of new enterprises, and the diversification of ownership have lead to massive structural changes in agriculture. Despite these upheavals, production has gradually increased, and over the past four years the average production of agricultural produce has increased by 13.5%.

Further increase in production of agricultural produce requires establishment of a firm technical base and resources. The population is increasing rapidly and the scope for further expansion of agricultural land, and irrigated land in particular, is limited. According to the forecast and current growth rate there were 0.08 ha of arable land available per capita in 2008, of which 0.06 ha was irrigated land. The four major crops—wheat, cotton, potato and rice—on average contribute 37.3% of the value added in overall agriculture. Wheat alone contributes 11.2% to agricultural domestic product and 5.6% to GDP. During recent years, wheat has occupied about 307 000 to 310 000 ha and with total production of wheat about 640 000 to 650 000 t from an average yield of 1.7–1.9 t/ha (Anon., 2008).

Bread in Tajikistan, as in other countries of the region, is the staple food product for the population, and after gaining independence, the agricultural policy of the government was focused on food security in general and grain independence in particular. As a consequence, the main focus is on wheat production, since wheat provides Tajikistan with approximately 60% of the domestic need for food.

Farmers grow wheat in almost all parts of the country, and after independence the area under wheat increased drastically in both irrigated and rainfed zones. The yield remains relatively low because of lack of improved varieties, poor seed quality, lack of inputs (fertilizer, chemicals, etc.), diseases, pests, weeds, poor crop management and lack of modern field equipment (Figures 1 and 2).

Any further expansion of arable lands is increasingly difficult due to limited land resources and lack of water for irrigation. Any increase in grain production therefore has to come from increased yield per unit area, through introduction of new, high yielding varieties resistant to diseases, pests and tolerant of unfavourable conditions (drought, high temperature, etc.), together with more intensive utilization of irrigated land for the cultivation of a second crop during summer. Regional and International cooperation has been started with the Turkey-based Turkey-CIMMYT-ICARDA IWWIP winter and facultative wheat nurseries in a number of countries, including Tajikistan. Cooperation in wheat breeding and germplasm exchange has also been established with Oklahoma University, USA, whereby segregating F_2 population nurseries are received for further selection in Tajikistan. Since 1999, through the National Wheat Breeding Programme initiated by the GTZ-CIMMYT Project "Regional Network on Wheat Variety Promotion and Seed Multiplication" and continued through the Sida Project "Support to Seed Industry Development in Tajikistan", several advanced lines selected by the public and private breeding sectors are annually tested in multilocation yield trials, with the best lines submitted for official variety testing for release in Tajikistan (Pett and Muminjanov, 2004). During recent years, ten new wheat varieties have been submitted for official trials, and in 2007 two cultivars—Alex and Norman—were released, and cvs Ormon and Somoniin in 2008.

Wheat in Tajikistan is attacked by a number of diseases (rusts, smut, bunt, powdery mildew, black point, Septoria, etc.) that cause great losses, affecting both grain yield and quality. Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is a major disease of wheat in Tajikistan, suppressing the synthesis and deposition of starch and protein in the endosperm and resulting in poor yield and low baking quality.

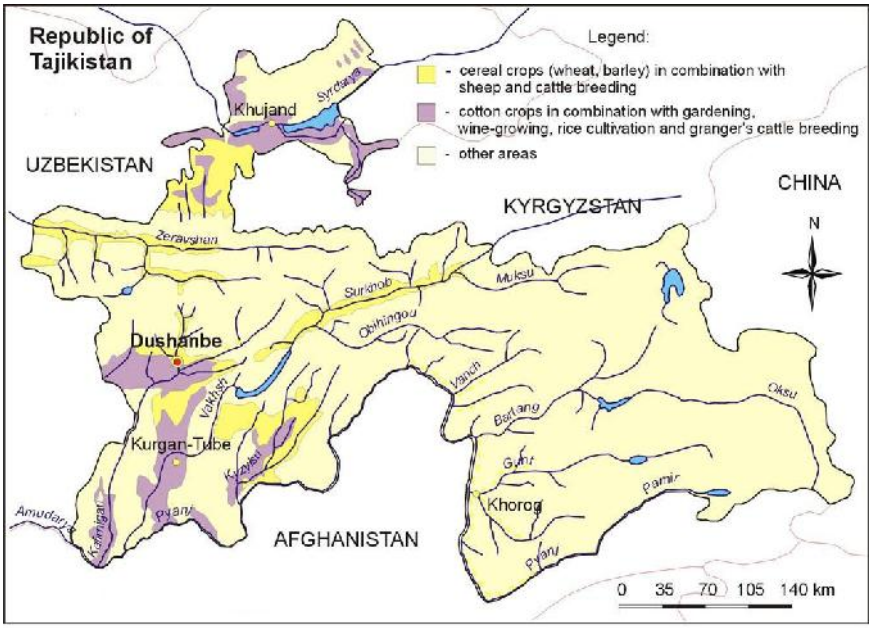


Figure 1. Map of the Republic of Tajikistan with the different wheat production environments

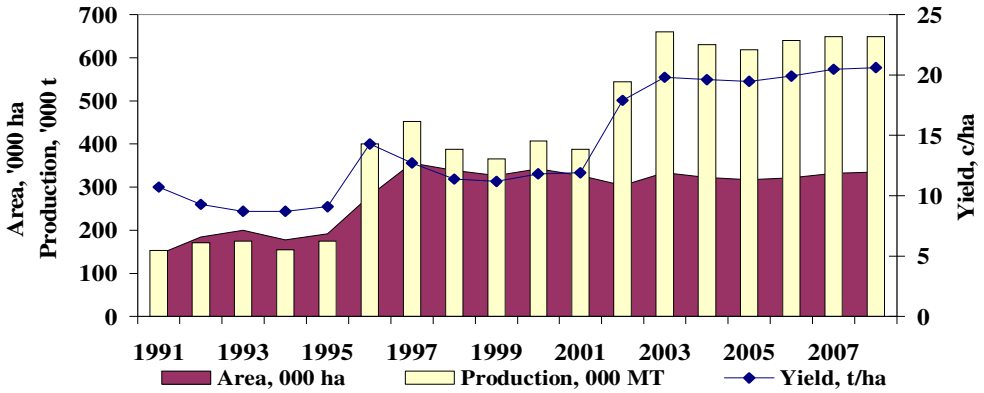


Figure 2. Wheat production (tonne), 1991–2008. Source: Anon., 2008.

Material and methods

The germplasm used for the breeding programmes in Tajikistan originates mainly from the international breeding programmes of CIMMYT and ICARDA, the Turkey-CIMMYT-ICARDA IWWIP, USA and Tajikistan.

The germplasm used for this study originated from three nurseries: ESWYT (entries 25, 26, 27 and 28), FAWWON (entries 5, 7, 9 and 10) and WWERYT (entries 1, 3 and 5). The standard checks used were the local cv. Navruz, and the recently released cvs Alex and Jagger from Kansas, USA. Jagger was introduced to Tajikistan through the IWWIP programme and is now widely grown by Tajik farmers.

Monitoring of diseases for selection of rust-resistant lines with high yield and good bread making quality was implemented from 2003 to 2009 in different agro-ecological zones of Tajikistan: in Central Tajikistan in the Hissar Valley (780–800 masl) at the Farming Institute of the Tajik Academy of Agriculture, and at a private farm, Latif Murodov; in the south in the Vakhsh Valley Branch of the Farming Institute (600 masl); and in the north in the Isfara region (820–850 masl) at a private farm, Chilgazi.

The parameters used as criteria for breeding new varieties were: grain yield, gluten content, gluten deformation index, and resistance to the most important diseases in Tajikistan, namely yellow rust, brown rust, tan spot and powdery mildew.

The evaluation scale used for yellow rust was 0–5% (resistant) – R; 5–20% (moderately resistant) – MR; 20–50% (moderately susceptible) – MS; and 50–100% (susceptible) – S

Results and discussion

The monitoring and evaluation of wheat fields during 2003–2009 carried out in different parts of Tajikistan showed that both yellow rust and tan spot are important wheat diseases (Figure 3).

The result from 2003 averaged over three locations (Hissar, Isfara and Vakhsh) demonstrated that 65% of varieties and advanced lines in the breeding nurseries were damaged (MS or S) by yellow rust. The most susceptible lines and their infection levels were Navruz (90%), Attila (50%), Delta (50%), Somoni (40%), Bezostaya (40%) and ATAY/GALVEZ (30%). Several advanced lines, such as PASTOR/3/VEE#3//DOVE, DUCULA//VEE/MYNA, OK 81306//ANB/BUC/3/SAU and MV 218-98, were resistant to yellow rust. Infections of yellow rust were observed in all zones of Tajikistan under both irrigated and rainfed conditions.

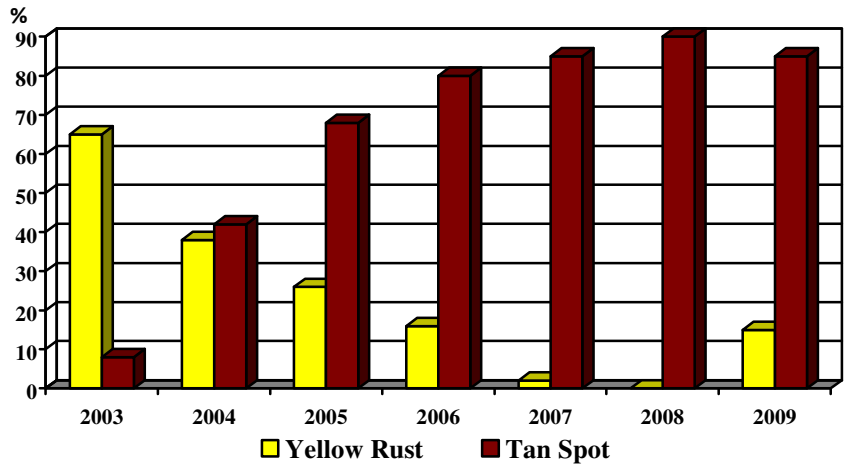


Figure 3. Frequency of wheat entries in breeding nurseries damaged by yellow rust and tan spot (i.e. moderately susceptible (MS) and susceptible (S)) in 2003–2009

In comparison with 2003, the severity of yellow rust decreased in the period from 2004 to 2008 in all agro-ecological zones of Tajikistan, whereas the severity of tan spot increased. The reasons for decreased yellow rust levels were dry climatic conditions, unfavourable for the formation of yellow rust, and the introduction of new varieties resistant to yellow rust and other diseases.

The results from 2006 over three locations showed that the cvs most susceptible to yellow rust were Navruz with 50% level infestation; Somoni with 40% in Isfara and 20% at the Farming Institute; Ziroat 70 with 30% in Isfara and no yellow rust in the farming institute and at Vakhsh. Genotypes showing resistance to yellow rust were Alex, Kauz, Norman, TAM200/KAUZ and SHARK/F4105W2.1.

During growing seasons 2007 and 2008, yellow rust was not observed in Tajikistan. Even cv. Navruz, which under normal conditions is susceptible, was not infected by yellow rust.

The humidity was very high during the spring of 2009, but still yellow rust infestation was low, with an average of 10% of entries in breeding nurseries being characterized as either medium susceptible or susceptible. The wheat varieties most susceptible to yellow rust were standard cvs Navruz (50% damage) and Eskina (80%) in all zones.

The results from 2009 demonstrate that brown rust is becoming a serious wheat disease in Tajikistan. The most susceptible cvs and their infestation levels were Krasnodar 99 (100%), Gelibolu (100%), Trakya Aktar (100%), Kazakhstran 10 (70%), Navruz (60%) and Konya-2002.

Table 1 presents superior varieties and advanced lines selected from multilocation trials over three locations (Hissar, Isfara and Vakhsh) during the period 2005–2008. Several of the varieties and advanced lines combine resistance to yellow rust with high grain yield and good baking quality. The varieties and advanced lines showing highest gluten content are Vahdat (26.7%), Yusufi (24.1%), Isfara (23.8%), Norman (23.6%), Iqbol (23.4%), SHARK/F4105W2.1 (22.2%) and Sarvar (21.6%). The lowest gluten content is found in varieties like Somoni (16.5%), Jagger (16.6%) and Attila (18.6%). For measuring the strength and elasticity of wheat gluten, the Gluten Deformation Index (GDI) was measured using the Gluten Deformation Instrument IDK-3M from Russia. According to the references, GDI levels from 0 to 15 are characterized as unsatisfactory strong, from 20 to 40 as satisfactory strong, from 45 to 75 as satisfactory, from 80 to 100 as satisfactory weak, and from 105 to 120 as unsatisfactory weak. The results indicate that a high frequency of varieties and advanced are satisfactory (IDK values 45 to 75), in particular Navruz, Alex and Vahdat, but also SHARK/F4105W2.1, Sarvar, Isfara, Attila, Yusufi, Jagger and Ormon. The remaining varieties and advanced lines in Table 1 are all characterized as satisfactory or satisfactory weak (IDK values from 80–100), namely Kauz, Tacikar, Somoni, Ziroat 70, Norman and Iqbol.

The 1000-kernel weight of the selected varieties and lines ranged from 33.3 to 43.0 g.

Table 1. Grain yield and reaction to yellow rust (2005–2008)

No.	Genotype	Source	Grain yield (t/ha)	YR (%)	1000-kernel weight (g)	Gluten content (%)	GDI*
1	Navruz	Tajikistan	3.56	50	35.9	21.6	67.4
2	Jagger	USA, Kansas	3.70	20	34.2	16.6	76.6
3	Somoni		3.81	10	43.0	16.5	85.0
4	Alex	1WWERYT #11	4.70	10	38.3	20.7	69.5
5	Tacikar	5FAWWON #35	4.20	20	37.8	20.2	83.8
6	Norman	5FAWWON #37	4.42	10	38.1	23.6	87.0
7	Iqbol	5EYT-IR	4.90	0	37.6	23.4	94.3
8	Ormon	8FAWWON#36	4.41	0	37.8	18.9	76.9
9	Attila		4.00	10	38.2	18.6	76.2
10	Kauz		5.63	0	33.9	20.7	83.7
11	Ziroat-70		5.20	0	40.8	20.3	85.3
12	SHARK/F4105W2.1		4.47	0	41.7	22.2	70.6
13	Yusufi	25ESWYT #22	5.40	0	46.3	24.1	76.5
14	Isfara	25ESWYT #5	4.38	0	36.0	23.8	73.0
15	Sarvar	25ESWYT #9	4.25	0	30.9	21.6	71.7
16	Vahdat	25ESWYT #31	4.68	0	32.7	26.7	57.7

NOTES: GDI = Gluten deformation index

In comparison with the local varieties the new varieties selected and advanced lines have several advantages: higher yield and better grain quality, coupled with resistance to yellow rust, brown rust and tan spot. The multilocation evaluation of germplasm has resulted in new lines being released, such as cvs Alex, Norman, Ormon, Kauz, Ziroat 70, Iqbol and Tacikar, and promising new advanced lines being submitted for official testing, such as Yusfi, Vahdat, Sarvar, Isfara and SHARK/F4105W2.1. These varieties and advanced lines have yellow rust infestation levels of 10–20% while the local cv. Navruz has 50–60% in all locations.

As can be seen from Table 1, the new varieties yield more than 4 t/ha, with the highest yielding being Ziroat 70 at 5.20 t/ha, Iqbol at 4.90 t/ha and Alex at 4.70 t/ha, while the lowest yielding cvs are Navruz (3.56 t/ha) and Jagger (3.70 t/ha). Among the new advanced lines submitted for official variety testing the highest yielding are Yusufi (5.40 t/ha), Vahdat (4.68 t/ha), Isfara (4.38 t/ha) and Sarvar (4.25 t/ha). These lines are also resistant to yellow rust and other diseases.

Conclusions

Yellow rust is an important disease of wheat in Tajikistan. Cultivating resistant varieties is the most economical and environmentally safe control measure and has no additional costs for farmers. According to the results from testing a number of wheat lines in three locations (Hissar, Isfara and Vakhsh) during 2006–2008, it is recommended that the following lines be submitted for official variety testing trials: Sarvar, Yusufi, Vahdat, Isfara and SHARK/F4105W2.1. In 2007, the two cvs Alex and Norman were released, and cvs Ormon and Somoni in 2008.

References

Anon[ymous]. 2008. Agriculture of the Republic of Tajikistan. The statistical collection. Dushanbe.

Pett, B. & Muminjanov, H. 2004. Report on the GTZ-CIMMYT project in Tajikistan [In Russian]. Information Bulletin. *Seed Production and Breeding of Wheat in Asia*, 1: 10–22.

Study of selected wheat genetic resources for yellow rust resistance in Uzbekistan

Z. Khalikulov,[1] Z. Ziyaev,[2] A. Amanov,[3] S. Alikulov[2] and R.C. Sharma[1]

1. ICARDA, Central Asia and the Caucasus Regional Programme, Tashkent, Uzbekistan
2. Uzbek Research Institute of Plant Industry, Tashkent, Uzbekistan
3. Principal Consultant to the President's Office, Uzbekistan

Abstract

Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, is an important disease of wheat (*Triticum aestivum* L.) in Central Asia and many other wheat growing regions in the world. Wheat breeders continuously seek new sources of resistance for improving resistance of commercial cultivars. A field study was conducted using 272 wheat accessions in Uzbekistan in the 2008–2009 wheat growing season. The germplasm derived from Uzbekistan (59 entries); International Winter Wheat Improvement Programme, a cooperative breeding project between the Ministry of Agriculture and Rural Affairs of Turkey, CIMMYT and ICARDA) (103 entries); Russia (82 entries); Italy (10 entries); Ukraine (10 entries); and USA (7 entries). Approximately 90% of the germplasm represented wheat developed for irrigated conditions. Since there were severe epidemics of wheat yellow rust in Uzbekistan in 2009, the germplasm was indeed evaluated under heavy natural inoculum pressure. This was confirmed by 100% yellow rust severity on several susceptible genotypes. A quarter of the accessions (68 out of 272) showed high levels of resistance to yellow rust, while 33% of entries (91 out of 272) were highly susceptible (>60% severity). Many accessions resistant to yellow rust also showed resistance to leaf rust; a few were resistant to powdery mildew as well. In a situation where most of the commercial cultivars in Uzbekistan showed high levels of susceptibility to yellow rust in 2009, the resistant genotypes identified in this study are valuable wheat genetic resources. The genotypes with resistance to yellow rust, leaf rust and powdery mildew could prove outstanding parents to improve resistance to these three most important diseases of winter wheat under irrigated management condition.

Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal in Uzbekistan, occupying 1.3×10^6 ha. Both winter and facultative wheat varieties are cultivated in Uzbekistan. Irrigated wheat occupies 1.1×10^6 ha with average productivity of nearly 5 t/ha. This makes irrigated wheat very significant in food security in the country. Among the biotic constraints to irrigated wheat production, yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is most important. Yellow rust is a perennial problem in wheat cultivation. In order to sustain irrigated wheat production in Uzbekistan, yellow rust must be managed efficiently. At present, wheat yellow rust is managed through fungicide sprays, which is a costly solution, besides being hazardous for the environment. Yellow rust-resistant wheat varieties would offer a more sustainable option to minimize the economic impact of the disease.

Since most of the leading wheat cultivars of Uzbekistan show susceptibility to yellow rust, new sources of resistance must be identified for use in the wheat breeding programmes to develop resistant varieties. This study was therefore conducted to examine yellow rust resistance in a set of wheat landraces, old and improved cultivars and advanced breeding lines adapted to the irrigated wheat growing conditions in Uzbekistan.

Materials and methods

A set of 272 winter wheat accessions were included in this study. These were primarily from Uzbekistan (59 entries); the International Winter Wheat Improvement Programme (IWWIP), a cooperative breeding project between the Ministry of Agriculture and Rural Affairs of Turkey, CIMMYT and ICARDA (103 entries); Russia (82 entries); Italy (10 entries); Ukraine (10 entries); and USA (7 entries). Approximately 90% of the germplasm represented wheat developed for irrigated conditions.

A field experiment was conducted with 1 m^2 plots planted in the research plots of the Uzbek Scientific Research Institute of Crop Production at Kibray, Tashkent, in the 2008/09 winter wheat growing season. The plots were exposed to natural infection by yellow rust. Data collected in each plot were percent severity of and host reaction type to yellow rust on three occasions during the grain filling period; the highest yellow rust scores were calculated. Data were also recorded on maturity, plant height and 1000-kernel weight.

Results and discussion

Since there was a severe epidemic of wheat yellow rust in Uzbekistan in 2009, the experimental germplasm was indeed evaluated under heavy natural

inoculum pressure. This was confirmed by 100% yellow rust severity on susceptible checks.

High levels of resistance were shown by 25% of accessions (68 out of 272), whereas 33% entries (91 out of 272) were highly susceptible (>60% severity) to yellow rust. Many accessions resistant to yellow rust also showed resistance to leaf rust; a few were resistant to powdery mildew as well (data not presented). Many yellow rust-resistant genotypes also had early maturity, short plant height (<1 m) suitable for high-yield potential irrigated management, and high 1000-kernel weight.

In a situation where most of the commercial cultivars in Uzbekistan showed high levels of susceptibility to yellow rust in 2009, the resistant genotypes identified in this study are valuable wheat genetic resources. Several yellow rust-resistant genotypes with early maturity, short plant height and high 1000-kernel weight could be further tested for grain yield performance to determine their suitability for release as new cultivars. The yellow rust-resistant wheat genotypes could also be used in crossing programmes to improve resistance of the susceptible commercial cultivars.

Conclusions

This study has identified a large number of yellow rust-resistant winter wheat genotypes. Several yellow rust wheat genotypes also possessed superior agronomic characters, which could prove outstanding parents for improving yellow rust resistance in local commercial cultivars for irrigated management conditions. The findings of this study are useful for improving resistance to wheat yellow rusts in Uzbekistan and could be valuable for other countries in Central Asia and the Caucasus.

Virulence and avirulence factors of wheat yellow rust in Ardabil, Iran

S.A. Safavi,[1] F. Afshar[2] and J. Mohammadzadeh[1]

1. Ardabil Agricultural Research Station, Ardabil, Islamic Republic of Iran
2. Seed and Plant Improvement Research Institute, Karaj, Islamic Republic of Iran

Abstract

Stripe [yellow] rust caused by *Puccinia striiformis* f.sp. *tritici* is the most devastating disease of bread wheat (*Triticum aestivum*) in the cool winter areas. This rust disease represents a constant threat to wheat production in several countries in Central and Western Asia (CWA). A wide range of virulent yellow rust pathotypes is evolving in this region causing the breakdown of widely utilized sources of resistance in wheat. Hence, knowledge of effective resistance genes in the region will enable breeders to target those useful genes in their breeding programmes. From 2006 to 2009 in order to determine effective resistance genes in Ardabil, near-isogenic lines (NILs) and yellow rust differential varieties with defined resistance genes were planted in two 1-m long rows (rod row design). The experiment was conducted under mist irrigation and without artificial inoculation. Infection type and disease severity of each genotype was recorded at flag leaf stage using a modified Cobb's scale. The results showed presence of virulence for *Yr6, Yr2, YrSU, Yrll, YrA, Yr8, Yr7, Yr9, Yr12, Yr22, Yr23, Yr25, Yr10, Yr24, Yr17* and *Yr18.* In this study we concluded that *YrSD, Yr4, Yr5, Yr3, Yr1, YrSP, YrCV, Yr15, Yr13, Yr14, Yr16, YrND, Yr7+* and *Yr2+* were effective resistance genes. Among new and promising lines, C-84-4, C-80-4, C-81-10, C-81-4, C-85-4, MS-81-14, MS-83-9, MS-83-12, MS-85-12, Bam, Akbari, Alemot, Sistan, Shahriar, Mahdavi, Zarin, Moghan 2, Moghan 1, Kavir, Tos and Gods were susceptible to the Ardabil race.

Introduction

In breeding programmes, annual monitoring of pathogens is necessary to detect new pathotypes that can overcome resistance genes (McIntosh and Brown, 1997). Therefore, for a disease such as yellow rust, virulence analysis is important for the detection of new pathotypes of the pathogen and for the identification of effective genes for resistance. Both seedling and adult plant resistance (APR) genes are studied. Seedling-resistance genes are evaluated in

the greenhouse. APR genes are investigated at the adult plant stage under field conditions. The first differential system for physiological races of wheat yellow rust was established in 1930 (Allison and Isenbeck, 1930). The present system for identification of races, which is utilized in many parts of the world, was proposed by Johnson and Taylor (1972). This system was modified by Wellings and McIntosh (1990).

Until now, many resistance genes have been recognized, among them the genes *Yr11, Yr12, Yr13, Yr14, Yr16* and *Yr18.* They are APR genes. The first study on virulence factors of wheat yellow rust was conducted in a trap nursery by Zadoks (1961). The seedling-resistance genes are naturally expressed at all growth stages, and thus can be surveyed in field condition (in trap nurseries). Besides seedling-resistance genes, APR genes can be expressed as well. In order to monitor annual changes in races and virulence factors of wheat yellow rust, national experiments have been carried out since 1993 in Iran. In some of these studies, virulence factors of pathogen have been distinguished, and effective resistance genes have also been recognized. For example, results of Nazari and associates showed that Ardabil races have virulence for genes *Yr9, Yr7, Yr8, Yr2, Yr6, YrSU, Yr19, Yr8, Yr17, Yr25, Yr23, Yr22* and *Yr10.* In their study they also concluded that genes *YrSP*, *Yr1, Yr3, Yr49, Yr5, Yr16, Yr24, Yr13, Yr14, Yr15* and *YrCV* were effective genes (Nazari *et al.*, 2000).

Virulence on *Yr1* and *Yr17* has spread rapidly in central Asia. Virulence on *Yr1* was first observed in Tajikistan in 1999 and by 2004 it was found across central and West Asia. Virulence on *Yr10* and *Yr17* was observed in Yemen in 1999, virulence on *Yr18, 27* and *24* were recorded in 2002, and by 2005 these virulence types were recovered at many locations in CWANA (Yahyaoui, 2006).

Comprehensive information on pathogen virulence and variation, and epidemiological information on pathogen movements, provides a basis for the development of early warning systems (Yahyaoui *et al.*, 2001).

The objective of this study was to determine effective and ineffective resistance genes to wheat yellow rust in the period 2006–2009.

Material and methods

In this investigation 192 different genotypes were used. The entries included differential cultivars with seedling-resistance genes, cultivars with APR and durable resistance genes, near-isogenic lines and promising lines. The entries were sown in Ardabil agricultural research station under natural infection conditions. Each entry was planted in two 1-m long rows 30 cm apart. Plots were spaced at 65 cm. One susceptible cultivar (Bollani) was used after each 10 entries. The disease severity was estimated based on a modified Cobb scale

(Peterson, Campbell and Hannah, 1948) and infection type also was recorded (Roelfs, Singh and Saari, 1992).

Results and discussion

The results of this study showed that Ardabil races have virulence for genes *Yr6, Yr2, YrSU, Yrll, YrA, Yr8, Yr7, Yr9, Yr12, Yr20, Yr22, Yr23, Yr25, Yr10, Yr24, Yr17* and *Yr18*, but no virulence for genes *YrSD, Yr4, Yr5, Yr3, Yr1, YrSP, YrCV, Yr15, Yr13, Yr14, Yr16, YrND, Yr7*$^{+}$, *Yr2*$^{+}$ or *Yr26*. Therefore they are effective genes. In this investigation we also concluded that promising lines and cultivars C-84-4, C-80-4, C-81-10, C-81-4, C-85-4, MS-81-14, MS-83-9, MS-83-12, MS-85-12, Bam, Akbari, Alemot, Sistan, Shahriar, Mahdavi, Zarin, Moghan 2, Moghan 1, Kavir, Tos and Gods were susceptible. Some cultivars, such as Goscogene and MV17, were resistant during the study period. They were also resistant before starting this investigation. In Iran, disease breeding programmes were based on selecting for race-specific resistance. This kind of resistance is typically of short duration (Hovmøller, 2001; Ben Yehuda *et al.*, 2004). Therefore it is recommended that selection when breeding should emphasize multigenic resistance or partial resistance which is durable. This kind of resistance can sustain yield production of wheat and prevent the breakdown of resistance. Such genes in combination with slow-rusting *Yr18, YrTr1, YrTr2, Yr13* and high-temperature, adult-plant (HTAP) resistance genes from cultivars Luke and Express, which kept their resistance for a long time (Line, 2002), should be used in order to produce cultivars with durable resistance.

Table 1. Results of survey on virulence factors of wheat yellow rust pathogen 2006–2009 in Ardabil, Iran

No.	Genotype	Gene(s)	Severity and infecti0n type			
			2006	2007	2008	2009
1	Chinese 166	*Yr1*	0	0	5R	0
2	Lee	*Yr7,22,23*	40MS-S	50MS-S	60S	80S
3	Heines Kolben	*Yr2*	40MS-S	40MS	50MS-S	100S
4	Vilmorin 23	*Yr3*	Tr-R	10MR	5R	5MR
5	Moro	*Yr10*	20MR	20MS	10MS	50MS-S
6	Strubs Dikkopf	*YrSD*	10MR	0	5R	20M
7	Suwon 92/Omar	*YrSU*	30MS	70S	40MS-S	50MS-S
8	Clement	*Yr2,Yr9*, +	Tr-R	30MS	5R	20MS
9	Hybrid 46	*Yr4*	Tr-R	Tr-R	5R	0
10	Reichersberg 42	*Yr7*+	Tr-MR	0	5R	10MR
11	Heines Peko	*Yr2,Yr6*, +	10MR	20MS	10MR	30MR
12	Nord Desprez	*YrND*	Tr-R	10MR	5R	10MR
13	Compair	*Yr8*	Tr-MR	5R	20M	40M

No.	Genotype	Gene(s)	Severity and infecti0n type			
			2006	2007	2008	2009
14	Carstens V	*YrCV*	Tr-R	0	5R	5R
15	Spalding Prolific	*YrSP*	Tr-MR	40MS	5R	0, 80MS
16	Heines VII	*Yr2*+	Tr-R	Tr-MR	5R	30MR
17	Federation *4/Kavkaz	*Yr9*	10M	50MS	5R	90S
18	Anza	*YrA,Yr18*	40S	50MS	100S	50MS-S
19	Avocet "R"	*YrA*	80S	100S	70MS-S	100S
20	Avocet "S"		70S	90MS-S	80MS-S	100S
21	Kalyansona	*Yr2*	Tr-MR	60MS	—	100S
22	*Triticum spelta* var. *album*	*Yr5*	Tr-R	0	0	5R
23	TP981		Tr-MR	70MS-S	10MS	70MS
24	TP1295		10MS-S	100S	50MS-S	100S
25	Meering + *Yr*24	*Yr24*	Tr-MR	80S	100S	20MR
26	*Bolani*		—	100S	80S	100S
27	*Yr1*/6*Avocet "S"	*Yr1*	0	0	5R	0
28	*Yr5*/6*Avocet "S"	*Yr5*	Tr-R	0	20MR	0
29	*Yr6*/6*Avocet "S"	*Yr6*	10MR	90S	60MS-S	100S
30	*Yr7*/6*Avocet "S"	*Yr7*	40MS-S	90S	60MS-S	100S
31	*Yr8*/6*Avocet "S"	*Yr8*	Tr-R	20MS	5R	70MS
32	*Yr9*/6*Avocet "S"	*Yr9*	80S	70S	90S	100S
33	*Yr10*/6*Avocet "S"	*Yr10*	Tr-MR	10M	5R	40MR
34	*Yr11*/6*Avocet "S"	*Yr11*	70S	40MS	90S	100S
35	*Yr12*/6*Avocet "S"	*Yr12*	10M	20MS	40MS	100S
36	*Yr15*/6*Avocet "S"	*Yr15*	20M	0	10MR	0
37	*Yr17*/6*Avocet "S"	*Yr17*	Tr-R, 30MS	10MS	40MS-S	100S
38	*Yr18*/6*Avocet "S"	*Yr18*	60MS	60MS	70MS-S	70MS-S
39	*YrSP*/6*Avocet "S"	*YrSP*	20MS	0	10MR	0
40	YrSK/6*Avocet "S"	*Yr27*	Tr-MR	40M	—	40M
41	*Avocet "R"*		Tr-R	100S	—	100S
42	*Avocet "S"*		50M	100S	—	70MS
43	*YrSP*/6*Avocet "S"		Tr-R	0	—	
44	YrSK/6*Avocet "S"		20M	50MS	—	
45	Avocet "R"		100S	80S	—	
46	Avocet "S"		90S	90S	—	
47	Egret		30MS	40MS-S	90S	
48	Angas		Tr-MR	10MR	40M	
49	Banks		Tr-R	10MR	—	
50	Janz		10MR	20M	30M	
51	Blade		40MS	40M	40MR	
52	Cook		Tr-MR	10MR	20M	
53	Oxely		0	10MR	10MR	
54	Luke		10MS	10MR	20MR	

No.	Genotype	Gene(s)	Severity and infecti0n type			
			2006	2007	2008	2009
55	Yoman	*Yr13*	Tr-R	0	Tr-MR	
56	Maris Huntsman	*Yr13*	Tr-R	5R	5R	
57	Holdfast		Tr-MR	30MR	10M	
58	Bouquet	*Yr14*	Tr-MR	0	5R	
59	Elite Lepeuple		Tr-R	0	0	
60	Atou		0	R	5R	
61	Champlein		Tr-R	0	0	
62	Flanders		Tr-R	R	0	
63	Little Joss		Tr-MR	R	0	
64	Cappelle Desprez	*Yr16*	Tr-R	Tr-MR	5R	
65	Nugaines		40MS	60MR	80MS-S	
66	Hybrid de Bersee		Tr-R	R	5R	
67	Aristocrat		40MS	50MR	0	
68	Andante		Tr-R	Tr-R	0	
69	Charger		0	0	5R	
70	Beaver		0	5R	0	
71	Galahad	*Yr14, Yr1, Yr2*	0	5R	5R	
72	Hunter		Tr-R	5R	5R	
73	Mercia		Tr-MR	0	5R	
74	Norman		Tr-R	5R	5R	
75	Morocco		80S	100S	100S	
78	ALEMOOT		0	80S	60MS-S	100S
87	MAHDAVI		30MS-S	80S	40MS,100S	80MS-S
88	ZARRIN		10M	80MS-S	40MS	90S
89	KAVIR		Tr-R	70M	50MS	100S
90	SHAHRIAR		20MS	70MS	80S	90S
91	TOS		Tr-MR	70MS-S	40MS	80S
94	GODES		80S	100S	100S	100S
96	GASCOGEN		0	0	5R	0
97	MOGAN 1		—		70MS-S	90S
98	MOGAN 2		—		30MS	100S
99	Produra	*YrPr1, YrPr2*	20M			
100	Fielder	*Yr6, Yr20*	50MS-S			
101	Tres/6*AVS	*YrTr1, YrTr2*	10MR			
102	*Yr26*	*Yr26*	10MR			
103	Express	HTAP	10MR			
104	C-84-4					80S
105	C-80-4					90S
106	MS-81-14					100S
107	Bolani		90S	100S	100S	100S

NOTES: HTAP = high-temperature, adult-plant [resistance].

References

Allison, C. & Isenbeck, K. 1930. Biologisch specialisierung von *Puccinia glumarum tritici* Eriks and Henn. *Phytopathologische Zeitschrift,* 2: 87–98.

Ben Yehuda, P., Eilam, T., Manisterski, J., Shimoni, A. & Akster, Y. 2004. Leaf rust on *Aegilops speltoides* caused by a new *forma specialis* of *Puccinia triticina*. *Phytopathology,* 94: 94–101.

Hovmoller, M.S. 2001. Disease severity and pathotype dynamics of *Puccinia striiformis* f.sp. *tritici* in Denmark. Plant Pathology, 50: 181–189.

Johnson, R. & Taylor, A.J. 1972. Isolates of *Puccinia striiformis* collected in England from the wheat varieties Maris Beacon and Joss Combier. *Nature*, 238: 105–106.

Line, R.F. 2002. Stripe Rust of wheat and barley in North America: A retrospective historical review. *Annual Review of Phytopathology*, 40: 75–118.

McIntosh, R.A. & Brown, G.N. 1997. Anticipatory breeding for resistance to rust diseases in wheat. *Annual Review of Phytopathology,* 35: 311–326.

Nazari, K., Torabi, M., Dehghan, M.A., Ognum, R., Ahmadian-Moghaddam, M.S. & Fallah, H. 2000. Virulence factors of *Puccinia striiformis* and reaction of improved cultivars and advanced lines to yellow rust in Northern provinces of Iran. *Seed and Plant*, 16: 393–424.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. *Rust Diseases of Wheat: Concepts and Methods of Disease Management.* CIMMYT, Mexico D.F., Mexico. 81 p.

Wellings, C.R. & Mclntosh, R.A. 1990. *Puccinia striiformis* f.sp. *tritici* in Australasia: pathogenic changes during first 10 years. *Plant Pathology*, 34: 316–325.

Yahyaoui, A. 2006. Monitoring stripe rust in the Caucasus, Central and West Asia and North Africa (CWANA). *In:* Abstracts of the Third Regional Yellow Rust Conference, Tashkent, Uzbekistan, 8–11 June 2006. [This volume].

Yahyaoui, A.H., Hakim, M.S., Nazari, K., Torabi, M. and Wellings, C.R. 2001. yellow rust (*P. striiformis* f.sp. *tritici*) in central and western Asia. Abstracts of First Regional Yellow Rust Conference for Central & West Asia and North Africa. 8–14 May 2001, Karaj, Iran.

Zadoks, J.C. 1961. Yellow rust of wheat. Studies in epidemiology and physiologic specialisation. *Tijdschrift over plantezieken [Netherlands Journal of Plant Pathology],* 67: 69–256.

An overview of results of five years of wheat yellow rust trap nurseries in Iran

F. Afshari[1], K. Nazari,[1] M. Patpour,[1] M. Atahosaini,[2] S. Rejaei,[3] M. Dehgan,[4] S. Safavei,[5] M. Nasrolahi,[6] T. Dadrezaei,[7] R. Hoshyar,[8] M. Hassanpour-Hosni,[9] S. Kemangar,[10] S. Ebrahimnejad,[11] M. Chaeichei,[12] F. Jebalbarez,[13] A. Kohkan,[14] M. Galandar,[15] R. Hagparast,[16] K. Shahbazi,[17] Z.H. Bayat[1] and S. Sarkarei[17]

1. Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran
2. Khorasan Agricultural Research Centre, Islamic Republic of Iran
3. Fars Agricultural Research Centre, Islamic Republic of Iran
4. Golestan Agricultural Research Centre, Islamic Republic of Iran
5. Ardabil Agricultural Research Centre, Islamic Republic of Iran
6. Lorestan Agricultural Research Centre, Islamic Republic of Iran
7. Khozastan Agricultural Research Centre, Islamic Republic of Iran
8. E. Azarbaijan Agricultural Research Centre, Islamic Republic of Iran
9. Dari Agricultural Research Centre, Islamic Republic of Iran
10. Kordestan Agricultural Research Centre, Islamic Republic of Iran
11. Mazanderan Agricultural Research Centre, Islamic Republic of Iran
12. Hamadan Agricultural Research Centre, Islamic Republic of Iran
13. Kerman Agricultural Research Centre, Islamic Republic of Iran
14. Zabol Agricultural Research Centre, Islamic Republic of Iran
15. Markazi Agricultural Research Centre, Islamic Republic of Iran
16. Kermanshah Agricultural Research Centre, Islamic Republic of Iran
17. Ardabil, Agricultural Research Centre, Islamic Republic of Iran

Introduction

Stripe [yellow] rust disease has been a major problem of wheat production in most parts of Iran over the last 15 years. Wheat stripe rust epidemics in certain regions of Iran caused significant crop losses over several seasons in the 1990s, with the detection of virulence for *Yr9* in 1993. Cv. Falat, a high yielding wheat cultivar with *Yr7* and *Yr9*, became susceptible with the appearance of a new pathotype, and crop losses due to that were estimated to be 1.5 million tonne (Torabi *et al.*, 1995). There are three main broad factors in epidemic development. Firstly, an environmental effect, such as a mild winter, that is ideal for rust development. Thus the yellow rust epidemic in Mogan, Iran, in 1993 was exacerbated by extended moderate (10–20°C) wet spring weather in a region that normally experiences rapid temperature increase. The second

factor is cultivation of moderately susceptible to susceptible cultivars over a large area. The third factor is the pathogen and its pathogenicity.

The most common mechanisms driving evolution in the yellow rust pathogen are mutation and migration, either natural or anthropogenic. For example, the first appearance of yellow rust pathogen in Australia was in 1979, probably due to human agency or migration (O'Brien *et al.,* 1980). Virulence for *Yr27*, which was widely deployed in cultivars selected from CIMMYT materials, such as Attila 50 (Chamran), apparently spread rapidly through the West Asia and North Africa (WANA) region and arrived in Iran in 2003 (Afshari, Torabi and Malihipour, 2004). Monitoring of pathogen virulence factors and their changes provides basic information for the development of an early warning system. To monitor yellow rust virulence and virulence changes, this study was carried out at 28 sites in wheat growing areas in Iran.

Materials and methods

This study comprised 45 lines that included a standard set of stripe rust differentials, supplemental lines, and near-isogenic lines developed by Dr Wellings from Sydney University. Entries were sown in 2-m rows for each line in cropping seasons 2004–2008 (Table 1). At the flag leaf stage, when the infection and severity under natural infection on the susceptible control was high, field assessments were done for disease severity according to the modified Cobb scale of Peterson, Campbell and Hannah (1948) and disease reaction according to Roelfs (1978).

Results and discussion

Over the five years of this study, stripe rust developed in most nurseries. The results are summarized for four main regions of Iran (west, north, east and central) and presented in Table 1. According to the results, virulence on Heines Kolben (with gene *Yr2*), Kalyansona (*Yr2*), Lee (*Yr7*), Avocet R (*YrA*), Federation*4/Kavkaz (*Yr9*), *Yr6*/6*Avocet "S", *Yr7*/6*Avocet "S", *Yr9*/6*Avocet "S", *Yr17*/6*Avocet "S" and TP 1295 (*Yr25*) and *YrSU* was common during the study (Table 1). The frequencies of virulence on plants with *Yr2, Yr6, Yr7, Yr9* and *YrA* were up to 70%. Virulence for *Yr1* was common in Central Asia and China, rare in most parts of the Middle East and absent in Iran (Afshari, unpublished). No virulence was observed on plants with *Yr1, Yr3, Yr4, Yr5, Yr10, Yr18, YrND* or *YrCV* genes in our trap nurseries. Ma and Singh (1996) noted that *Yr18* might not provide adequate protection when deployed alone in a susceptible background. According to them, the preferred option for achieving durable stripe rust control is to have

combinations of adult plant resistance (APR) genes giving protection approaching the levels of the most effective seedling-resistance genes.

The *Yr18* gene remains resistant in Iran as an APR gene and is being used in the breeding programme in combination with other resistance sources to obtain an acceptable level of resistance in new cultivars. Virulence for *Yr27* (Selkirk gene) was reported from trap nurseries in the west (Hamadan) and centre (Zargan); virulence for this gene appeared in farmers' fields and was confirmed by seedling tests in the greenhouse (Afshari, Torabi and Malihipour, 2004). Moreover, the population of this pathotype is still limited and not yet common. However, use of those resistance genes with a combination of APR genes could be a useful method to control yellow rust in Iran. Virulence surveys of pathogen populations have provided valuable information over the last 15 years and have been frequently used in our breeding programmes.

References

Afshari, F., Torabi, M. & Malihipour, A. 2004. Appearance of new race of *Puccinia striiformis* f.sp. *tritici*. *Seed and Plant Journal of Agricultural Research* [Karaj, Islamic Republic of Iran], In press.

Ma, H. & Singh, R.P. 1996. Contribution of adult plant resistance gene *Yr18* in protecting wheat from yellow rust. *Plant Disease,* 81: 66–69.

O'Brien, L., Brown, J.S., Young, R.M. & Pascoe, T. 1980. Occurrence and distribution of wheat stripe rust in Victoria and susceptibility of commercial wheat cultivars. *Australasian Plant Pathology Society Newsletter,* 9: 14.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States, 1918–1976. *USDA Miscellaneous Publication*, No. 1363. 85 p.

Torabi, M., Mardoukhi, V., Nazari, K., Afshari, F., Forootan, A.R., Ramai, M.A., Golzar, H. & Kashani, A.S. 1995. Effectiveness of wheat yellow rust resistance genes in different parts of Iran. *Cereal Rusts and Powdery Mildews Bulletin*, 23: 9–12.

Table 1. Yellow rust differentials, cultivars and their responses in the four main regions during 2004–2008 in Iran

No.	Line	Yr gene	North	West	Centre	East
1	Chinese 166	*Yr1*	R	R	R	R
2	Lee	*Yr7*	S	S	S	S
3	Heines Kolben	*Yr2*	S	S	S	S
4	Vilmorin 23	*Yr3*	R	R	R	R
5	Moro	*Yr10*	R	R	R	R
6	Strubs Dikkopf	*YrSD*	R	S	R	R
7	Suwon 92/Omar	*YrSU*	R	R	S	R
8	Clement	*Yr2,Yr9,* +	R	R	R	R
9	Hybrid 46	*Yr4*	R	R	R	R
10	Reichersberg 42	*Yr7*+	R	R	R	R
11	Heines Peko	*Yr2,Yr6,* +	R	R	R	R
12	Nord Desprez	*YrND*	R	R	R	R
13	compare	*Yr8*+	R	R	R	R
14	Carstens V	*YrCV*	R	R	R	R
15	Spalding Prolific	*YrSP*	S	S	S	R
16	Heines VII	*Yr2*+	R	R	S	R
17	*Triticum spelta* var. *album*	*Yr5*	R	R	R	R
18	Anza	*YrA*+	S	S	S	S
19	Jupateco '73R'	*Yr18*	R	R	R	R
20	Jupateco '73S'		S	S	S	S
21	Avocet 'R'	*YrA*	S	S	S	S
22	Avocet "S"		S	S	S	S
23	Kalyansona	*Yr2*	S	S	S	R
24	Federation *4/Kavkaz	*Yr9*	S	S	S	S
25	Federation		S	S	S	S
26	Trident(=Spear*4/VPM1)		S	S	S	S
27	TP981		S	R	S	R
28	TP1295	*Yr25*	S	S	S	S
29	Meering + *Yr24*	*Yr24*	S	S	S	S
30	Meering		S	R	S	R
31	*Yr1*/6*Avocet "S"	*Yr1*	R	R	R	R
32	*Yr5*/6*Avocet "S"	*Yr5*	R	R	R	R
33	*Yr6*/6*Avocet "S"	*Yr6*	S	S	S	S
34	*Yr7*/6*Avocet "S"	*Yr7*	S	S	S	S
35	*Yr8*/6*Avocet "S"	*Yr8*	S	S	S	R
36	*Yr9*/6*Avocet "S"	*Yr9*	S	S	S	S
37	*Yr10*/6*Avocet "S"	*Yr10*	R	R	R	R
38	*Yr15*/6*Avocet "S"	*Yr15*	S	S	S	S
39	*Yr17*/6*Avocet "S"	*Yr17*	R	R	S	R
40	*Yr18*/6*Avocet "S"	*Yr18*	R	R	R	R
41	*YrSP*/6*Avocet "S"	*YrSP*	R	R	R	R
42	YrSK/6*Avocet "S"	*Yr27*	R	S	S	R
43	Avocet 'R'	*YrA*	S	S	S	S

NOTES: R = Resistant; S = Susceptible.

Sources of resistance to wheat stripe [yellow] rust resistance in elite germplasm in Iran

F. Afshari, S.A.. Safavi, M. Ata Hosaini and Sh. Ebrahim Nejad

Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Abstract

Stripe (yellow) rust is the most important disease in the major wheat growing regions in Iran. In the 2007/08 cropping season, ten lines of ERWYT-C, 20 lines of ERWYT-N and 16 lines of ERWYT-M were tested for resistance to stripe rust at the adult plant stage at four sites. The lines were planted in two 1-m long rows with 30 cm between lines. A susceptible wheat cultivar (Bolani) was planted as spreader around the field and among the rows. The susceptible cultivar was artificially inoculated. Field assessments were based on disease severity according to the modified Cobb scale and disease reaction. The results showed that 7 lines of ERWYT-C were susceptible and remaining lines were resistant. For ERWYT-N, 12 lines were found resistant in all sites. In a separate seedling test of ERWYT-N material with the pathotype 166E6A+, all lines were found resistant. The results showed also that nine lines of ERWYT-M were susceptible as seedlings but resistant as adults. This indicates that these lines have expressed adult plant resistance.

Introduction

Common wheat is the most important source of energy in the world. Wheat is a host for many groups of parasites and major threats to wheat production on a worldwide basis come from one or more of the three rust diseases. Stripe (yellow) rust is the most important disease of wheat in the West Asia and North Africa (WANA) region. Use of resistant cultivars is the best method of the disease control. Multilocational disease testing is used to obtain data to support breeding strategies aimed at broadening the genetic base of resistance in CIMMYT germplasm. Assuming a broad-based resistance, this material should also serve as useful germplasm for local breeding programmes. Gene postulation based on comparative response data from multi-pathotype tests (Dinoor and Peleg, 1972; Day, 1974; Browder and Eversmeyer, 1980) and genetic and cytogenetic analyses of segregating hybrid populations make up

the principal methods for identifying rust resistance genes in wheat germplasm. In Iran, various nurseries have been screened for yellow rust.

While CIMMYT germplasm is believed to carry broad-based and often durable resistance, it is also known to carry a broad array of genes for seedling resistance to each of the three rusts. If this germplasm is to be used in national breeding programmes it is essential that some data on local pathotypes are available. It is an even greater advantage if the actual genes for resistance are known. The use of actual infection-type data and pedigree information can also contribute to the resistance gene identification process. The objective of this study was to obtain resistant lines through a group of nurseries distributed from international centers, such as CIMMYT, and to interpret those seedling and adult plant resistances from field assessments.

Materials and methods

In the 2007/08 growing season, 46 lines of Elite Regional Wheat Yield Trials Cold (ERWYT-C), North (ERWYT-N) and Moderate (ERWYT-M) nurseries were tested for resistance to stripe [yellow] rust.

In the seedling stage, ERWYT nursery lines were tested with *Pst* pathotype 166E6A+, *Yr27*+ in the greenhouse. All genotypes were inoculated with the *Pst* pathotype in the greenhouse when the second leaves appeared. Seedlings were then placed in an incubation room for 24 h at 10°C and 100% RH in the dark. Following incubation, plants were moved to greenhouse chambers at 18–20°C. Infection types were recorded 15–18 days after inoculation using a scale (0–9) similar to that described by McNeal *et al*. (1971). Infection types 7 to 9 were regarded as susceptible.

In the field, all lines of the three nurseries were planted in as two 1-m long rows 30 cm apart, with artificial inoculation. A susceptible wheat cultivar (Bolani) was planted as spreader around the field and among the rows. Field assessments were based on disease severity according to the modified Cobb scale of Peterson, Campbell and Hannah (1948) and disease reaction according to Roelfs (1978).

Results and discussion

Data of the three ERWYT nurseries are presented in Tables 1 to 3. In seedling tests of the ERWYT-N nursery, all lines and cultivars were resistant, but at the adult plant stage 12 lines showed resistance, which is attributed to presence of seedling resistance gene(s) (Table 1). In the ERWYT-M 86-87 nursery 9 lines (Nos. 3, 4, 5, 7, 11, 12, 13, 14 and 15) were susceptible at the seedling stage but resistant as adult plants, which confirms APR gene(s) (Table 2). APR was reported as durable resistance but there are examples of the ineffectiveness of

APR. A spectacular example was the ineffectiveness of the APR gene alone in Joss Cambier against a new pathotype identified in 1972 (Johnson and Taylor, 1972). Among ERWYT-C nursery entries, 7 lines were resistant in the field and 5 lines were resistant in the seedling stage (Table 3), and Nos. 3 and 7 were susceptible in seedling tests, but resistant at adult plant stage in the field, and consist of presence of adult plant gene(s). Lines No. 7 (ID800994W/Vee//F900K/3/Pony/Opata) and 9 (Bilinmiyen 96.40) had adult plant responses of 30MS-40MS. Ma and Singh (1996) noted that the single adult plant resistant gene (*Yr18*) did not give an acceptable level of resistance against yellow rust.

Table 1. Pedigrees and names of entries in the ERWYT-N 86–87 nursery and their seedling and adult plant responses to wheat stripe rust disease at two sites in Iran

No.	Pedigree or name	Adult plant response		Seedling response
		Sari	Mashhad	
1	MOGAN	40MS	50S	0
	TOB/ERA//TOB/CNO 67/3/PLO/4/VEE #5/5/KAUZ…	0	50MS	6
2	NANJING 82149/KAUZ/3/PFAU/SERI//BOW (DH)	0	0	0
3	MILAN CM75118//KA CM 75118/K1/3/TAJAN (DH)	0	0	0
4	SITE/MO//MILAN CMSS93B00579S-4Y-010M-010Y-…	0	0	0
5	VORONA/CNO79//KAUZ/3/MILAN	0	0	0
6	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92	0	0	0
7	PASTOR/3/VORONA/CNO79//KAUZ	0	30MR	0
8	SITE/MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC	0	0	0
9	CMH82A.1294/2*KAUZ//MUNIA/CHTO/3/MILAN	0	40S	0
10	CMH82A.1294/2*KAUZ//MUNIA/CHTO/3/MILAN	0	30S	0
11	TNMU/6/CEP80111/CEP81165/5/MRNG/4/YKT406/3/AG/ASN//ATR	0	0	0
12	SW89-5124*2/FASAN	0	0	0
13	ALD/CEP75630//CEP75234/PT7219/3/BUC/BJY/4/CBRD/5/TNMU/PF85487	0	60MS	0
14	PGO/SERI//BAU/3/DUCULA	0	40MR	6
15	MILAN/NOBO//PASTOR	5MR	0	0
16	TNMU/PASTOR	0	60MS	0
17	ALD/COC//URES/3/TNMU/4/PRINIA	0	70MS	0
18	H9433/PARU//PASTOR	0	60MS	0
19	CROC 1/AE.SQARROSA(205)//KAUZ/3/DUCULA	0	30MR	6
20	Bolani (Susceptible check)	90S	100S	7

Table 2. Pedigrees and names of entries in the ERWYT-M 86–87 nursery and their seedling and adult plant responses to wheat stripe rust disease at two sites in Iran

No.	Pedigree or name	Adult plant response		Seedling response
		Sari	Mashhad	
1	Pishtaz	5MR	20MR	9
2	Bahar	30MS	40MR	5
3	Gaspard/3/Jup/Bjy//Kauz/4/Kayson/Glenson	0	10MS	9
4	Ombu1/Alamo//M-73-18	0	50MR	9
5	Alvd//Aldan/las*2/3/Gaspard	0	0	9
6	Alvd//Aldan/las*2/3/Gaspard	0	0	0;
7	Alvd//Aldan/las/3/Druchamps/4/kauz/Stm	0	0	9
8	Owl 85256-*3OH-*O-*EOH/Mv17/3/Alvd//Aldan/las	0	0	2
9	Owl 85256-*3OH-*O-*EOH/Mv17/3/Alvd//Aldan/las	0	0	2
10	HAAMA-11	10MR	10MR	0;
11	FISCAL	0	0	9
12	CROC—1/AE.SQUARROSA (224)//OPATA/3/KAUZ*2/BOW//KAUZ/4/NL 683	0	0	9
13	ELVIRA/MILAN	0	0	9
14	PBW 343//CAR422/ANA	0	0	9
15	CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/MILAN	10MS	0	9
16	CROC-1/AE.SQUARROSA (2005)//KAUZ/3/ATTILA	0	0	5
17	Bolani (Susceptible check)	80S	100S	9

Table 3. Pedigrees and names of entries in the ERWYT-C 86–87 nursery and their seedling and adult plant responses to wheat stripe rust disease at two sites in Iran

No.	Pedigree or name	Adult plant response		Seedling response
		Ardabil	Mashhad	
1	Shahryar	40MS-S	60S	9
2	C-80-4	50 MS	40MS	9
3	Bloudan/3/Bb/7C*2//Y50E/3*Kal/4/MV 17	5R	0	9
4	Yan 7578.128//Chil/2*Star	5R	0	2
5	Yan 7578.128//Chil/2*Star	5R	0	2
6	Yan 7578.128//Chil/2*Star	5R	0	2
7	ID800994W/Vee//F900K/3/Pony/Opata	30MS	0	9
8	Bhr*5/Aga//Sni/3/Trk13/4/Drc	5R	0	4
9	Bilinmiyen 96.40	40MS	40MS	9
10	LC 909 Mima	5R	0	4
11	Bolani (Susceptible check)	80S	100S	9

In our breeding programme we are looking for combinations of seedling and adult plant resistance genes or numerous APR genes (4 or 5) to provide durable resistance. Further study needs to be undertaken of these resistant lines to map the inheritance pattern and to know the number of gene(s) conferring resistance.

References

Browder, L.E. & Eversmeyer, M.G. 1980. Sorting of *Puccinia recondita, Triticum* infection-type data sets toward the gene-for-gene model. *Phytopathology*, 76: 666–670.

Day, P.R. 1974. *Genetics of Host : Parasite Interaction*. Freeman Company, San Francisco, USA.

Dinoor, A. & Peleg, N. 1972. The identification of genes for resistance or virulence without genetic analysis, by the aid of the 'gene-for-gene' hypothesis. pp. 115–119, *in:* Proceedings of the European and Mediterranean Cereal Rusts Conference. Prague, Czechoslovakia.

Johnson, R. & Taylor, A.J. 1972. Isolates of *Puccinia striiformis* collected in England from the wheat varieties Maris Beacon and Joss Cambier. *Nature*, 238: 105–106.

Ma, H. & Singh, R.P. 1996. Contribution of adult plant resistance gene *Yr18* in protecting wheat from yellow rust. *Plant Disease*, 81: 66–69.

McNeal, F.H., Konzak, C.F., Smith, E.P., Tate, W.S. & Russell, T.S. 1971. A uniform system for recording and processing cereal research data. *USDA ARS Bulletin* 34-121: 1–42.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States, 1918–1976. *USDA Miscellaneous Publication*, No. 1363. 85 p.

Resistance response of promising wheat lines to yellow rust by evaluation of AUDPC in Ardabil

S. A. Safavi[1], A. Babaei[2], F. Afshari[3] and M. Arzanlou[2]

1. Research Centre of Agriculture and Natural Resources of Ardabil, Ardabil, Islamic Republic of Iran
2. Plant Pathology Department of Tabriz University – Tabriz, Islamic Republic of Iran
3. Seed and Plant Improvement Research Institute- Karaj, Islamic Republic of Iran

Abstract

Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is undoubtedly the most important fungal disease of wheat, especially in central and western Asia, and causes significant annual yield losses. In 1993 and 1995, losses due to yellow rust epidemics were estimated to be 1.5 and 1 million tonne, respectively. Production and use of resistant cultivars is the best control method. For this purpose, study of the reaction of 29 promising genotypes (lines) to yellow rust was carried out in Ardabil in the 2008/09 cropping season. Each genotype was planted as two 1-m long rows in a complete block design with three replications. The experiment was conducted under field conditions with artificial inoculation. In addition, seedling tests were conducted in the greenhouse. The disease severity and infection type were recorded based on the modified Cobb's scale of Peterson, Campbell and Hannah (1948) and the method of Roelfs, Singh and Saari (1992). Coefficients of Infection (CI) were then calculated by combining disease severity and constant values of infection type. Results of variance analysis showed significant differences among lines at the 1% probability level. Mean comparison of CI and rAUDPC (Relative Area Under Disease Progress Curve) indicated that the lines C-86-1, C-86-2, C-87-1, C-87-2, C-87-3, C-87-18 had the highest CI and rAUDPC. The lines C-86-3, C-86-9, C-87-6, C-87-8, and C-87-11 were susceptible at the seedling stage but resistant at the adult plant stage. The rest of the lines had no infection or a low level of infection. Thus, they were selected as resistant or moderately resistant lines.

Introduction

Stripe Rust of wheat, caused by *Puccinia striiformis* Westend f.sp. *tritici* Eriks. & Henn., is one of the most widely destructive plant diseases in the world and the most important disease of wheat in Iran. In Iran, epiphytotics of yellow rust have occurred frequently since 1991. The losses exceeded 30% in some cases (Torabi and Nazari, 1998). On highly susceptible cultivars, yellow rust severity can reach 100% and can cause yield losses of up to 96% (Ochoa, 1997). The rusts of cereal can be controlled by fungicides, but it is not always economical nor environmentally appropriate to use fungicide. Use of resistant cultivars is the most economical and the preferred method of controlling the rusts (Chen and Line, 2002). Although some resistant cultivars are deemed to be non-specific, changes in the pathogen's races have caused the failure of many cultivars nominally resistant to stripe rust, suggesting race specificity (Roelfs, Singh and Saari, 1992). Non-durability of resistance in cultivars has caused breeders to look for slow-rusting resistance in breeding programmes (Wiese, 1991). Slow-rusting resistance that appears to be race-non-specific and durable has been found in wheat and efforts to find cultivars with this type resistance have continued for the last few years (Lee and Shaner , 1985).

Slow-rusting wheat cultivars, when infected by *Puccinia striiformis,* exhibit a longer latent period, smaller and fewer uredinia, and less spore production than susceptible cultivars (Parlevliet, 1988; Roelfs, Singh and Saari, 1992). The latent period is one of the most important components of slow-rusting resistance (Dehgani *et al*., 2002). Analysis of variance in the study of Dehghani and Moghadam (2004) showed the importance of both additive and dominance effects in controlling the latent period. In several cereal-rust pathosystems the quantitative aspects of cultivar resistance have been described by means of the disease severity at a certain moment or plant development stage, by the area under disease progress curve (AUDPC) or by means of the apparent infection rate, *r* (Broers, Cuesta-Subias and Lopez-Atilano, 1996). Sandoval-Islas *et al.,* (2007) showed that quantitative resistance components have association with one another. The latent period (LP) and infection frequency (IF) were well correlated with the AUDPC (r = 0.7–0.8).

The objective of this study is to identify wheat lines with slow-rusting resistance.

Materials and methods

Seedling tests

The resistance response of wheat seedlings was evaluated by planting seeds of lines in pots. At first leaf emergence, ca 10 days post-sowing, inoculation was carried out by spraying seedlings with a mixture of spores and talc powder.

The seedlings were transferred into a favourable environment in which temperature, light and humidity were controlled until 14–17 days post-inoculation, whereupon disease reaction was recorded based on the 0–4 scale described by McIntosh, Wellings and Park (1995), with 0 = immune and 4 = fully susceptible).

Field tests

The study used 29 promising lines, and was conducted in Ardabil, Iran, in 2009. Each entry was planted in two 1-m long rows 30 cm apart. The adopted experimental design was a complete block design with three replicates. Percent severity was recorded based on the modified Cobb scale of Peterson, Campbell and Hannah (1948) and disease reaction recorded according to Roelfs, Singh and Saari (1992). The Coefficient of Infection (CI) was calculated by multiplying of disease severity (DS) and constant values of infection type (IT). The constant values for infection types were used based on the scale: immune = 0; R = 0.2; MR = 0.4, M =0.6; MS = 0.8; and S = 1 (Stubbs *et al.*, 1986). Estimation of AUDPC and rAUDPC was performed as per Milus and Line (1986):

$$AUDPC = [N_1 (X_1+X_2)/2] + [N_2 (X_2+X_3)/2].$$

Where: X_1, X_2 and X_3 are the rust intensities recorded on the first, second and third recording dates.
N_1 is the interval (days) between X_1 and X_2
N_2 is the interval (days) between X_2 and X_3.

$$rAUDPC = [lineAUDPC/susceptible\ AUDPC] \times 100$$

Then variance of final rust severity, CI and rAUDPC were analysed using MSTAT© software. Finally, disease reactions at seedling and adult plant stages were compared.

Results and discussion

Seedling evaluation

Seedling reactions are listed in Table 1. Many lines had a susceptible reaction at the seedling stage, but lines C-86-3, C-86-9, C-87-6, C-87-8 and C-87-11 expressed a susceptible reaction at seedling stage and moderately resistant reaction at adult plant stage. The rest of the lines had resistant or moderately resistant reactions.

Table 1. Adult plant infection type, seedling reaction and mean comparison for coefficient of infection, final rust severity and rAUDPC in promising wheat lines to yellow rust, in Ardabil, Iran, in 2009

No.	Line	Seedling reaction[2]	Infection type	Mean values of different parameters[1]		
				Final rust severity	Coefficient of Infection	rAUDPC
1	C-86-1	3+	MS-S	73.3 bc	66 b	64.5 b
2	C-86-2	3+	MS-S	63.3 cd	55 c	47.9 cd
3	C-86-3	3+	M	23.3 fg	12.6 fg	20.2 efg
4	C-86-4	0	R	3.6 i	0.7 i	4.1 ij
5	C-86-5	2-CN	R	3.3 i	0.6 i	3.6 hj
6	C-86-6	0	R	2.3 i	0.4 i	2.1 j
7	C-86-7	2-CN	M	12.3 ghi	6.7 fghi	10.7 ghij
8	C-86-8	0	R-MR	3.6 i	1 hi	4 ij
9	C-86-9	3+	M	15 ghi	8.6 fghi	14.5 fghij
10	C-86-10	2-CN	M	33.3 ef	16 ef	30.7 e
11	C-87-1	3+	MS-S	76.6 b	69 b	63.2 b
12	C-87-2	3+	MS	56.6 d	41.3 d	54.4 bc
13	C-87-3	3+	MS-S	73.3 bc	66 b	54.3 bc
14	C-87-4	0	R	2.3 i	0.4 i	2.1 j
15	C-87-5	0	R	3.3 i	0.6 i	4 ij
16	C-87-6	3+	M	5.3 i	2.5 hi	5 hij
17	C-87-7	Fleck1 CN	M	10.3 hi	5.4 ghi	10.6 ghij
18	C-87-8	3+	M	23.3 fg	10.6 fgh	25.5 ef
19	C-87-9	Fleck1 CN	R-MR	18.3 gh	12.6 fg	16.2 fghi
20	C-87-10	0	Tr-MR	6.6 hi	3.3 ghi	6.5 hij
21	C-87-11	3+	M	13.3 ghi	7.3 fghi	12.4 ghij
22	C-87-12	0	R-MR	5.6 hi	1.6 hi	6 hij
23	C-87-13	Fleck1 CN	R	3.6 i	0.7 i	4.3 ij
24	C-87-14	Fleck1 CN	R	3.6 i	0.7 i	4.4 ij
25	C-87-15	0	R	4.3 i	2.2 hi	4.1 ij
26	C-87-16	Fleck1 CN	MR	11.6 ghi	6 ghi	11.6 ghij
27	C-87-17	0	R	2.3 i	0.4 i	2.9 j
28	C-87-18	3+	M	40 e	24 e	42.2 d
29	C-87-19	0	R-MR	18.3 gh	7.3 fghi	17.2 fgh
30	Bolani (Check)	3+	100S	100 a	100 a	100 a

NOTES: (1) Means followed by the same letter(s) in each column are not statistically significant at 1% level. (2) Infection type based on McIntosh, Wellings and Park (1995): 0, 1 and 2 are resistant, and 3+ is susceptible. Minus and plus signs were used to indicate variation in ITs. C = more than normal chlorosis. N = more than normal necrosis

Field assessment

The results of adult plant evaluation indicated that lines C-86-1, C-86-2, C-87-1, C-87-2, C-87-3 and C-87-18 had the highest CI and rAUDPC. The rest of the lines showed resistant reaction at this stage. The lines with low rAUDPC at the adult plant stage and susceptible reaction at seedling stage could have durable resistance, and lines with resistance reaction at both stages may carry race-specific resistance (Sandoval-Islas *et al.*, 1998). Durable resistance persists, even if the pathogen changes its genotype. Such slow-rusting and high-temperature, adult-plant (HTAP) resistance is controlled by more than one gene, at least 2 or 3 (Dehghani and Moghadam, 2004).

Researchers should select for durable resistance because although the rust pathogen can easily change its genotype by mutation in the face of selection pressure based on single-gene resistance it changes much more slowly when faced with multiple-gene resistance (Hovmøller, 2001; Ben Yehuda *et al.,* 2004).

Genetic diversity is often low at both field and regional scales in populations of *P. striiformis* f.sp. *tritici*, but the potential diversity is higher when taking into account the changes that may occur over time (years) and samples representing large geographical areas (Hovmoller and Justesen, 2006). Spores of the yellow rust fungus potentially may move across very large distances within a relatively short time, a factor highlighting the need for multinational disease and pathogen surveys.

Screening for slow-rusting using various disease-tolerant sources and the use of appropriate cultural practices would enhance sustained use of high yielding cultivars for a longer time (Resgui *et al.*, 2006).

Based on slow-rusting traits, the lines tested may probably have genes for varying degrees of slow yellow rusting and can be used for future manipulation in wheat improvement programmes after confirmatory studies.

References

Ben Yehuda, P., Eilam, T., Manisterski, J., Shimoni, A. & Akster, Y. 2004. Leaf rust on *Aegilops speltoides* caused by a new *forma specialis* of *Puccinia triticina*. *Phytopathology,* 94: 94–101.

Broers, L.H.M., Cuesta-Subias, X. & Lopez-Atilano, R.M. 1996. Field assessment of quantitative resistance to yellow rust in ten spring bread wheat cultivars. *Euphytica*, 90: 9–16.

Chen, X. & Line, R.F. 2002. Identification of genes for resistance to Puccinia striiformis f.sp. hordei in 18 barley genotypes. *Euphytica*, 129: 127–145.

Dehghani, H. & Moghaddam, M. 2004. Genetic analysis of latent period of stripe rust in wheat seedlings. *Journal of Phytopathology*, 122: 325–330.

Dehghani, H., Moghadam, M.R., Ghannada, R., Valizadeh, M. & Torabi, M. 2002. Inheritance of the latent period of stripe rust in wheat. *Journal of Genetics and Breeding*, 56: 155–163.

Hovmøller, M.S. 2001. Disease severity and pathotype dynamics of *Puccinia striiformis* f.sp. *tritici* in Denmark. *Plant Pathology*, 50: 181–189.

Hovmøller, M.S. & Justesen, A.F. 2006. Pathotype – and molecular variability of yellow rust in western and central Asia in a global contact. Abstracts of the Third Regional Yellow Rust Conference, Tashkent, Uzbekistan, 8–11 June 2006. [This volume].

Lee, T.S. & Shaner, G. 1985. Oligogenic inheritance of length of latent period in six slow leaf-rusting wheat cultivars. *Phytopathology*, 75: 636–643.

Milus, E.A. & Line, R.F. 1986. Gene action for inheritance of durable, high-temperature, adult-plant resistances to stripe rust in wheat. *Phytopathology*, 76: 435–441.

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia. 200 p.

Ochoa, J. 1997. La roya amarilla del trigo en el Ecuador aspectors epidemiologico y de resistancia. pp. 45–52, n: D.L. Danial (editor). Primer Taller de resistancia duradera en cultivos Altos en la Zona Andina. PREDUZA, Quito, Ecuador.

Parlevliet, J.E. 1988. Strategies for the utilization of partial resistance for the control of cereal rusts. pp. 48–62, *in:* N.W. Simmonds and S. Rajaram (editors). *Breeding Strategies for Resistance to the Rusts of Wheat.* CIMMYT, Mexico.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Resgui, S., Fakhfakh, M., Nafti, A. & Yahyaoui, A. 2006. Yellow Rust: A revolving of disease that threatens wheat production in Tunisia. *In:* Abstracts of the Third Regional Yellow Rust Conference, Tashkent, Uzbekistan, 8–11 June 2006. [This volume].

Roelfs, A.P., Singh, R.P. & Saari, E.E. 1992. *Rust Diseases of Wheat: Concepts and Methods of Disease Management.* CIMMYT, Mexico D.F., Mexico. 81 p.

Sandoval-Islas, J.S., Broers, L. H.M., Mora-Aguilera, G., Parlevliet, J.E., Osada-Kawasoe, S. & Vivar, H.E. 20007. Quantitative resistance and its components in 16 barley cultivars to yellow rust, *Puccinia striiformis* f.sp. *hordei*. *Euphytica*, 153: 295–308.

Sandoval-Islas, J.S., Broers, L.H.M., Vivar, H. & Osada, K.S. 1998. Evaluation of quantitative resistance to yellow rust (*Puccinia striiformis* f.sp. *hordei*) in the ICARDA-CIMMYT barley-breeding programme. *Plant Breeding*, 117: 127–130.

Stubbs, R.W., Prescott, J.M., Saari, E.E. and Dubin, H.J. 1986. *Cereal Disease Methodology Manual*. CIMMYT, Mexico. 46 p.

Torabi, M. & Nazari, K. 1998. Seedling and adult plant resistance to yellow rust in Iranian bread wheat. *Euphytica*, 100: 51–54.

Wiese, M.V. 1991. *Compendium of Wheat Diseases.* 2nd ed. APS Press, St Paul, Minnesota, USA.

Evaluation of bread and durum wheat lines and genotypes for rusts under Menemen conditions of Turkey

R. Ünsal , H. Geren and İ. Sevim

Aegean Agricultural Research Institute, Izmir, Turkey

Abstract

Wheat rusts are very important on the Aegean Coast. The climate of the region is often conducive to epidemics. Varieties possessing various resistance genes for rust have helped prevent epidemics. The major means of protection against the disease is development and utilization of genetically resistant wheat varieties. Every year in the period 2003–2007 more than 15 000 bread wheat and durum wheat accessions used in two regional breeding programmes implemented in the Aegean Agricultural Research Institute have been screened for resistance to rusts. Studies have shown that stripe [yellow] rust (*Puccinia striiformis* f.sp. *tritici*) resistance genes *Yr2*, *Yr6*, *Yr7*, *Yr9*, *Yr11*, *Yr12*, *Yr1*8 and *YrA* are not effective in the Aegean area. For leaf rust (*Puccinia triticina*) the only effective genes were *Lr29, Lr36* and *Lr37.*

Introduction

The fact that Mendel's laws are valid for resistance to plant diseases was first demonstrated in wheat in 1905 (Biffen, 1905). Studies conducted in the last century on the genetics of rust disease, which has the most important place among wheat diseases, revealed that the most effective method for disease control is to grow resistant varieties (Wiese, 1977). The fact that rust spores can be carried by wind long distances in a very short time and the pathogen being very dynamic makes the continuing search for resistance genes necessary (Stubbs *et al.*, 1986).

Along the Aegean coastline, leaf diseases and irregular rainfall come first among the factors restricting productivity. Although it was widely advertised both verbally and in print that a new species of yellow rust had been found in the Aegean Region in 1995, extensive loss occurred in 1997 due to that yellow rust race because the farmers in Söke plain insisted on growing the Serial 82 cultivar that was known to be susceptible. Studies to determine yellow rust

species in the region determined that the *Yr2*, *Yr6*, *Yr7* and *Yr9* genes were rendered ineffective by the yellow rust pathotype, and of the 28 leaf rust resistance genes included in the study, only *Lr15* and *Lr24* were effective against the leaf rust pathotypes widespread in the region (Kanbertay, 1999).

In studies carried out by the Agricultural Research Institute aimed at determining the races of rust in the region, it was found that pathotypes in the region are virulent against yellow rust resistance genes *Yr2*, *Yr6*, *Yr7*, *Yr9*, *Yr11*, *Yr12*, *Yr1*8 and *YrA*, and against leaf rust resistance genes except for *Lr 23, Lr29, Lr36* and *Lr37* (Anon., 2008).

One of the most difficult problems in the struggle against diseases is that there are physiological differences in their populations, and that they may present differences over time. For this reason, it is necessary to monitor pathogen populations to identify virulence changes that result in material that was resistant becoming susceptible.

Materials and methods

The study material drew on bread and durum wheat lines and varieties grown in the Aegean Agricultural Research Institute, plant genetic resource material, and over 10 000 accessions from international research institutions and universities.

One way to monitor virulence differentiation in wheat rust diseases is through trap nurseries comprising genotypes with single-gene resistances. The set of material used in the current study was obtained from the Field Plants Research Institute.

Rust spores used as inoculum in the disease studies were obtained from rust spores collected and stored by the Aegean Agricultural Research Institute and from rust samples obtained from Ankara Field Plants Research Institute. Hypodermic inoculations were applied at least three times in periods appropriate for disease-spreading rows. On cool and wet days, artificial inoculation in the form of spray was applied to the whole material at least once (Stubbs *et al.,* 1986). Rust diseases were evaluated according to a modified Cobb's scale (Loegering, Johnston and Hendrix, 1967).

Results and discussion

It is important to determine the resistance to diseases of genetic material. For this reason, disease resistance properties of the breeding and processed material for bread wheat and durum wheat were assessed. Results of inoculation under field conditions in Menemen during 2003–2006 are given in Tables 1 to 4. Under Menemen conditions, in March and April, with conducive

moisture and temperature, yellow rust spores began to be seen, but as temperatures increased rust spread slowed. Leaf rust was seen extensively (Table 1).

Table 1. The material sets tested for rust diseases in 2003

Nursery	Yellow rust			Leaf rust		
	R	MS	S	R	MS	S
Bread Wheat Crossing Block	852	139	47	247	435	386
Bread Wheat Screening Nursery	222	89	4	125	153	37
Durum Wheat Crossing Block	108	99	15	93	128	1
Durum Wheat Screening Nursery	93	199	27	174	139	6

NOTES: R = Resistant; MS = Moderately Susceptible; S = Susceptible.

In Menemen in 2004, where the long-term mean annual precipitation is 544 mm, total rainfall accrued was about 250 mm. Due to the lack of moisture and dew, especially in the period when yellow rust appears, yellow rust infection did not take place. Because climatic conditions were not appropriate, leaf rust, which was seen extensively in previous years, did not develop sufficiently (Table 2).

Table 2. The material sets tested for rust diseases in 2004

Nursery	Yellow rust			Leaf rust		
	R	MS	S	R	MS	S
Bread Wheat Crossing Block	-	-	-	386	6	5
Bread Wheat Screening Nursery	-	-	-	140	5	3
Durum Wheat Crossing Block	-	-	-	158	30	5
Durum Wheat Screening Nursery	-	-	-	163	10	9

NOTES: R = Resistant; MS = Moderately Susceptible; S = Susceptible.

Table 3. The material sets tested for rust diseases in 2005

Nursery	Yellow rust			
	0-R	MR	MS	S
Bread Wheat Crossing Block	132	20	53	91
Bread Wheat Screening Nursery	57	4	58	62
Durum Wheat Crossing Block	7	17	10	4
Durum Wheat Screening Nursery	10	5	2	8

NOTES: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible. Leaf rust not assessed.

Table 4. The materials tested for rust diseases (2006)

Nursery	Yellow rust			
	0-R	MR	MS	S
Bread Wheat Crossing Block	12	2	168	134
Bread Wheat Screening Nursery	6	0	18	170
Durum Wheat Crossing Block	44	2	43	102
Durum Wheat Screening Nursery	1	0	1	51
Bread Wheat Regional Yield Trial	4	0	9	12
Durum Wheat Regional Yield Trial	0	0	2	17

NOTES: R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible. Leaf rust not assessed.

In 2005 and 2006, the material was evaluated in terms of yellow rust. Since the development of leaf rust occurs at the same time, leaf rust infection could not become effective, so it was not evaluated (Tables 3 and 4).

To monitor change in the species pattern of the existing rusts, wheat rust trap nurseries were planted and the reactions of resistance genes were determined under artificial and natural epidemics under field conditions. In an evaluation made for yellow rust, taking previous years into consideration, resistant, variable and susceptible genes are given in Table 5.

Table 5. Reaction of resistance genes to yellow rust at Menemen, 2003–2006

Resistant		Variable	Susceptible
Yr1	*YrCV*	*Yr2*	*Yr2*
Yr5	*YrSU*	*Yr5*	*Yr6*
Yr8	*Sp. Pr.*	*Yr10*	*Yr7*
Yr15	*Yr4 +*		*Yr9*
Yr17	*Yr6+*		*Yr11*
Yr26	*Yr7+*		*Yr12*
Yr3N	*Yr9+*		*Yr18*
Yr3V	*Yr8, Yr18*		*YrA*
Yr24	*YrA, Yr18*		
Yr27	*Yr2, Yr11, Yr25*		

In an evaluation made for leaf rust taking previous years into consideration, resistant, variable and susceptible genes are given in Table 6.

According to the results obtained from wheat rust trap nurseries during the period of study (2003–2006), for yellow rust resistance genes it was found that *Yr2*, *Yr6*, *Yr7*, *Yr9*, *Yr11*, *Yr12*, *Yr18* and *YrA* resistance genes in Menemen were affected by the existing yellow rust population. At the same time, *Yr5* and *Yr10*

resistance genes showed variable reactions in different years. Yellow rust resistance genes other than these showed tolerance against the existing yellow rust population.

Table 6. Reaction of resistance genes to leaf rust in Menemen, 2003–2006

Resistant	Variable	Susceptible		
Lr23	*Lr9*	*Lr1*	*Lr13*	*Lr32*
Lr29	*Lr17*	*Lr2a*	*Lr14a*	*Lr33*
Lr37	*Lr18*	*Lr2b*	*Lr14b*	*Lr34*
Lr36	*Lr19*	*Lr2c*	*Lr15*	*Lr35*
	Lr21	*Lr3*	*Lr16*	*Lr38*
	Lr24	*Lr3bg*	*Lr22*	*Lr44*
	Lr(10, 27+31)	*Lr3ka*	*Lr25*	*LrB*
		Lr10	*Lr26*	*LrW*
		Lr11	*Lr28*	
		Lr12	*Lr30*	

Leaf rust resistant genes *Lr23, Lr29, Lr36* and *Lr37* were not affected by the rust population existing in the region during the years of the study. *Lr9*, *Lr17, Lr18, Lr19, Lr21, Lr24* and *Lr*(10, 27+31) resistance genes showed variable reactions in different years, while the other resistance genes were susceptible to the rust population in the region.

In the way that variation in some resistance genes might reflect virulence differences in the pathogen population, it may have occurred as a result of inadequate levels of disease development under natural conditions.

References

Anon[ymous]. 2003–2007. Ege Tarımsal Araştırma Enstitüsü Buğday Araştırmaları Yıllık Raporları.

Anon. 2008. Ülkesel Serin İklim Tahıl Hastalıkları Araştırmaları Projesi, Sonuç Raporu, TAGEM Yayınlanmamı.

Biffen, R.H. 1905. Mendel's Law of Inheritance and wheat breeding. *Journal of Agricultural Science,* 1: 4–48.

Kanbertay, M. 1999. Spring wheat production and breeding in Turkey. *In:* Bill Angus (editor). *The World Wheat Book.* Limagrain.

Loegering, W.Q., Johnston, C.O. & Hendrix, J.W. 1967. Wheat rust. pp. 307–355, *in:* K.S. Quisenberry and L.P. Reitz (editors). *Wheat and Wheat Improvement.* American Society of Agronomy, Madison, Wisconsin, USA.

Stubbs, R.W., Prescott, J.M., Sari, E.E. & Dubin, H.J. 1986. *Cereal Disease Methodology Manual.* CIMMYT, Mexico.

Weise, M.V. 1997. *Compendium of Wheat Diseases*. The American Phytopathological Society. St Paul, Minnesota, USA.

Breeding for resistance to rust diseases of wheat in Kyrgyzstan

M. Dzhunusova,[1] A. Yahyaoui,[2] A. Morgounov[3] and J. Egemberdieva[1]

1. Kyrgyz National University, Bishkek, Kyrgyzstan
2. Wheat Coordinator, ICARDA-CIMMYT, Aleppo, Syria
3. Turkey-CIMMYT-ICARDA International Winter Wheat Improvement Programme, Turkey

Abstract

Bread wheat in Kyrgyzstan is an important strategic crop as it is a major food source for the population. It occupies more than half the total arable area of agricultural crops cultivated in the country. At present, virtually all farms have no possibility of growing intensive varieties with a high level of productivity and high grain quality due to their susceptibility to rusts. Annual crop losses caused by leaf and stripe [yellow] rusts in Kyrgyzstan are between 10 and 30%. In 2001, an epidemic of yellow rust was recorded in Kyrgyzstan with crop losses estimated between 40 and 60%. Although wheat research in Kyrgyzstan started in 1936, breeding wheat for biotic stresses such as rust diseases was initiated only in recent years. In 2002, a wheat breeding programme for resistance to yellow rust started in Kyrgyzstan with the close collaboration of CIMMYT and ICARDA. Since then, about 1000 wheat lines have been screened in Chui region under natural epidemic conditions. A few hundred resistant lines were selected and incorporated in the breeding programme for adaptation to ecological conditions. Yield trials were conducted for selection of the most adapted varieties (Azibrosh, Zubkov, Zagadka, Almira, Djamin, Hans and Petr). Monitoring of the yellow rust population started in 1999 based on CWAYRTN distributed by ICARDA. The results of yellow rust tests in Chui region of Kyrgyzstan indicated that the genes most effective against *Puccinia striiformis* f.sp. *tritici* are *Yr2*+, *Yr4*+, *Yr5*, *Yr10* and *Yr15*. In 2006, we planted the nursery CWANA-6th RWKLDN, but, because of drought, selection for resistance was not possible. We selected the best germplasm for yielding capacity and tolerance to drought (AO41, Emu'S'/.TEVEE'S'3/SD8036, and Entries 27, 75, 76, 88, 91 and 94). The same situation happened in 2008. We selected only the best germplasm for yielding capacity and drought tolerance (Cook, Pavon 76, Vernstein, CnSSrTmp, and Bt/Wld). In 2009, we planted the nursery CWANA-1st Stem Rust Resistance Spring Bread Wheat Yield Trial. Among the 17 entries that showed resistance to yellow rust, we selected the four best lines for productivity and resistance to rust diseases (Jawahir-14, Durra 1, Durra 4, and Durra 5). These entries will be incorporated in the breeding programme.

Introduction

Bread wheat in Kyrgyzstan is an important strategic crop as it is a major food for the population. It occupies more than half the total arable area of agricultural crops cultivated in the country. At present, virtually all farms have no possibility of growing high yielding varieties with a high level of productivity and high grain quality because of rust diseases, the main factors limiting wheat yield.

Annual crop losses due to rust diseases *(P. striiformis, P. triticina)* in Kyrgyzstan are 10–30%. In 2001, an epiphytotic of yellow rust was recorded in Kyrgyzstan with crop losses estimated at between 40 and 60% (Dzhunusova, Yahyaoui and Morgounov, 2002).

Although wheat research in Kyrgyzstan started in 1936, breeding wheat for biotic stresses such as rust diseases was initiated only in recent years. In 2002, a wheat breeding programme started in Kyrgyzstan for resistance to yellow rust, in close collaboration with CIMMYT and ICARDA. A few hundred resistance lines were selected and went to the breeding programme for adaptation to ecological conditions, and yield trials were conducted for selection of the best cultivars (Azibrosh, Zubkov, Zagadka, Almira, Djamin, Hans, Petr).

Material and methods

A total of 930 samples of wheat were included in field tests, including 450 from the Central and West Asian Rust Trap Nursery (CWA-RTN), RWKLDN and 1st Ug99IRSTN2007; 370 entries from FAWWON-SA, FAWWON-IRR, WON-SA and WON-IRR nurseries; 76 entries from Central Asian countries; and 34 released cultivars from Kyrgyzstan.

The nurseries and varieties were evaluated at two experimental sites in Chu region and Issyk-Kul region. The accessions were evaluated for resistance to disease by observation under natural infection. Each sample was hand-sown in 1 m rows with 35 cm between rows. Cvs Morocco, Dostuk and DKyzyl were used as susceptible check varieties and as spreaders in the field.

Disease severity and reaction types of each entry were scored using the modified Cobb's scale (R-MR-MS-S) of Peterson, Campbell and Hannah (1948). The entries were then classified according to their CI values: resistant (0–10); moderately resistant (10–30); moderately susceptible (30–50); and susceptible (50–100). The samples in the resistant and moderately resistant groups were selected as candidate resistance lines. They were screened again in the following 1 or 2 years and for the final breeding phase they were also evaluated for their agronomic qualities in the field (Breeding nursery, AYT, YET). In the final selection they were also evaluated for their reaction to rust

diseases, powdery mildew, sunn pest and Cereal Leaf Beatle, and general stand in the field.

The analysis of data was performed according to the methods of the State Commission Variety Trials (SCVI, Moscow, 1978).

Result and discussion

Monitoring of the yellow rust population started in 1999 based on the CWAYRTN distributed by ICARDA. The results of reaction to yellow rust of CWAYRTN differentials in the Chui region of Kyrgyzstan indicated that genes most effective against *Puccinia striiformis* are *Yr2+*, *Yr4+*, *Yr5*, *Yr10* and *Yr15*, which demonstrated R-MR infection types.

Evaluation to rust diseases for 34 winter and facultative wheat varieties released in Kyrgyzstan has shown that 7 varieties were resistant (R); 14 varieties were MR infection types; 9 varieties were MS infection types; and 4 varieties were susceptible to yellow rust (Azibrosh, Vinjett, Kasiet, Krasnovodopadskaya 25, Zubkov, Kairak, Merim- MIS) (Table 1).

Table 1. Agronomic data and disease reaction for yellow and leaf rusts and powdery mildew of commercial wheat varieties in Kyrgyzstan (Demo-Plot, 2008, MIS-Farm, Chui region)

Cultivar	Origin	YR	LR	PM	Heading date	Protein %	Gluten %	Yield (t/ha)	
								Chui	Issyk-Kul
Intensivnaya,st	Kyrgyzstan	80S	MS	S	14.05	13.6	30.7	6.2	8.7
Azibrosh	MIS-CIT	R	R	R	16.05	13.0	25.5	7.2	8.8
Vinjett	Sweden	R	R	R	20.05	15.3	29.9	5.7	9.1
Kyal	Kyrgyzstan	R	R	R	17.05	13.0	26.5	6.9	9.2
Krasnovod 25	Kazakhstan	R	MR	R	13.05	14.0	27.9	6.1	8.2
Zubkov	MIS-CIT	R	MR	R	16.05	13.2	27.0	7.3	9.6
Kasiet	Kyrgyzstan	R	MS	MR	24.05	14.5	29.0	6.9	8.8
Kairak	Kyrgyzstan	R	MR	S	17.05	13.6	27.8	6.8	8.6
Merim-MIS	MIS-CIT	R	MS	MR	18.05	13.5	27.0	7.4	9.2

NOTES : YR = yellow rust; LR = leaf rust; PM = powdery mildew.

The 2nd International Yellow Rust Trap Nursery (2nd IYRTN 2007–2008) including a standard set of differentials, commercial cultivars and lines (50 samples) of wheat and was studied in 2 locations.

Virulence for *Yr5* (Avocet) and *Yr17/6**(AOC) occurred in Issyk-Kul region, but not in Chui region. Virulence for *Yr8* (Avocet) was high in two different ecological zones (Table 2).

In 2008 we monitored the CWANA-1st Stem Rust Resistance Spring Bread Wheat Yield Trial. Monitoring these nurseries showed that 17 entries were resistant to yellow rust diseases, with R-MR infection types; and 5 were susceptible to yellow rust (Amir 1, Amir 2, Zafir 3, Borej 2 and Zain 2). There are varieties with MS-S infection types. The four best lines of wheat for productivity and resistance to rust diseases were selected for future breeding purposes (Awahir 14, Durra 1, Durra 4 and Durra 5).

Table 2. Field responses to yellow rust in the Second International Yellow Rust Trap Nursery (2nd IYRTN 2007–2008) in two ecological zones

Entry	Cultivar and *Yr* Gene	Heading Date	Field response	
			Chui	Issyk-Kul
33	Morocco (susceptible check)	16.05	40 MS	80 MS
19	Vilmorin 23(W), *Yr3V*	14.05	R	70 S
20	Moro, *Yr10*	25.05	R	R (LR-80S)
21	Strubes Dickopf (W), *YrSD*	27.05	R	MR
26	Kalyansona (S), *Yr2*	16.05	R	R
37	*Yr5*/6*Avocet S, *Yr5*	18.05	R	60S
40	*Yr8*/6*Avocet S, *Yr8*	16.05	60S	80S
42	*Yr10*/6*Avocet S, *Yr10*	18.05	R	R
43	*Yr15*/6*Avocet S, *Yr15*	16.05	R	R
44	*Yr17*/6*AOC, *Yr17*	21.05	R	70S

Conclusion

Evaluation of rust diseases in 34 winter and facultative wheat varieties released in Kyrgyzstan has shown 7 resistant (Azibrosh, Vinjett, Kasiet, Krasnovodopadskaya 25, Zubkov, Kairak and Merim-MIS).

In Kyrgyzstan yellow rust is more harmful than other diseases under irrigated and rainfed conditions. Monitoring in Chui region of Kyrgyzstan indicated that the most effective genes against *Puccinia* were *Yr2+*, *Yr4+*, *Yr5*, *Yr10* and *Yr15*, expressing R-MR infection types. Virulence to *Yr5* (Avocet) and *Yr17/6**(AOC) occurred in Issyk-Kul region, but not in Chui region. Avocet isogenic lines *Yr10* and *Yr15* expressed resistant reactions to yellow rust under field conditions in Chui and Issyk-Kul regions in the period 2006–2008.

References

Dzhunusova, M., Yahyaoui, A. & Morgounov, A. 2002. Results of evolution of ICARDA/CIMMYT winter wheat nurseries for resistance to YR in Kyrgyzstan. Abstract. *In:* R. Johnson, A. Yahyaoui, C. Wellings, A. Saidi and H. Ketata (editors). *Meeting the Challenge of Yellow Rust in Cereal Crops.* Proceedings of the [First] Regional Yellow Rust Conference for Central and West Asia and North Africa, 8–14 May 2001, Karaj, Islamic Republic of Iran. ICARDA, Syria.

Peterson, R.F., Campbell, A.B. & Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems on cereals. *Canadian Journal of Research*, 26c(5): 496–500.

Identification of wheat germplasm with effective yellow rust resistance genes

A. Kokhmetova[1] and Sh. Rsaliev[2]

1. Institute of Plant Biology and Biotechnology, Almaty, Kazakhstan
2. Institute of Problems of Biological Safety, Gvardeysky, Kazakhstan

Abstract

Yellow or stripe rust of wheat (*Puccinia striiformis* f.sp. *tritici*) causes severe damage to wheat production throughout the world, including Central Asia. During the epidemic of 2009 in Kazakhstan, most high yielding widely grown cultivars were severely attacked by stripe rust. Effectiveness of most known *Yr* genes broke down due to changes in virulence of the pathogen. This study aimed to identify new wheat germplasm resistant to yellow rust, using greenhouse and field tests. Seedlings of winter wheat recombinant inbred lines (RILs) and parental cultivars were tested under controlled greenhouse conditions against two races of *P. striiformis* f.sp. *tritici* prevalent in Kazakhstan: 27E9 and 47E159. The IT data of seedling reactions were scored. Genetic analysis based on the reaction data of RILs to infection was used for identifying the genes for resistance. Observed and expected data were analysed using the Chi-squared test. The results of field evaluation of wheat isogenic lines and yellow rust differentials in Almalybak (Almaty oblast) indicated that the most effective genes against stripe rust were *Yr5, Yr10, Yr15* and *Yr24*. In comparison with 2006 and 2007 data, most of the lines and cultivars carrying genes for resistance to yellow rust expressed increased susceptibility to the disease in 2009. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* are the races virulent to these genes. A total of 11 pathotypes of rust were identified as the most virulent from the yellow rust samples. The pathotypes 47E223, 15E191, 47E159, 71 191, 71E175, 111E155 and 111E158 were virulent on cultivars Vilmorin 23, Heines Kolben, Lee, Chinese 166, Heines VII, Compair, Nord Desprez, Heines Peko, Reichersberg 42 and Hybrid 46. Pathotype 31E158 was virulent on Moro (*Yr10, YrMor*) and pathotype 47E223 on Spaldings Prolific (*Yr6, YrSP*). All pathotypes studied were virulent on the cultivars Heines Kolben, Lee, Chinese 166, Heines VII and Reichersberg 42. Among the differentials, Spaldings Prolific had immunity to the most isolates. Heines Kolben (*Yr6*) had a susceptible reaction to almost all isolates. Cv. Moro was resistant to the majority of the isolates. The evaluation of field response to yellow rust in commercial cultivars and advanced lines of wheat showed that during the epidemic of 2009, most

high yielding widely grown cultivars, such as Steklovidnaya 24, Naz, Progress and Zhetisu, had severe stripe rust. Cultivars that were previously resistant were susceptible in 2009. Thus, cultivars Bermet, Sharora and Ulugbek 600 that were resistant and moderately resistant in 2007 became highly susceptible (100S) in 2009. The cultivars Oktyabrina, Arap, Almaly, Kupava, Knyazhna and Umanka that were immune became susceptible in 2009 (30–40S). However, new wheat cultivars Tungysh, Mereke 70 and Yrym demonstrated high levels of resistance to yellow rust. From the F_4-F_5 hybrid populations, 35 new sources of resistance to yellow rust with infection type 5R-15MR were identified. All new sources of resistance were considered in the programme of crosses for improvement of yellow rust resistance. Genetic analysis was done to determine inheritance of yellow rust resistance of 173 RILs from Almaly × Avocet S. It was found that the most virulent race of *P. striiformis* f.sp. *tritici* for RILs Almaly/Avocet S is 27E9. Based on seedling tests, cultivar Almaly resistance to race 27E9 was conferred by three recessive complementary genes, and resistance to race 47E159 was controlled by three dominant complementary genes.

Introduction

Yellow, or stripe, rust of wheat (*Puccinia striiformis* f.sp. *tritici*) periodically causes severe damage to wheat production throughout the world. In most wheat producing areas, yield losses caused by stripe rust have ranged from 10 to 70% depending on susceptibility of the cultivar, earliness of the initial infection, rate of disease development and duration of disease (Chen, 2005). The Central Asia region (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) is one of the major wheat areas in the world. Wheat is grown on 15 million ha, including 5 million ha of winter or facultative wheat, and 10 million ha of spring wheat. In this area, wheat stripe rust over the past few years has been the major factor adversely affecting wheat yield and quality, causing considerable economic damage. In the late 1990s and early 2000s, yield losses reached 20–40% (Morgounov *et al.*, 2004). During the epidemic of 2009, most high yielding widely grown cultivars had severe stripe rust. Effectiveness of most known *Yr* genes break down due to changes in pathogen race composition. This study aimed to identify new wheat germplasm resources resistant to yellow rust.

Materials and methods

Seedlings of winter wheat recombinant inbred lines (RILs) and parental cultivars were tested under controlled greenhouse conditions for two races of *P. striiformis* f.sp. *tritici* currently prevalent in Kazakhstan: 27E9 and 47E159. The infection type (IT) data of seedling reactions were analysed using the method described by Konovalova, Semenova and

Sorokina (1977). The decimal system of numbering was used for the designation of races. The base of this system is two characters: 0 for resistant type and 1 for susceptible. The first number was according to the international number, then followed by the number in the European set, indicated by letter E between the two numbers. Disease severity and adult plant response was recorded following McIntosh, Wellings and Park (1995). Five infection types are described: 0 = immune (no uredia or other symptoms of disease infection); R = resistant (uredia minute, supported by distinct necrotic areas); MR = moderately resistant (uredia small to medium, in green islands surrounded by chlorotic tissue); MS = moderately susceptible (uredia medium in size, no necrosis but chlorotic areas may be present); and S = susceptible (uredia large, no necrosis but chlorosis may be evident). Cv. Morocco and local cv. Steklovidnaya 24 were used as susceptible checks, for multiplication of the pathogen spores in the greenhouse and as spreaders in the field tests. Genetic analysis based on the reaction data of RILs to infection was used for identifying the genes for resistance. Observed and expected data were analysed using the Chi-squared test (Serebrovsky, 1970).

Results

The results of field evaluation of wheat isogenic lines and yellow rust differentials in Almalybak (Almaty oblast) indicated that the most effective resistant sources against stripe rust in this region are those of genes *Yr5, Yr10, Yr15* and *Yr24*, which demonstrated 0-R infection types.

In comparison with 2006 and 2007 (Kokhmetova *et al.*, 2007), most carriers of yellow rust resistance genes were susceptible in 2009. The carriers of *Yr1* were susceptible: 40S on Chinese 166 and 80S on the isogenic line *Yr1*/6*Avocet S. In 2007, Heines VII (*Yr2, Yr11* and *Yr25*) demonstrated a high level of resistance (IT 0), but in 2009 this cultivar was highly susceptible (IT 80S). Cv. Kalyansona (*Yr2*) showed 60S, but Sonalika, which also has *Yr2*, was resistant (IT 0). The same reaction was observed on carriers of *Yr3*: cultivar Vilmorin 23 (*Yr3a* and *YrV23*) was moderately susceptible (10MS), but cultivars Nord Desprez (*Yr3a*, *YrND*) Hybrid 46 (*Yr4b* and *YrH46*) were susceptible (40S) in 2009. However, in previous years (2005–2007) these cultivars were more resistant to yellow rust. Cultivars Heines Peko (*Yr6* and *YrHP*) and Oxley (*Yr6* + APR) were highly resistant (R), while the isogenic line *Yr6*/6*Avocet S was susceptible (100S). Cranbrook (*Yr7*), Lee (*Yr7*, *Yr22*, *Yr23*) and Reichenberg 42 (*Yr7*) demonstrated a high level of resistance (IT 0-R), but in previous years the first two cultivars were susceptible (20-30S). However, Corella (*Yr6*+*Yr7*) and *Yr7*/6*Avocet S were susceptible (60S). The presence of genes *Yr8* and *Yr18* in cv. Compare provided an R-MR reaction under severe yellow rust development in 2009. The source of *Yr9,* Federation 4/Kavkaz, Clement, Federation and the *Yr9*/6*Avocet isogenic line were moderately

susceptible to susceptible in 2007, but this year they became highly susceptible (70-90S). Consistent resistant reaction was observed in the *Yr5*/6*Avocet S, *Yr10*/6*Avocet S and *Yr15*/6* Avocet S isogenic lines (IT 0-R). The *Yr18*/6*Avocet S isogenic line was more susceptible (90S) in comparison with cv. Anza, having *YrA* and *Yr18* (30MS). Cv. Cook, with adult-plant resistance (APR) was resistant (IT 0). The highest level of susceptibility was observed on cultivars Avocet S, Jupateco S and isogenic lines *Yr1*/6*Avocet S, *Yr2*/6*Avocet S, *Yr6*/6*Avocet S, *Yr7*/6*Avocet S, *Yr9*/6*Avocet S, 3*Avocet S and YrSk/3*Avocet S (IT 80-100S). Virulences to resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17* and *Yr18* have occurred in our region. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* are the races virulent to these genes.

The study of the inheritance of resistance is very important for improving stripe rust resistance. Genetic analysis was done to determine inheritance of yellow rust resistance of recombinant inbred lines Almaly × Avocet S. In this cross of RILs, resistant cultivar Almaly was crossed with susceptible check Avocet S to determine inheritance of resistance. Segregating ratios of resistant to susceptible plant of RILs were used to estimate the number of genes segregating for resistance in the cross.

Seedling tests for resistance to stripe rust were done for 173 RILs Almaly/Avocet S. Plants were tested under controlled greenhouse conditions. The reactions of the wheat genotypes, when tested with two races of *P. striiformis* f.sp. *tritici,* are shown in Table 1. Resistance to race 27E9 was detected in 73 lines out of 174 (IT 0–2). Race 27E9 was virulent on 101 RILs.

Table 1. Observed numbers of wheat plants or lines in reaction groups for parents and RILs of cross Almaly/Avocet S when tested with different races of *P. striiformis* f.sp. *tritici*

Genotype	Test race	Parent or population	No. of genotypes		Expected ratio	No. of genes conferring resistance	*P* value
			IT 0–2 (Res.)	IT 3–4 (Sus.)			
RILs Almaly/Avocet S	27E9	Almaly	15	—	—	3 recessive complementary genes	0.95
		Avocet S	—	14	—		
		RILs	73	101	27:37		
RILs Almaly/Avocet S	47E159	Almaly	13	—	—	3 dominant complementary genes	0.20–0.50
		Avocet S	—	12	—		
		RILs	107	67	37:27		

When plants of RILs were inoculated with race 27E9, the segregation was 27:37 (P = 0.95) for resistant and susceptible lines. The result indicated that resistance to 27E9 in Almaly is controlled by three complementary recessive genes. Similarly, the RILs Almaly/Avocet S plants inoculated with race 47E159 supported the model of three dominant genes with segregation rate 37:27 (P = 0.20-0.50). 107 out of 174 lines were resistant to race 47E159, which was virulent on 67 RILs.

Thus, the most harmful race of *P. striiformis* f.sp. *tritici* for RILs Almaly/Avocet S is 27E9. Based on seedling tests, resistance to race 27E9 in cv. Almaly is conferred by three recessive complementary genes, and resistance to race 47E159 is controlled by three dominant complementary genes.

Yellow rust race composition using differentials of *P. striiformis* f.sp. *tritici* was determined (Table 2).

Table 2. The most virulent pathotypes of yellow rust in Kazakhstan

	Pathogen races										
Reaction of differentials	15E159	15E191	31E158	47E143	47E159	47E223	71E191	71E175	79E143	111E155	111E158
International set											
Suwon 92×Omar (*YrSU*, Pa1-3)	R	R	R	R	R	R	S	S	S	S	S
Strubes Dickopf *(Yr2, SD*)	R	R	R	S	S	S	R	R	R	S	S
Moro (*Yr10*, Mor)	R	R	S	R	R	R	R	R	R	R	R
Vilmorin 23 (*Yr3V)*	S	S	S	S	S	S	R	R	S	S	S
Heines Kolben (*Yr6*)	S	S	S	S	S	S	S	S	S	S	S
Lee (*Yr7, 22, 23*)	S	S	S	S	S	S	S	S	S	S	S
Chinese 166 (*Yr1*)	S	S	S	S	S	S	S	S	S	S	S
European set											
Heines VII *(Yr2,* HVII)	S	S	S	S	S	S	S	S	S	S	S
Spaldings Prolific (*YrSP, 6*)	R	R	R	R	R	S	R	R	S	R	R
Carstens V (*YrCV*)	R	S	R	R	R	R	S	S	R	R	R
Compair (*Yr8, 18*)	S	S	S	R	S	S	S	S	R	S	S
Nord Desprez (*Yr3N, 3a*)	S	S	S	S	S	S	S	S	S	S	S
Heines Peko (*Yr6*+)	S	S	S	S	S	S	S	S	S	R	S
Reichersberg 42 (*Yr7*+)	S	S	S	S	S	S	S	S	S	S	S
Hybrid 46 (*Yr4*+)	S	S	R	S	S	S	S	S	S	S	R
Virulence %	66.7	73.3	66.7	66.7	73.3	80.0	73.3	73.3	66.7	73.3	73.3

Of the yellow rust samples collected in 2007–2008, 11 pathotypes of *P. striiformis* f.sp. *tritici* were identified as the most virulent, including pathotypes 47E223, 15E191, 47E159, 71E191, 71E175, 111E155 and 111E158, which were virulent on cultivars Vilmorin 23, Heines Kolben, Lee, Chinese 166, Heines VII, Compair, Nord Desprez, Heines Peko, Reichersberg 42 and Hybrid 46. Pathotype 31E158 was virulent on Moro (*Yr10, YrMor*), and pathotype 47E223 on Spaldings Prolific (*Yr6, YrSP*). All pathotypes studied were completely virulent (100%) on cvs Heines Kolben, Lee, Chinese 166, Heines VII and Reichersberg 42.

Among the differentials, Spaldings Prolific had immunity to the most isolates. Heines Kolben (*Yr6*) had a susceptible reaction to almost all isolates. Cv. Moro was resistant to the majority of the isolates.

The evaluation of field response to yellow rust in commercial cultivars and advanced lines of wheat showed that during the epidemic of 2009, most high yielding widely grown cultivars, such as Steklovidnaya 24, Naz, Progress and Zhetisu, had severe stripe rust. The cultivars that in previous years had demonstrated resistance became susceptible in 2009. Thus resistance and moderate resistance in 2007 in cvs Bermet, Sharora and Ulugbek 600 became highly susceptible (IT 100S). Cvs Oktyabrina, Arap, Almaly, Kupava, Knyazhna and Umanka that were previously immune became susceptible in 2009 (30-40S). New wheat cvs Tungysh, Mereke 70 and Yrym demonstrated a high level of resistance to yellow rust (IT R-MR). From the F_4-F_5 hybrid populations, 35 new sources of resistance to yellow rust with infection type 5R-15MR were identified. All new sources of resistance were included in the programme of crosses for improving yellow rust resistance.

Conclusions

The changes of reaction of wheat genotypes (differentials, isogenic lines and cultivars) to *P. striiformis* f.sp. *tritici* indicates changes in pathogen race composition.

The results of field evaluation of wheat isogenic lines and yellow rust differentials in Almalybak (Almaty oblast) indicated that the most effective resistant sources against stripe rust in this region are those of genes *Yr5, Yr10, Yr15* and *Yr24*, with 0-R infection types. In comparison with 2006 and 2007, most carriers of yellow rust resistance genes were more susceptible. Virulences to resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9, Yr17* and *Yr18* have occurred in the region. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* are the races virulent to these genes.

The study of the inheritance of resistance is very important for improving stripe rust resistance. Genetic analysis was done to determine inheritance of yellow rust resistance of recombinant inbred lines Almaly × Avocet S. It was

found that the most harmful race of *P. striiformis* f.sp. *tritici* for RILs Almaly×Avocet S is 27E9. Based on seedling tests, cv. Almaly resistance to race 27E9 is conferred by three recessive complementary genes, and resistance to race 47E159 is controlled by three dominant complementary genes.

A total of 11 pathotypes of *P. striiformis* f.sp. *tritici* were identified as the most virulent from the yellow rust samples collected in 2007–2008. The virulence patterns of the pathotypes ranged from virulent on the many differentials to highly virulent. The pathotypes 47E223, 15E191, 47E159, 71E191, 71E175, 111E155 and 111E158 were virulent on cvs Vilmorin 23, Heines Kolben, Lee, Chinese 166, Heines VII, Compair, Nord Desprez, Heines Peko, Reichersberg 42 and Hybrid 46.

As a result of yellow rust evaluation, several new wheat cultivars (Tungysh, Mereke 70 and Yrym) resistant to yellow rust were selected. From the F_4-F_5 hybrid populations, 35 new sources of resistance to yellow rust with good levels of resistance were identified. All new sources of resistance were included in the programmes of crosses for improving yellow rust resistance.

References

Chen, X.M. 2005. Epidemiology and control of stripe rust (*Puccinia striiformis* f.sp. *tritici*) on wheat. *Canadian Journal of Plant Pathology,* 27: 314–337.

Morgounov, A., Yessimbekova, M., Rsaliev, Sh., Boboev, S., Mumindjanov, H. & Djunusova, M. 2004. High-yielding winter wheat varieties resistant to yellow and leaf rust in Central Asia. Abstract A2.52, *in:* Proceedings of the 11th International Cereal Rust and Powdery Mildews Conference, 22–27 August 2004, John Innes Centre, Norwich, UK.

Konovalova, N., Semenova, L. & Sorokina, G. 1977. Methodological recommendations on studying race structure of cereal rust agents. VASKHNIL Moscow, Russia. 144 p

McIntosh, R.A., Wellings, C.R. & Park, R.F. 1995. *Wheat Rusts: An Atlas of Resistance Genes.* CSIRO, Australia. 200 p.

Serebrovsky A.S. 1970. *Genetic analysis*. Moscow. 342 p.

Kokhmetova, A., Bayzhanov, Zh., Morgounov, A., Yessimbekova, M. & Rsaliev, Sh. 2007. The study of winter wheat genotypes for yellow rust resistance. *Biological Sciences of Kazakhstan*, 1-2: 58–64

Abstracts of other papers presented at the Fourth Regional Yellow Rust Conference for the Central and West Asia and North Africa (CWANA) Region

Antalya, Turkey
10–12 October 2009

Monitoring pathogen dynamics in *Puccinia striiformis*: alternative methods and approaches for interpretation

C. Wellings

The University of Sydney, Plant Breeding Institute, Narellan NSW, Australia

The stripe or yellow rust pathogen, *Puccinia striiformis* f.sp. *tritici* (*Pst*), continues to be a major foliar disease threat to world wheat productivity. Disease control strategies are directed at the deployment of resistant varieties and the appropriate application of fungicides. In both instances, pathogen variability must be carefully considered in decisions taken to incorporate nominated resistance genes in breeding programmes, in monitoring the post-release deployment of commercial varieties, and in predicting the expected disease response for nominated varieties under field conditions. The approaches to developing practical and efficient pathogen monitoring will vary according to access to resources. Two methods are examined, their relative merits evaluated, and the interpretation of data arising from these monitoring programmes presented and discussed. Greenhouse testing of *Pst* samples received from regional co-operators is based on seedling tests on differential stocks of known resistance genotype. The advantages of surveys based on this approach include the capacity to manage large numbers of pathogen isolates in a growing season, the possibility to develop co-operator networks for sampling across broad regions, and the utility of pathogenic profile information (virulence vs avirulence) in relation to resistance genes deployed in commercial production. The disadvantages include the need for greenhouse facilities with at least some measure of temperature control, and the necessary expertise and experience of staff focused on the project. An alternative approach that has also been applied with success across regions is the deployment of trap plot nurseries. The advantages include the static exposure of selected material to *Pst* populations for the duration of a growing season, the opportunities to combine these with variety trials, and the integration with networks associated with national variety evaluation. Disadvantages include site access (travel, timing of visits) to record observations, potential for error with trap plot entries and the attendant potential for failure of field sites. Despite the advantages and disadvantages of these approaches, a factor governing success is the interpretation of the data. In all cases, it is vital to include experimental controls in order to provide a reasonable basis on which to draw conclusions. Examples are given in order to appreciate the difficulties associated with data interpretation, and the importance that these conclusions may have for breeding activities, variety recommendation and disease management decisions.

Global cereal rust surveillance and monitoring

D. Hodson[1] and M. Hovmøller[2]

1. AGP Division, FAO, Italy; 2. University of Aarhus, Department of Integrated Pest Management, Denmark

International efforts are underway to develop global cereal rust monitoring and surveillance systems. The emergence of new races of both wheat stem rust and yellow rust has catalysed these efforts and highlighted the current lack of integrated information systems. For instance, the identification of aggressive races of wheat yellow rust adapted to warmer environments is an issue of global concern, and the emergence of the Ug99 stem rust lineage is seen as a global threat. Approaches being undertaken as part of the Global Reference Centre – Yellow Rust, spearheaded by the University of Aarhus, CIMMYT, ICARDA and the Wheat Rust Disease Global Programme at FAO are described. Current activities and progress on the development of tools, methods and information products are outlined.

Field-based pathogenicity survey and likely migration pattern of wheat yellow rust in CWANA

K. Nazari,[1] D. Hodson,[2] A. Yahyaoui,[1] R. Singh,[3], C.R. Wellings,[4] F. Afshari,[5] A.R. Rattu,[6] A. Ramdani,[7] S. Murat,[8], E. Ibrahimov,[9] Noorul Haque[10] and A. Sailan[11]

1. ICARDA, Aleppo, Syria; 2. FAO, Rome, Italy; 3. CIMMYT, Mexico; 4. Plant Breeding Institute, University of Sydney, Australia; 5. Cereal Disease Research Unit, Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran; 6. Crop Diseases Research Programme, National Agricultural Research Centre, Islamabad, Pakistan; 7. Cereal Pathology Lab, INRA Meknès, Morocco; 8. Uzbekistan; 9. Azerbaijan; 10. ICARDA office, Kabul, Afghanistan; 11. Agricultural Research and Extension Authority, Sana'a, Yemen

Wheat is a staple food in all countries in Central and West Asia and North Africa (CWANA) and Caucasus (CAC) regions. In spite of large areas of cultivation of high yielding, modern cultivars with wide adaptability across the different CWANA climatic zones, annual wheat production in many countries suffers significant crop losses due to biotic stresses, of which wheat yellow (stripe) rust caused by *Puccinia striiformis* f.sp. *tritici* is the most destructive. Several epidemics of yellow rust have been reported in the region. Historically, west-to-east movement of the *Yr9* virulent lineage has been considered the cause of the most devastating epidemics of yellow rust since the

1980s. Occurrence of virulence for *Yr9*, widespread monoculture of wheat cultivars with similar genetic composition, favourable environmental conditions, overlapping crop calendars and high frequency of west-to-east wind movements during cropping seasons are the major factors in regional epidemics of yellow rust in CWANA. The recent wide spread of yellow rust in CWANA is possibly a consequence of such similar conditions. Transboundary rust pathogens can produce new virulence that could overcome resistance of commonly grown wheat cultivars and cause epidemics in a short period. Monitoring rust occurrences and movement would enable forecasting of the development of new races and would allow timely use of appropriate control measures by wheat growers to protect their production. Analysis of pathogenic variation in rust pathogens is fundamental to understanding pathogen population structure, host-pathogen co-evolution, and breeding for durable resistance. Over the last 80 years, rust workers have conducted pathogenicity surveys and race analysis using differential host genotypes for seedling and adult-plant resistance genes. Currently, the threat of long-distance migration of rust pathogens, monoculture of mega-genotypes and a lack of standard facilities and expertise in many developing countries have increased the importance of international collaboration in monitoring cereal rusts. Many national, regional and international biological rust trap nurseries comprising differential genotypes, known cultivars with widely used rust resistance genes and local commercial cultivars have been established successfully in almost all wheat growing areas worldwide. For example, rust trap nurseries were successfully distributed by ICARDA to 244 testing sites for the 2008/09 cropping season, with the 3rd International Yellow Rust Trap Nursery (3rd IYRTN-09) distributed to 76 sites in 31 countries. Although environmental conditions were unfavourable for yellow rust because of drought conditions in most CWANA countries, occasional severe yellow rust outbreaks were recorded on commercial cultivars mostly known to carry *Yr27* alone or in combination with *Yr9* and *Yr18*. Among the *Yr* genes present in the differential genotypes and commercial cultivars in YRTN, only a few known genes have been widely used in agriculture (such as *Yr1*, *Yr6*, *Yr7*, *Yr9*, *Yr27* and *Yr18*). Virulence for *Yr1* is varied among these genes, and virulence for *Yr6*, *Yr7* and *Yr9* is very common (nearly fixed) in CWANA regions, and it has been indicated that yellow rust can not be effectively protected by genotypes with *Yr18* alone. *Yr9* and *Yr27* are the most common *Yr* genes that have been used in many wheat cultivars grown in CWANA, such as PBW 343, Inqilab 91, MH 97, Chamran, Shiroudi, Kubsa, Imam and many advanced lines. During the 3rd Regional Yellow Rust Conference, detection of virulence for *Yr27* was highlighted, particularly for cultivars PBW 343 in India and Inqilab in Pakistan, and Chamran and Shiroudi in Iran. Severe infections of commercial cultivars were noted in India, Pakistan, Iran, Uzbekistan, Afghanistan, Azerbaijan, Turkey and Morocco during 2008/09. Field-based pathogenicity surveys have provided sufficient evidence of the usefulness of yellow rust

Trap Nurseries in epidemiology and pathogen evolutionary studies, but it has been of only very limited benefit to breeding programmes. In response to the global threat of wheat rust diseases, a Wheat Rust Disease Global Programme (WRDGP) has been established by FAO. Today, a GIS-based data analysis and management system is available to regional and international rust networks providing timely information relating to the current status of rust populations. Field-based pathogenicity survey data, rust surveillance and disease monitoring, in combination with use of geo-referenced positioning of trap nurseries sites and inclusion of meteorological information, are used to discuss possible movement and prediction of yellow rust in CWANA. Achievements and challenges ahead are also discussed and the regional yellow rust platform for CWANA will be presented to share with participants.

Epidemiological studies on *Puccinia striiformis* causing stripe [yellow] rust of wheat in Faisalabad, Pakistan

S. Ahmad,[1] M.A. Khan,[2] M.M. Haider,[2] Z. Iqbal,[1] M. Kamran[1] and N. Akhtar[1]

1. University College of Agriculture, University of Sargodha, Pakistan;
2. Department of Plant Pathology, Agricultural University, Faisalabad, Pakistan.

Fifty varieties and lines of wheat were screened against yellow rust to determine the ecology of the stripe rust. Among these, 36 genotypes showed reaction symptoms to yellow rust, of which 18 were found susceptible, 6 were moderately susceptible, 7 were moderately resistant and 5 remained resistant against yellow rust. All the other genotypes showed no response or remained asymptomatic against yellow rust. For the epidemiological study of the stripe rust, data was collected on environmental factors, including maximum and minimum temperatures, rainfall, relative humidity, sunshine radiation and wind speed. The stripe rust severity and related environmental factors was than determined through correlation analysis. Four environmental factors—maximum and minimum temperature, relative humidity and wind speed—were found significant in causing stripe rust disease, while rainfall and sunshine remained insignificant. It was found that three environmental factors—maximum temperature, relative humidity and wind speed—were positively correlated, while minimum temperature showed negative correlation. It means increasing maximum temperature, rainfall and wind speed increased disease incidence, while increasing minimum temperature decreased the disease incidence on various genotypes. This study may be helpful in the future to develop predictive models to forecast stripe [yellow] rust disease occurrence, which will be an economical tool in the management of this disease.

Race changes of *Puccinia striiformis* f.sp. *tritici* and *P. striiformis* f.sp. *hordei* in the United States of America

X.M. Chen,[1, 2] L. Penman,[2] A. Wan[2] and P. Cheng[2]

1. USDA-ARS Wheat Genetics, Quality, Physiology, and Disease Research Unit;
2. Department of Plant Pathology, Washington State University, Pullman, WA, USA.

Stripe [yellow] rust of wheat, caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*), is most frequently destructive on wheat in the western USA and has become more frequently epidemic in the Great Plains and south-eastern USA states since 2000. Stripe rust of barley, caused by *P. striiformis* f.sp. *hordei* (*Psh*), has caused damage mainly in the western USA since its first report in Texas in 1991. Races of the pathogens have been determined every year from infected leaf samples of wheat and grasses, collected throughout the USA. *Pst* races were identified on a set of 20 wheat differential genotypes and *Psh* races were identified on 12 barley genotypes. From 2000 to 2008, a total of 117 races were detected, of which 79 were first detected during this period. The predominant races, which were first detected in 2000, were the group with basic virulences to Lemhi (*Yr21*), Heines VII (*Yr2*, *YrHVII*), Lee (*Yr7*, *Yr22*, *Yr23*), Fielder (*Yr6*, *Yr20*), Express (*YrExp1*, *YrExp2*), AVS/6*Yr8 (*Yr8*), AVS/6*Yr9 (*Yr9*), Clement (*Yr9*, *YrCle*), and Compair (*Yr8*, *Yr19*). This race group continues to evolve into new races with additional virulences to differential genotypes, including Chinese 166 (*Yr1*), Moro (*Yr10, YrMor*), Paha (*YrPa1*, *YrPa2*, *YrPa3*), Druchamp (*Yr3a*, *YrDru*, *YrDru2*), Produra (*YrPr1*, *YrPr2*), Yamhill (*Yr2*, *Yr4a*, *YrYam*), Tyee (*YrTye*), Tres (*YrTr1*, *YrTr2*), and/or Hyak (*Yr17*, *YrTye*). From 2000 to 2003 the predominant races were *Pst*-78 (virulent on wheat differential genotypes Lemhi, Heines VII, Lee, Fielder, Express, AVS/6*Yr8, AVS/6*Yr9, Clement and Compair) and *Pst*-80 (the same virulences plus virulence on Produra). In 2004 to 2006, the predominant race throughout the USA was *Pst*-100 (the same virulences as *Pst*-80 plus virulences on Yamhill and Stephens). Starting in 2006, races with the virulences of *Pst*-100 or similar races plus virulence to *Yr1* became predominant in California, and *Pst*-114 with combined virulences of *Pst*-100 and virulence to *Yr10* became predominant in the Pacific Northwest. Over the nine-year period, races with more virulences became increasingly prevalent, indicating that races with more virulences have advantages over those with fewer virulences.

A total of 82 *Psh* races have been identified since 1991, of which 30 were first identified after 2000. In contrast to *Pst*, *Psh* races with few virulences have been predominant. Preliminary evidence has been obtained for somatic hybridization between *Pst* and *Psh* isolates using virulence tests of stripe rust collections on both sets of differential genotypes and microsatellite markers.

Changes of stripe [yellow] rust races and gene resistance efficacy in Egypt

M. M. EL-Shamy,[1] S. EL-Shereif[1] and M. Azab[2]

1. Wheat Diseases Research Department, Plant Pathology Research Institute, ARC, Giza, Egypt; 2. National Wheat Research Programme, Field Crops Research Institute, Egypt.

In the past, epidemics of wheat stripe [yellow] rust *(Puccinia striiformis* f.sp. *tritici)* occurred sporadically in Egypt. However, since the 1995 season, stripe rust has appeared annually and caused large losses in grain yield of the bread wheat cultivars Sakha 8, Sakha 69, Giza 163 and Gemmeiza 3. In the period 2004–2007, surveys were carried out. Single-pustule isolates were collected from nurseries, trap plots and commercial fields. Each single-pustule isolate was increased on seedlings of the susceptible cv. Morocco. Isolates were tested on a set of 17 differential single-gene lines of wheat. Stripe rust infection types were scored according to the scale of McNeal *et al.* (1971). Out of 270 isolates, 26 stripe rust races were identified in the period from 2004–2007. Some of these races were present in all four years, while others were found only in one season. Frequencies of occurrence of the races were compared for each of the four years. For example, race OEO was found at a frequency of 13.3% during the four years, while races 4E0, 4E2, 6E134 and 64E6 did not exceed 10% each. However, twelve stripe rust races—2E128, 32E0, 102E22, 102E128, 142E20, 198E144, 228E148, 230E158, 230E191, 238E0, 238E182 and 494E128—were identified for the first time in the 2006/07 season, at a frequency of 6% for each race. This may indicate that epidemics of stripe rust have resulted from inoculum exogenous to Egypt. The data obtained in the period 2004–2007 have shown that stripe rust populations were virulent on *Yr6*, *Yr7*, *YrSD, YrSU*, *Yr7*, *Yr6*, *Yr3*, *Yr8* and *Yr2*. Single-gene lines with *Yr1*, *Yr10*, *YrSP*, *Yr5* and *YrCV* were the most resistant. The genes *Yr3*, *Yr4* and *Yr9* were intermediate in their efficacy.

High-temperature, adult-plant (HTAP) resistance, the key for sustainable control of stripe [yellow] rust

X.M. Chen

USDA-ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit and Department of Plant Pathology, Washington State University, Pullman, WA, USA

Stripe [yellow] rust, caused by *Puccinia striiformis* f.sp. *tritici*, is the most frequent destructive disease of wheat in the USA Pacific Northwest (PNW) and many other regions in the world. Control of the disease using race-specific all-stage (also called seedling) resistance is not sustainable. High-temperature, adult-plant (HTAP) resistance that expresses when the weather becomes warm and as plants grow older has been used successfully to control stripe rust of wheat in the PNW and other regions of the USA since the 1960s. Leading cultivars with adequate levels of HTAP resistance were developed in later years. Recently, several genes, or quantitative trait loci (QTL), for HTAP resistance in commercial wheat cultivars and genotypes have been mapped. A major QTL (gene) in cv. Alpowa spring wheat, named *Yr39*, was mapped to the long arm of chromosome 7B. A major QTL (*Qyrlo.wgp-2BS*) in cv. Louise spring wheat was mapped on chromosome 2BS. A major QTL (*Qyr8.wgp-2DS*), tightly linked to the race-specific all-stage resistance gene *Yr8*, was mapped on chromosome 2DS in line AVS/6**Yr8* NIL and its donor genotype, cv. Compair. Three QTLs (*Qyrex.wgp-6AS*, *Qyrex.wgp-3BL* and *Qyrex.wgp-1BL*) were mapped on chromosomes 6AS, 3BL and 1BL, respectively, in cv. Express spring wheat. Two QTLs (*Qyrst.wgp-6BS.1* and *Qyrst.wgp-6BS.2*) were mapped in cv. Stephens winter wheat.

Wheat lines completely free of stripe rust were developed through molecular marker-assisted pyramiding of HTAP resistance QTLs from Alpowa and Express. HTAP resistance is durable because it is non-race-specific. Transcript profiling studies using microarrays revealed that more genes are involved in non-race-specific HTAP resistance than those involved in race-specific all-stage resistance. Different HTAP resistance genes share relatively few regulated genes compared with genes controlling all-stage resistance. Broader spectra of defence genes contribute to the molecular basis of non-race-specific, and therefore durable, types of HTAP resistance.

Adult plant resistance effective against new strains of wheat stripe [yellow] rust

J. Sthapit and E.A. Milus

Department of Plant Pathology, University of Arkansas, Fayetteville, Arkansas, USA

Stripe [yellow] rust, caused by *Puccinia striiformis* West. f.sp. *tritici*, has been an important disease of soft red winter wheat in eastern USA since 2000, when a new strain of stripe rust with virulence on resistance gene *Yr9* and enhanced aggressiveness and adaptation to warmer temperature appeared. Although the new strain was devastating when it first appeared in 2000, stripe rust severities and losses have been low since 2006. Many cultivars and lines have low severities even in inoculated and irrigated nurseries, indicating that these may have effective adult-plant resistance (APR). The objective of this research was to characterize APR to stripe rust in contemporary wheat cultivars and breeding lines. Seedlings of 50 lines with low to moderate levels of stripe rust in fields infected with the new strain were evaluated for resistance to races *Pst*-3 (isolate AR90-01) and *Pst*-100 (isolate AR00-05) that are representative of the old and new strains, respectively. Nineteen lines that were susceptible to both races and one line with *Yr9* that was susceptible to *Pst*-100 but resistant to *Pst*-3 at the seedling stage were selected for adult-plant experiments. To determine the effect of race and post-inoculation temperature on the expression of APR, the 20 lines (including susceptible and very susceptible checks) were inoculated with each race at heading stage and incubated in growth chambers at low (10 to 18ºC) and high (12 to 28ºC) temperatures, gradually changing temperature regimes. To characterize resistance on flag and flag-1 leaves, the time from inoculation to the first sporulation was recorded to estimate latent period, and the infection type (0 to 9 scale) and percentage of leaf area diseased were recorded 21 days after inoculation. The same 20 lines were planted in two fields at University Farm in Fayetteville during October 2008. The experimental design in each field was a randomized complete block with six replications. At jointing stage, one field was inoculated with *Pst*-3, and the other field was inoculated with *Pst*-100. Lines were rated several times for infection type. Many infections on resistant lines produced few or no spores, indicating that latent period may not be an appropriate variable for characterizing such resistance, and no latent period results will be reported. In the field, the susceptible checks had high infection types to both races; six lines had higher infection types with race *Pst*-3 than with *Pst*-100, and the other lines had low to intermediate infection types with both races. Under the low temperature regime, both races produced high infection types on the susceptible checks, and all except two lines had a higher range of infection

types with race *Pst*-3 than with *Pst*-100. Compared with results at low temperature, both races produced lower ranges of infection types at the high temperature. The line × race interaction was significant ($P<0.0001$) for percentage of leaf area diseased, indicating that the APR in some of the lines is race specific. Both races produced similar levels of disease on the checks and 11 resistant lines, but race *Pst*-3 caused significantly more disease than *Pst*-100 on seven lines. The results of this study indicate that APR is common in contemporary cultivars and breeding lines of soft red winter wheat and that some resistance is race specific for the new strain. Therefore, the new strain lacks virulence on at least one gene for APR for which the old strain was virulent. The APR in several lines appears to provide useful levels of resistance to both races and may be race-non-specific. The APR was expressed in both low and high temperature regimes, indicating that it may be different from the HTAP resistance that is common in cultivars from north-western USA. The increased aggressiveness and adaptation to warmer temperature in the new strain was not sufficient to overcome the APR, and APR appears to be an effective method for protecting wheat from the new strain of stripe rust.

A novel gene for resistance to stripe [yellow] rust in wheat genotype PI 181434

Q. Li,[1, 2] M.N. Wang[1, 2] and X.M. Chen[1, 3]

1. Department of Plant Pathology, Washington State University, Pullman, WA, USA;
2. College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China;
3. USDA-ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit, Pullman, WA, USA

Stripe [yellow] rust, caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*), is one of the most devastating diseases of wheat worldwide. Growing resistant cultivars is the most effective approach to control the disease, but only a few effective genes are available. The common spring wheat genotype PI 181434, originally from Afghanistan, was resistant in all greenhouse and field tests. To identify the resistance genes, PI 181434 was crossed with susceptible genotype Avocet 'S'. Adult plants of 103 F_2 progenies were tested in the field under natural infection conditions. Seedlings of the parents, F_2 and F_3 were tested with USA races *Pst*-100 and *Pst*-127 under controlled greenhouse conditions. The genetic study showed that PI 181434 has a single dominant gene conferring all-stage resistance. The resistance gene analogue polymorphism (RGAP) and simple sequence repeat (SSR) techniques were used to identify molecular markers linked to the gene. A linkage map of 8 RGAP markers and 2 SSR markers was

constructed for the gene using the 103 F_2 plants. Amplification of a set of nulli-tetrasomic lines of cv. Chinese Spring and di-telosomic lines with an RGAP marker and the two SSR markers mapped the gene on the long arm of chromosome 3D. Polymorphism of the two closest flanking markers in 45 wheat genotypes was 82.2% and 73.3%, respectively, indicating that these markers are useful in incorporating the gene into wheat cultivars and pyramiding with other genes for durable resistance.

Gene effects and combining ability in some of bread wheat genotypes to yellow rust disease

A.R. Razavi,[1] M. Taeb[2] and F. Afshari[3]

1. Scientific Board of Agricultural Research and Natural Resources Research Centre, Mashhad, Islamic Republic of Iran; 2. Islamic Azad University Science and Research Branch, Faculty of Agriculture and Natural Resources, Islamic Republic of Iran; 3. Cereal Research Department, Seed and Plant Improvement Institute, Karaj, Islamic Republic of Iran

Ten lines of bread wheat were studied to determine gene effects and combining ability to yellow rust disease. Ten parental lines and F_1 were evaluated in a randomized complete block design with three replicates in the Agricultural and Natural Resources Research Centre, Mashhad, Iran. Two races, 134E134A+ and 4E0A+ were used in the study. Latent Period (LP) and Infection Type (IT) were measured in the field and greenhouse. Results showed significant differences among races in their pathogenicity and among genotypes in their resistance to the pathogen. Diallel crosses carried out between the parents and progenies were analysed by the method of Griffing and Haymans. The General Combining Ability (GCA) and Special Combining Ability (SCA) for all traits were significant, and showed that additive variance was more important. Test for validity of diallel hypothesis proved an epistasis effect for all traits. P_1, P_2 and F_1 showed significant differences between all traits in generation mean analysis. Average degrees of dominance ranged from partial to over-dominance for resistance or susceptibility. Dominance, additive and epistatic types of gene action were responsible for the genetic control of the traits.

Investigation of genetic resistance to yellow rust disease in some wheat cultivars

A.R. Souhani Darban[1] and A.R. Razavi[2]

1. Department Agriculture. Azad University Branch Mashhad, Islamic Republic of Iran; 2. Agricultural and Natural Resources Research Centre, Khorasan Razavi, Mashhad, Islamic Republic of Iran

Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is an important disease of wheat in many regions of the world. In Iran, severe epidemic of the disease occurred in 1993 and 1995. In our study, we conducted a genetic analysis of crosses involving eight cultivars (three resistant, three moderately resistant and two susceptible). The eight cultivars were crossed in half diallel. The plants of the parents, F_1, F_2, BC_1 and BC_2 were inoculated with race 4EOA+. Pustule size and pustule density were measured The experiment was conducted in the greenhouse. The chosen experimental design was a randomized complete block with three replications. Genetic analysis and heritability of partial resistance were determined using the method of Griffing and Haymans. The analysis of variance showed both additive genetic variance and dominance in different cultivars. MS(GCA)/MS(SCA) ratio for both traits were significant. The most important of the additive variance ratio is non-additive variance. Mean degree of dominance for the traits pustule size and density were calculated to be 1.119 and 0.8, respectively. The three parameters m, [d] and [h] are significant. Interaction dominance × dominance for traits was significant.

Recognition of four subspecies of *Puccinia striiformis* and development of real-time PCR detection assays

M. Liu and S. Hambleton

Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, Canada

In recent years, the incidence of yellow rust of wheat has increased in the USA and Canada, causing substantial losses. Early detection and differentiation from other wheat diseases is important for initiating appropriate pest management measures. Monitoring of air-borne spore dispersal can provide

advance warning of locations at risk for heavy spore deposition and subsequent disease pressure. In order to develop reliable DNA-based assays for screening environmental samples, a systematic study of the species was undertaken to evaluate existing sub-specific classifications. Historical taxonomic treatments have been fragmentary and at times contradictory, and conflicting concepts at the *forma specialis* and *varietas* level are in current use. Specimens from eight international herbaria were obtained to maximize geographical origin and host range, and supplemented with new collections from the field. Phylogenetic analyses of DNA sequences for 30 representative *Puccinia striiformis* specimens from a wide geographical and host range revealed four strongly supported monophyletic lineages. Based on comparisons of morphological characteristics, and after consideration of previous subspecific classifications, four corresponding subspecies were recognized.

Our systematic treatment of the species comprises descriptions of and a tabular key to four subspecific taxa, including a new taxon from China, and phylogenetic analyses of the nuclear ribosomal RNA internal transcribed spacer (ITS) and β-tubulin (BT) gene sequences. The taxa were recognized at the subspecies level on the basis of subtle morphological distinctions and molecular differences. The subtlety of the morphological characters useable for identification was underscored by our DNA analyses of herbarium material. A high percentage of the specimens preserved as *P. striiformis* in herbaria and examined for this study were incorrectly identified (ca. 45%). Therefore the use of DNA sequence-based techniques for detection and identification of *P. striiformis* increases the reliability of the determinations. We designed TaqMan real-time PCR probes and primers based on the BT protein coding gene, and developed assay protocols for identification at the species level and for the subspecies infecting wheat. Assay sensitivities were tested on 10-fold serial concentrations of DNA extracted from pure urediniospore samples. Specificities were evaluated for a comprehensive set of target *P. striiformis* specimens and close relatives of wide host and geographical range. Fluorogenic PCR-based (TaqMan) assays are more effective than conventional PCR assays because of the efficient amplification of short amplicons (usually <150 bp), enhanced specificity and sensitivity of SNP-based probes, the elimination of the need for post-PCR treatment and capability of generating quantifiable results in a timely manner.

Gene sequencing reveals heterokaryotic variations in *Puccinia striiformis*

B. Liu,[1, 2] X.M. Chen[1, 3] and Z.S. Kang[2]

1. Department of Plant Pathology, Washington State University, Pullman, WA, USA;
2. College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China;
3. USDA-ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit, Pullman, WA, USA

Puccinia striiformis, the causal agent of stripe [yellow] rust, is an obligate biotrophic fungus without known sexual reproduction. The objectives of this study were to identify polymorphic genes for determining the mechanisms of the pathogen variation. Primers were designed for seven important putative genes, including elongation factor, beta-tubulin, TATA-box binding protein, serine/threonine kinase, conidiation protein, mitogen-activated protein kinase, and cell wall glucanase, selected from the full-length cDNA library of *P. striiformis* f.sp. *tritici*, the wheat stripe rust pathogen. The full-length genomic sequences of the seven genes were obtained for 21 isolates to represent different race groups of *Pst* in the USA and China and *P. striiformis* f.sp. *hordei*, the barley stripe rust pathogen. The TATA-box binding protein and conidiation protein genes had identical sequences among all tested isolates. The five remaining genes had various levels of polymorphism. Phylogenetic trees generated with each of the five genes showed different relationships among the isolates, but the consensus tree had a low, but clear association with the virulence patterns. We found that some of the isolates had clearly distinct base pair differences, providing the first evidence at the DNA level for heterokaryotic variations in the stripe rust pathogen. The heterokaryotic variations may help to understand the molecular mechanisms by which the asexual fungus evolves into various races.

Constructing physical and genomic maps for *Puccinia striiformis* by comparing EST sequences with the genomic sequence of *P. graminis*

J.B. Ma,[1, 2] X.M. Chen,[1, 3] M.N. Wang[1, 2] and Z.S. Kang[2]

1. Depart. of Plant Pathology, Washington State University, Pullman, WA, USA;
2. College of Plant Protection, Northwest A&F University, Yangling, Shaanxi, China;
3. USDA-ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit, Pullman, WA, USA.

The stripe [yellow] rust fungus, *Puccinia striiformis* (*Ps*), does not have a known alternate host for sexual reproduction, which makes it impossible to study gene linkages through the classic genetic approach. The objective of this study was to determine if the genomic sequence of *P. graminis* (*Pg*), the stem rust fungus, can be used to establish linkage relationships for *Ps* genes. A total of 4219 *Ps* expression sequence tags (ESTs) were compared with the *Ps* genomic sequence database using BLAST searches. Of the genes, 1432 (34%) had significant homology (e-value $<1e^{-5}$) with the *Pg* sequence. On the hypothesis that many *Ps* genes retain a colinear, syntenic relationship with the *Pg* genes, physical maps were constructed for the 1432 *Ps* genes into 242 supercontigs corresponding to the *Pg* supercontigs. To validate the linkage relationships of *Ps* genes, 21 pairs of genes were selected to screen the *Ps* BAC library. The pairs of genes were those within 50 kbp in the *Pg* genome. Primers for the first gene in a pair were used in PCR amplification to screen the BAC library using a three-dimensional pooling approach. Identified individual positive clones were amplified with the primers for the second gene in a pair. Genes in 12 pairs (57%) were successfully identified in same clones, supporting their linkage relationships. These results show that the *Pg* genome sequence is useful in constructing physical maps for *Ps* genes and in studying important genes in the two rust fungi.

Molecular characterization of wheat BI-1 homologues that weaken the hypersensitive reaction triggered by stripe [yellow] rust fungus

X. Wang, J. Lv, P. Ji, L. Deng, X. Liu, L. Huang and Z. Kang

College of Plant Protection and Shaanxi Key Laboratory of Molecular Biology for Agriculture, Northwest A & F University, Yangling, Shaanxi, China

Programmed cell death (PCD) is a genetically controlled process that plays a vital role in the development, differentiation and disease resistance of higher organisms. To date, a few homologues of animal PCD regulators have been identified in plants. Among these is the plant Bax Inhibitor-1 (BI-1) protein, which is a conserved cell death regulator protein that inhibits mammalian BAX induced cell death in yeast. The role of BI-1 in the regulation of plant PCD remains to be elucidated. Plant BI-1 genes have been isolated from various plant species such as rice, *Arabidopsis*, tobacco, *Brassica napus* and barley. We cloned a *TaBI-1* from cDNA libraries of cv. Suwon 11 wheat challenged by *Puccinia striiformis* f.sp. *tritici* (*Pst*). Sequence analysis of *TaBI-1* revealed an open reading frame of 1095 nucleotides, which encodes a predicted protein of 247 amino acids and shares 97% identity with barley BI-1. A variety of computer algorithms predict unambiguously that *TaBI-1* contains seven trans-membrane domains with an N terminal signal peptide. Hydropathy analysis and targeting-motif detection for *TaBI-1* predicted proteins strongly suggest their association with plant membranes. According to PSORT, iPSORT and ChloroP programmes, *TaBI-1* proteins can be located within the thylakoid membranes. At the same time, basic residues at their C-terminal end look like some nuclear targeting sequences, which are also detected by PSORT. Phylogenetic analysis and protein alignment reveal that similarity between the predicted proteins spans the entire length of the sequence, except for the N-termini, where many amino acids are lacking in the alignment. Divergence between predicted sequences is represented as an inferred tree. It is noteworthy that plant sequences are grouped together and apart from animal sequences, with a separation between monocotyledonous and dicotyledonous species. This inferred tree is thus closely related to accepted evolutionary classification. *TaBI-1* gene expression was studied in the leaves of wheat cv. Suwon 11 inoculated with urediospores of a compatible race CYR31 and incompatible race CYR23 of *Pst* and treated with SA, JA and ETH. Wheat leaves show low basal expression of *TaBI-1* (indicated by 0 h). After the inoculation of CYR23, *TaBI-1* expression was transiently repressed (12 hpi), followed by slight induction (24 hpi), and recovery at 48–72 hpi equally for mock-treated plants (0 h), finally peaked at 120 hpi. qRT-PCR analysis showed

only a slight differential in transcript accumulation between a compatible and incompatible interaction, and the constitutive expression pattern was observed in compatible reaction. The expression of *TaBI-1* was only induced after ETH treatment, which indicated *TaBI-1* plays an important role in the interaction of wheat and *Pst* by the ETH signal pathway. To identify the function of *TaBI-1* in response to stripe [yellow] rust fungus, the transcriptional productions were repressed using a virus-induced gene silencing (VIGS) technique. The results show the area of cell death expanded after being induced by *Pst*, which indicated the function of *TaBI-1* is to weaken the hypersensitive reaction triggered by *Pst*. This study may help to dissect the mechanism of *BI-1*-induced suppression of apoptosis or cell death.

Ultrastructure and molecular cytology of interaction between wheat and *Puccinia striiformis* f.sp. *tritici*

Z. Kang, L. Huang, Q. Han, C. Wang and H. Zhang

College of Plant Protection and Shaanxi Key Laboratory of Molecular Biology for Agriculture, Northwest A&F University, Yangling, Shaanxi, China.

Wheat stripe [yellow] rust, caused by *Puccinia striiformis* West. f.sp. *tritici*, occurs worldwide and is considered a major disease in temperate regions, particularly in China. To reveal the resistance mechanism of wheat to stripe rust, we recently examined the compatible and incompatible combinations between wheat and *P. striiformis* by means of electron microscopic and immuno-gold labelling techniques. The infection process of *P. striiformis* is similar to that of other cereal rusts. After penetrating the stoma of wheat leaves, it forms a substomatal vesicle, infection hyphae, haustorial mother cell and haustorium within the host tissue. A multinucleate condition, i.e. more than two nuclei, is usually found in the intercellular hyphal cells, haustorial mother cells and haustoria. In the infected wheat leaves of the susceptible cultivar, a higher hyphae number was usually detected compared with the corresponding tissues in the resistant cultivar, indicating that fungal development was restricted in wheat leaves of the resistant cultivar. The structural defence reactions, such as formation of cell wall apposition, collar or papillae, and encasement of haustorium were essentially more pronounced in the infected wheat leaves of the resistant cultivar than in the susceptible one. Sometimes, in the wheat leaves of the incompatible combination the typical papillae of large size, detected in the host cell subjacent to the penetration site of the haustorial mother cell, stopped the pathogen's further development. Immuno-gold studies demonstrated the presence of callose in the collars or

papillae, cell wall appositions and encasements formed in *P. striiformis*-infected wheat leaves. Immuno-gold localization of lignin revealed a markedly higher labelling density in host cell walls of the infected wheat leaves of the resistant cultivar than in the cell walls of the infected wheat leaves of the susceptible wheat cultivar. These findings indicated that lignin accumulation in the infected wheat leaves may play an important role in resistance to the spreading of the pathogen in the host tissues. Two antisera raised against acidic chitinase and acidic β-1,3-glucanase were used to investigate the subcellular localization of the two enzymes in the compatible and incompatible interactions between wheat and *P. striiformis*. The studies demonstrated that the labelling patterns for both enzymes were very similar in the uninoculated healthy and the infected wheat leaves. The enzymes were localized mainly in the host cell walls, while no labelling was observed in cytoplasm and organelles of the host cells. However, the accumulation of the two enzymes in the infected wheat leaves differed markedly between resistant and susceptible wheat cultivars. The labelling densities for the two enzymes in the infected leaves of the susceptible cultivar increased slightly in comparison with the uninoculated healthy leaves, whereas significantly higher labelling densities of chitinase and β-1,3-glucanase were found in the infected leaves of the resistant cultivar compared with the uninoculated healthy leaves. Furthermore, the labelling of chitinase and β-1,3-glucanase also occurred over the extrahaustorial matrix and the fungal cell walls in the infected wheat leaves. The extrahaustorial matrix and the hyphal cell walls in the infected leaves of the resistant cultivar usually showed a higher density of the labelling than those in the susceptible cultivar. These finding indicated that chitinase and β-1,3-glucanase accumulation have potentially a role in the defence reactions in the incompatibility interaction between wheat and *P. striiformis.*

Mining genes for resistance to yellow rust (*Puccinia striiformis* f.sp. *tritici*)

A. Yahyaoui, A. Amri, M. Naimi, J. Konopka and S. Rajaram

ICARDA, Aleppo, Syria

Broad genetic diversity for biotic stress resistance is critical to stabilize wheat production. In the past, international germplasm exchange has been the determining factor for realizing large increases in yield potential and ensuring yield stability of wheat in developing countries. Marked increases in yield potential are only possible through the exploitation of wheat genetic diversity. Identification of resistance sources among wild wheat relatives would allow

the maintenance of genetic variability and hence reduce the impact of biotic and abiotic stresses. Significant differences for resistance to yellow rust were observed among and between *Aegilops* and *Triticum* species. The evidence is that adequate levels of resistance could be obtained with a few additive genes each of small to moderate effect. Modern plant breeding methodologies, including marker-assisted selection, are useful in the exploitation and utilization of these genes in wheat improvement. In this paper, we describe the role of genes from *Aegilops* and *Triticum* species for improved wheat production in relation to disease resistance and yield potential.

Agronomic performance of yellow rust-resistant winter wheat germplasm in Central and West Asia

A. Morgounov,[1] B. Akın,[1] L. Cetin,[2] Y. Kaya,[3] M. Keser,[4] Z. Mert[2] and R.C. Sharma[5]

1. CIMMYT, Ankara, Turkey; 2. Central Field Crop Research Institute, Yenimahalle, Ankara, Turkey; 3. Bahri Dagdas International Agricultural Research Institute, Konya, Turkey; 4. ICARDA, Ankara, Turkey; 5. ICARDA, Tashkent, Uzbekistan

The International Winter Wheat Improvement Programme (IWWIP) (www.iwwip.org) is a joint project of the Ministry of Agriculture and Rural Affairs of Turkey, CIMMYT and ICARDA. The programme, established more than 20 years ago, aims to develop winter wheat germplasm, suitable for Central and West Asia, with broad adaptation and resistance to prevailing biotic stresses. IWWIP also plays a key role in facilitating global germplasm exchange among winter wheat breeding programmes. The germplasm developed by IWWIP, as well as the material received from co-operators, is distributed to more than 130 collaborators in 50 countries through the Facultative and Winter Wheat Observation Nursery (FAWWON) and the International Winter Wheat Yield Trial (IWWYT). By 2009, 40 cultivars originating from IWWIP germplasm had been released in 12 countries of the region, sown on an estimated of 1.5 million hectare. Breeding for resistance to yellow rust is a high priority for IWWIP since the pathogen represents a major biotic threat in the region. The breeding methodology is based on crosses of broadly adapted parents with resistance to yellow rust. The segregating populations in F_2-F_5 are subjected to rust screening under both natural and artificial inoculation at several hot-spots in Turkey. The Preliminary Yield Trial lines, originating from F_6 Head Rows, are planted at several locations in Turkey and Syria for evaluation of agronomic performance and disease resistance, including to yellow rust. The key sites for yellow rust evaluation and screening are Haymana near Ankara, where consistently high levels of

infection are obtained through artificial inoculation, and Aleppo, Syria, under natural infection. The resistant germplasm meeting agronomic performance criteria is distributed to co-operators regionally and globally. The yield and disease performance data have been analysed for the last five years, demonstrating availability of superior germplasm with good performance in individual countries and across environments. The best performing lines from the IWWYT for Semi-Arid environments were JI5418/Maras, YE2453//PPBB68/CHRC, F130-L-1-12/LAGOS and Tr.Dur/Bez/3/2*Yub. /P49//Akht./6/SN64//Ske/2*Ane/3/SX/4/Bez/5/Jun/7/Bonito. The best performing lines identified through testing of the IWWYT for irrigated conditions were ID800994.W/Falke, Agri/Nac//Attila, ID800994W/Vee //F900K/3/Pony/Opata, AU//YT542/N10B/3/II8260/4/JI/Hys/5/Yunnat Odesskiy/6/KS82W409/Spn and F130-L-1-12/MV12. The germplasm identified through international testing is recommended for utilization as parental material as well as for direct testing and possible submission as new cultivars providing proof of their competitiveness with the commonly grown cultivars.

Progress in yellow rust resistance over time in derived winter and facultative wheat lines selected at Tel-Hadya, Syria

M. Mosaad,[1] O. Abdalla,[2] A. Yahayoui,[2] A. Morgounov,[3] M. Keser[4] and B. Akın[3]

1. FCR, ARC, Egypt; 2. ICARDA, Aleppo, Syria; 3. CIMMYT International, Ankara, Turkey; 4. ICARDA International, Ankara, Turkey

Winter and facultative wheat cover about 16.4 million hectare in Central and West Asia and North Africa (CWANA). Yellow rust (YR), caused by the fungus *Puccinia striiformis* f.sp. *tritici*, is one of the most damaging diseases of winter and facultative wheat, and has continued to attract researcher's attention due to the associated yield losses in CWANA, which reach 30 to 60%. The development of wheat cultivars resistant to the disease leads to higher grain yield and reduced use of chemicals, thus benefiting human health and the environment. Through the International Winter Wheat Improvement Programme (IWWIP), a partnership between Turkey, CIMMYT, ICARDA and NARS in the CWANA region, efforts have increased toward development of resistant wheat germplasm. Multi-disciplinary teams of scientists regularly conduct artificial inoculation in the field to screen germplasm for YR resistance at Tel Hadya, Syria. The results of both PYT-A&B (targeted for irrigated and semi-arid conditions) showed that the frequency of YR susceptible lines in all

nurseries has decreased, while the frequency of YR resistance due to major and minor genes increased. Also the frequency of YR resistant germplasm improved from 2001 to 2006 in AYT-IRR and AYT-SA. Combined results allow identification of germplasm with a broad spectrum of resistance. This strategy has significantly increased YR resistance levels in germplasm developed by IWWIP. Genetic stocks with YR resistance have been developed, used in crossing programmes, and been made available to NARS partners.

Genetic diversity of *Aegilops* L. in Tajikistan

F. Nasyrova, S. Naimov and Kh. Khurmatov

Institute of Plant Physiology and Genetics, Tajik Academy of Sciences, Dushanbe, Tajikistan

The analysis of genetic diversity is one of the basic approaches for the identification of gene resources. In recent years, attention has been given to the introgression of wild cereal resistance genes. The aim of the transmission of these genes to cultivated crops was to increase plant adaptation to harsh environmental conditions. Special attention has been given to the incorporation in agricultural crops of genes for resistance or tolerance to biotic and abiotic stresses. The genus *Aegilops* L. has attracted the attention of researchers as prospective genetic sources, and Tajikistan can be considered a unique natural reserve of diversity for the genus. The geographical situation of Tajikistan, with its typical soil and climatic conditions and a number of extreme factors (temperature differences, high altitude areas, drought, soil salinity, etc.), has promoted the genesis of diverse species of *Aegilops* L. and wheat landraces. Some species are adapted to hot and salt conditions; others are drought tolerant. The moderate climatic conditions, acting as a selective filter, have promoted the preservation and the distribution of the most adapted biotypes. With the purpose of studying the diversity of *Aegilops* species available in various climatic conditions of Tajikistan, collections were made in the mountains of the Gissar, Turkistan and Zeravshan ranges and valleys in the southern areas of the country. It was found that in the territory of Tajikistan, the most widely distributed species of *Aegilops* are: *Ae. tauschii, Ae. triuncialis, Ae. cylindrica* and *Ae. crassa.* The large range of types found within species testifies to the existence of gene variability that has enabled these species to adapt to diverse adverse factors such as drought and soil salinity, and to have an increased immunity to diseases. Each of these four *Aegilops* species has its limit of distribution: *Ae. crassa* is found from 400 to 550 masl; A*e. triuncialis* grows in northern and southern Tajikistan up to

2000 masl; *Ae. cylindrica* is located in middle highlands and valleys up to 1800 masl; and *Ae. tauschii* is distributed everywhere from 360 to 2000 masl.

The genus *Aegilops* is closely related to the genus *Triticum*, and its value as a source of genetic improvement of wheat is well documented. The diploid *Ae. tauschii* is the D-genome donor to hexaploid wheat, *Triticum aestivum* (AABBDD). The level of genetic variation in the D genome of *Ae. tauschii* is extensive. *Ae. tauschii* contains more genetic variability for diseases and insect resistance, isozymes, and seed storage protein than the D genome of *T. aestivum.* Microsatellite analysis of *Ae. tauschii* germplasm has been studied by estimating the genetic relation between 113 accessions from the genebank collection at IPK, Gatersleben, Germany. Microsatellite markers developed from *T. aestivum* and *Ae. tauschii* sequences showed a high level of polymorphism. All accessions from various regions could be distinguished and clustered according to their taxonomic classification and their geographical distribution. *Ae cylindrica* (genome CD) is one of the wild wheat species that could serve as a genetic resource for resistance against the rusts. To use *Ae. cylindrica* efficiently in breeding programmes, detailed knowledge of homoeology between this wild species and hexaploid wheat would be helpful. *Ae. triuncialis* (genome UC) is another wild wheat species that is a potential source of resistance to yellow rust.

Improvement of drought tolerant winter and facultative wheat promising lines resistant to yellow and stem rusts (Ug99)

S. Mahfoozi and F. Afshari

Department of Cereal Research, Seed and Plant Improvement Institute (SPII), Karaj, Islamic Republic of Iran

Yellow rust (*Puccinia striiformis* f.sp. *tritici*) and stem rust (*P. graminis*) diseases of wheat are significant threats to wheat production, even in drought-stressed regions of Iran. Although research efforts have effectively reduced crop damage, rust populations continue to evolve due to changes in the environment and the wheat production system in the region. Pathogenic variation is the underlying reason for the elusiveness of rust resistance. A new yellow rust race (*166E134A+, Yr27+*) spread widely in Iran in 2006/07 and caused damage to most wheat cultivars grown. For stem rust epidemics, an emerging new race (*Ug99*) in Africa and its spread to neighbouring countries such as Yemen (2006) and Iran (2007) is also a big threat for wheat production.

Breeding for qualitative resistance is a widely adopted method. This paper introduces seven promising lines of drought-tolerant, stem and yellow rusts-resistant and high yielding bread wheat. Two sets of wheat material, including 44 F_3 segregating populations and 100 drought-tolerant high yielding lines received from ICARDA were evaluated in Early Generation tests and an Advanced Yield Trial, respectively, at Seed and Plant Improvement Institute (SPII), Karaj, Iran, during the 2003/04 cropping season in two sets of experiments.

In the first set, the 44 F_3 segregating populations were planted under mist conditions and the selected bulk method was used to handle the F_3 generation. Selected plants from the segregating populations were planted under terminal drought stress (TDS) conditions to assess their drought tolerance through to the F_6 generation. Selected pure lines were then tested for grain yield in Regional Preliminary Yield Trials at Karaj (temperate zone) and Ardabil stations (cold zone) as the F_7 generation in 2007/08. The selected lines were then sent to Kenya for evaluation of their reaction to the aggressive new stem rust race (*Ug99*). Data received from Kenya showed resistance to *Ug99* in four selected lines with pedigrees 474S10-1/Bolero/3/Tirchmir 1/LCO//Sabalan; 130L1.11//F35.70/MO73/4/YMH/TOB//MCD/3/Lira/5/Tirchmir 1/LCO//Sabalan; Skauz/4/TJB916.46/CB306//2*MHB/3/BUC/5/Tirchmir 1/LCO//Sabalan; and Sabalan/KINACI97. The selected lines showed an acceptable level of resistance to yellow rust race 166E134A+. Determination of yield stability was carried out using a non-parametric ranking statistic method, and results showed that these four lines with good resistance to Ug99 and 166E134A+, *Yr27*+ races also had yield superior to the check cultivars.

In the second set of experiments, 100 advanced lines were planted in an alpha lattice design Advanced Yield Trial under TDS conditions and relevant agronomic and morphological traits, grain yield and reactions to rusts were recorded. Selected lines were evaluated for rust resistance in several hot-spots over three cropping seasons and evaluated for grain yield stability and adaptability on four agricultural research stations for two years. Considering both the recorded stem rust data from Kenya, and yellow rust data from hot-spot sites in Iran, and based on grain yield, five superior drought-tolerant lines were selected from this trial. The lines Bkt/Zhong; OK82282//BOW/NKT/3/ SARDARI-HD 75; SARDARI-HD 93/6/SN64//SKE/ 2*ANE/3/SX/4/ were resistant to the 166E134A+, *Yr27* yellow rust race, but were susceptible to Ug99. Although the line with pedigree of AGRI/BJY//VEE/3/PRINIA was moderately-resistant to Ug99, it showed high susceptibility (90S) to a new yellow rust race. The new line (SARDARI-HD83//LINFEN875072/KAUZ) was resistant to both stem rust (Ug99) and yellow rust (166E134A+, *Yr27*+) with high yield under both irrigated and TDS conditions.

Reaction of winter facultative wheat to yellow rust in Turkey and Syria

M. Keser,[1] A. Morgounov,[2] B. Akın,[2] Y. Kaya,[3] Z. Mert,[4] S. Rajaram[5] and N. Kumarse[5]

1. ICARDA, Ankara, Turkey; 2. CIMMYT, Ankara, Turkey; 3. BDIARI, Ankara, Turkey; 4. RIFC, Ankara, Turkey; 5. ICARDA, Aleppo, Syria

Wheat is the major crop in the Central and West Asia and North Africa (CWANA) region, and the main disease is yellow rust (YR). The International Winter Wheat Improvement Programme (IWWIP) is a joint programme of the Government of Turkey, CIMMYT and ICARDA that aims to develop material to cope with biotic and abiotic stresses prevalent in CWANA. The material has been evaluated for YR reaction in Ankara, Turkey, and Aleppo, Syria, under artificial inoculation conditions in order to select material resistant at both locations. The Preliminary Yield Trial (PYT) (1573 entries, including checks) and Winter Facultative Crossing Block (CBWF) were planted in both locations. CBWF had 295 entries that included genotypes coming not only from IWWIP but also from various breeding programmes with wide genotypic diversity. They were both inoculated three times with the YR populations collected from the same location in the previous year. Inoculation times reflected both crop growth stage (tillering, booting and heading) and climatic conditions. Comparisons were based on the reactions to YR in both locations. Resistance and susceptibility of most of the material was the same in both locations, indicating that the YR populations were basically the same or resistance genes are the same. However, there was some material resistant in Ankara but susceptible in Aleppo, and vice versa. There were also some genotypes showing different degrees of resistance or susceptibility between the locations. These results indicate that even though the YR populations are mostly similar, there are also differences, although slight. Some genotypes had very early first YR symptoms, and though most of them showed very high susceptibility, some had low YR severity in later growth stages. Sets from this material have been selected for further evaluation.

Influence of yellow rust on photosynthesis indices of wheat

E.R. Ibragimov and A.A. Zamanov

Scientific Research Station of Farming, Baku, Azerbaijan

Yellow rust is an important disease causing substantial economic loss in Azerbaijan. Sustainable management of yellow rust is a key strategy for improving wheat yield in the country. In order to manage this disease, better understanding is needed of the mechanisms of damage caused by yellow rust to the physiology of the wheat plant. The yellow rust pathogen causes morphological and physiological changes in wheat plants, which results in yield reductions. A study was conducted to determine the role of yellow rust on the physiology of four wheat cultivars—Ekinci 84, Gaymetli, Kirmizygul and Azemetli 9—differing in their levels of yellow rust resistance. The experiment was conducted under natural infection challenge from yellow rust. To determine the effect of disease, half of the experimental plots were sprayed with 25% Tilt to control yellow rust. Photosynthesis indices were measured from heading to milk stage of wheat plants, using an infrared gas analyser. The amount of CO_2 was measured in leaf tissues. Yellow rust appeared at heading stage in susceptible varieties. The assimilated CO_2 levels reached 9–14, 22–28, 31–39 and 43–45% at heading, flowering, grain formation and milk stages, respectively. There were large genotypic differences among the cultivars for photosynthesis indicators. Different levels of infection resulted in yield reductions from 5 to 15%. The results indicated that the influence of yellow rust on wheat productivity was greater than brown rust under Azerbaijan conditions, because yellow rust damage lasted longer on the crop than brown rust. The findings of this study are important for developing a wheat yellow rust management strategy.

Yellow rust in the south of Ukraine and resistance of wheat varieties

O. Babayants, L. Babayants and N. Chusovitina

Plant Breeding and Genetics Institute, National Centre of Seed and Cultivar Investigation, Odessa, Ukraine.

Yellow rust (*Puccinia striiformis*) in the Steppe region of Ukraine is a highly harmful disease and potentially hazardous to susceptible varieties of wheat. In the pathogen population, the races OEO, 6EO and 6E16 were prevailing and accompanied by races 6E4, 6E17, 6E20, 7EO and 7E16. In 2009 the resistance to the pathogen of 660 domestic and foreign wheat varieties was studied in an artificially infected field nursery. Varieties showing high resistance to the disease (absence of disease symptoms) were: Dobirna, Farandole, Favorytka, Kiriia, Kharus, Khersons`ka 99, Kolumbiia, Kolos Myronivschyny, Krasnodarskaya 99, Kyivs'ka 7, Kyivs'ka 8, Lybid', Myrkhad, Myronivs'ka 65, Myronivs'ka 66, Nela, Pereiaslavka, Perlyna Odes'ka, Pyvna, Polis'ka 90, Renan, Saskiia, Snizhana, Vdala, Vesta, Vinnychanka, Volodarka and Zolotokosa of Ukrainian origin; Akteur, CRWW 0708#1, CRWW 0708#2, CRWW 0708#3, CRWW 0708#4 and CRWW 0708#5 from Germany; and SG-S316-06, SG-U3007, SG-RUH-26, ST388-07 and ST-518-07 from the Czech Republic. Disease severity reached between 90 and 100% on susceptible cultivars. The varieties with genes *Yr3*c, *Yr5*, *Yr9*, *Yr10*, *Yr15* and *Yr17* were highly resistant.

Race composition and effective resistance genes to yellow rust in Azerbaijan

A.M. Abdullayev, J.M. Talai, E.R. Ibragimov and S.M. Mammadova

Azerbaijan Research Institute of Agriculture

Yellow rust is one of the most important factors limiting wheat productivity in Azerbaijan, causing heavy losses. Heavy epidemics of yellow rust led to yield losses of 28 to 60% in wheat, depending on the susceptibility the commercially grown cultivars and the level of challenge. In addition to yield loss, yellow rust also affects the quality of the grain. The occurrence of yellow rust increased in Azerbaijan between 1995 and 2000, attributed to the introduction of highly susceptible cultivars. For effective control of yellow rust, it is important to determine the race composition of the pathogen and to identify effective genes for resistance to be incorporated in breeding programmes for wheat. For this purpose, we conducted field surveys in various regions of Azerbaijan. Infected leaf samples were collected for race analysis. The collected samples were analysed for their virulence spectrum on *Yr* differentials. The race analysis of the samples revealed the presence of yellow rust races 70E6, 6E6, 6E2, 14E142, 22E6, 134E134, 134E150, 2E0 and 6E0. Using World and European differential sets, it was found that only four differentials were totally effective against all yellow rust races detected in Azerbaijan. These differentials were: Chinese 166 (*Yr1*), Strubes Dickopf (*YrSD*), *Triticum spelta* var. *album* (*Yr5*) and Spaldings Prolific (*YrSP*). Therefore the genes carried by these differentials are effective in Azerbaijan. Few differentials were susceptible to only one race. These differentials were Vilmorin 23 (*Yr3*) susceptible to 14E142; Moro (*Yr10*) susceptible to 22E6; Suwon 92×Omar (*YrSU*) susceptible to 70E6; Nord Desprez (*YrND*) susceptible to 14E142; and Compair (*Yr9-18*), susceptible to 134E150. Two differentials were susceptible to two races and immune to the rest: Clement (*Yr2*-9 +) and Hybrid 46 (*Yr4*). Finally, it is necessary to note that the genes *Yr2*, *Yr6*, *Yr7*, *Yr22* and *Yr23* were not effective genes for the country.

Study of diverse winter wheat germplasm for resistance to yellow rust in severe epidemics in Uzbekistan

S. Alikulov,[1] A. Amanov,[1] Z. Ziyaev,[1] Z. Khalikulov[2] and R.C. Sharma[2]

1. Uzbek Research Institute of Plant Industry, Tashkent, Uzbekistan; 2. ICARDA, Central Asia and the Caucasus Regional Programme, Tashkent, Uzbekistan

Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, is a serious disease constraint on successful wheat (*Triticum aestivum* L.) cultivation in Central Asia. In the past 20 years, Uzbekistan has often experienced more severe epidemics of yellow rust than other central Asian countries. This study was conducted to examine sources of resistance among diverse winter wheat germplasm in severe epidemics of yellow rust that swept through a large part Uzbekistan during February to May 2009. Continual precipitation during late winter continuing through the spring months created highly favourable conditions for development of a yellow rust epiphytotic; this also provided an opportunity to identify sources of resistance to this disease. Several sets of wheat experiments, including advanced yield trials, screening nurseries and segregating materials, were evaluated under severe yellow rust epidemic conditions, as confirmed by the >80% disease severity on a number of commercial cultivars. The results show that among more than 20 cultivars under cultivation in Uzbekistan, most of them are susceptible to yellow rust. The major cultivars showing susceptibility to yellow rust include Kroshka, Polovchanka, Tanya, Kupava, Umanka and Pamyat, which together occupied 40% of the irrigated wheat area in Uzbekistan in 2009. The local cvs Saidaziz and Zamin 1 were moderately resistant. Among 195 genotypes tested in the 12th IWWYT-Irrigated, 11th IWWYT-Semi-Arid, 16th FAWWON-Irrigated and 16th FAWWON-Semi-Arid nurseries of winter and facultative wheat, approximately 40% of the genotypes showed a high level of resistance to yellow rust in Uzbekistan. Many yellow rust-resistant genotypes showed resistance to leaf rust as well. Based on agronomic performance of the yellow and leaf rusts-resistant material, a number of advanced breeding lines have been selected either to further evaluate their suitability as candidate cultivars or to use them in hybridization programmes. This yellow rust-resistant winter wheat germplasm could also be valuable for yellow rust research in other countries in Central Asia.

Breeding of winter wheat for resistance to yellow rust in Kazakhstan

A.T. Sarbayev and A. Kydyrov

Kazakh Scientific Research Institute of Husbandry and Plant Growing, Almalybak, Kazakhstan.

In Kazakhstan, the main area for yellow rust is in the south and south-east. Epidemics of yellow rust occur every 2 to 3 years. In the last decade, yellow rust epidemics developed in 2000, 2004, 2007 and 2009. Climatic conditions, gradual accumulation of inoculum, landscape features of mountainous and foothill zones and wide use of susceptible cultivars such as Karlygash, Steklovidnaya 24, Progress, Bogarnaya 56, Erithrospermum 350, Zhetisou and Opaks, all combined to facilitate rapid proximal spread and aggressive behaviour of yellow rust. Yield losses in these cultivars reached 35 to 45%. At the same time, yield losses in moderately susceptible cultivars such as Arap, Derbes, Sapaly, Almaly and Naz were only 5–10%. However, the cultivars of the first group occupy greater areas in comparison with the cultivars of the second group. To deal with this situation, it has been necessary to breed constantly for resistance to yellow rust. The main tasks of our research programme were the selection of resistant wheat cultivars from the world collection and from local breeding material; determination of effective genes for resistance; selection of parents carrying race-specific and non-race-specific resistances; and to cross between different parents. Thus, in our research, we screened 5000–7000 cultivars, lines and hybrids of winter wheat under artificial infection conditions on an annual basis, and 773 wheat samples tested and selected in our laboratory were added to the Republic Gene Pool Data Base. After quarantine verifications, the collection materials from the international breeding centers of CIMMYT and ICARDA were tested. Some lines expressed resistance to the three rusts of wheat. Among the collection material from Turkey, 4 entries expressing complex resistance were detected. They were CBRD//Milan/SHA7; Milan/SHA7/3/ALD/COC//URES; Milan/SHA7/5/NDNG9144//KAL/BB/3/Y/CO/4/CHIL; and Milan/SHA7/5NDNG9//KAL/BB/3/Y/CO/4/CHIL. The entries of the CWA-RTN nurseries were sown to evaluate the reaction of isogenic lines carrying *Yr* genes. It was found that the genes *Yr5*, *Yr9*, *Yr10*, *Yr15* and *Yr24* were effective against yellow rust. There were 310 lines and 62 hybrid combinations from the F_5 Oklahoma nursery. Among them, 215 lines from 43 hybrid combinations were shown to have complex resistance to yellow, brown and stem rusts. In the F_5, 10 hybrids were revealed as combinations having complex resistance to the rust species and covered smut.

Yellow rust epidemics and virulence change on wheat in the Himalayas of Nepal

S. Sharma,[1] R.C. Sharma,[2] E. Duveiller[3] and G. Otiz-Ferrara[4]

1. Plant Pathology Division, Nepal Agricultural Research Council, Khumaltar, Nepal; 2. ICARDA, Central Asia and the Caucasus Regional Programme, Tashkent, Uzbekistan; 3. CIMMYT, Global Wheat Programme, El Batan, Mexico; 4. CIMMYT, South Asia Regional Programme, Kathmandu, Nepal

Yellow rust, caused by *Puccinia striiformis* f.sp. *tritici*, is the most important disease of wheat (*Triticum aestivum* L.), affecting millions of resource-poor farmers in the hills and mountains of Nepal. Since the Himalayas of Nepal stretch over Indian hills and beyond, the yellow rust epidemics in Nepal could have consequences for a vast region in the Indian subcontinent. The most commonly identified pathotypes in the hills of Nepal include 7E150, 46S119 and 71E32, which were highly virulent on widely grown wheat cultivars Sonalika, Annapurna 1 and Nepal 297 in the hills in Nepal. There were severe epidemics of wheat yellow rust in the hills of Nepal during 2004, 2005 and 2007, which extended to the lowlands in 2008. The widely cultivated wheat cultivar Nepal 297 became highly susceptible due to occurrence of a new pathotype of yellow rust with virulence on *Yr27* and Suwon/Omar; this was identified as 71E32 as shown by the Australian differential sets. This new YR pathotype had virulence to *Yr1*, *Yr6*, *Yr7*, *Yr8*. *Yr27* and Suwon 92×Omar The isolates carried avirulence to *Yr5 Yr10*, *Yr15*, *Yr17*,*Yr24*, *Yr26* and *YrSP*. The gene *Yr27* protecting important germplasm from yellow rust in this region had high rust levels in disease-prone areas during 2005, 2006 and 2007 wheat seasons, and a change in virulence pattern of yellow rust was experienced. In this changed virulence scenario, Annapurna 1 and Kanti, carrying the *Yr9* gene and which were susceptible in the past, have been found resistant. In addition, other wheat cultivars in Nepal (Gautam, Pasang Lahmu and WK 1204) have also shown resistance in yellow rust hot-spots in the hills of Nepal. These findings could have a bearing on developing yellow rust-resistant wheat cultivars for Nepal and similar areas in South Asia.

Development of wheat stripe [yellow] rust in Georgia

Z. Sikharulidze and K. Natsarishvili

Institute of Plant Immunity, Kobuleti, Georgia

Disease surveys are useful means to provide information on the prevalent diseases of crops and their distribution in space according to their incidence and severity. Wheat fields were investigated by Institute of Plant Immunity (IPI) staff in different geographical zones of Georgia at every critical stage of plant disease development. In 2009, rust researchers participated in the Global Rust Monitoring System. The location of the fields investigated (latitude, longitude) and elevation were determined by GPS. The elevation of investigated fields differed considerably from each other, from 427 masl (Marneuli region) to 1744 masl (Akhalkalaki region). During May, June and July four expeditions were carried out in ten regions of five zones (Imeretis Maglobi, Kvemo Kartli, Shida Kartli, Samtskhe and Dzhavakheti) and 40 wheat fields were investigated. Incidence and severity of stripe [yellow] rust were determined in farmer fields and private plots (roadsides). Mainly cv. Bezostaya 1 was planted. According to the survey results, stripe rust in comparison with other rust species was the most widely distributed disease. It was distributed in the nearly all zones. In Kvemo Kartli and Shida Kartli zones, stripe rust had reached moderate severity by the end of May, mainly on cv. Bezostaya 1, when plants were in early milk ripe stage. High incidence and severity of the disease was reached in the irrigated Marneuli region, differing from Khashuri and Tetritskharo rainfed regions, where severity was low or medium. Later, stripe rust was recorded in Samtskhe and Dzhavakheti zones, which are located above the other zones and consequently disease development was later in these zones. In Akhaltsikhe (Samtskhe) and Akhalkalaki (Dzhavakheti) regions, stripe rust occurred at the end of July and its incidence varied from traces to 80%. High severity of stripe rust was found on cvs Bezostaya 1 and Lomtagora. Armenian cv. Armenikum, which was sown in farm fields in Akhalkalaki region, was not infected by stripe rust.

Wheat yellow rust situation in Algeria during the last decade

A. Benbelkacem, C. Djenadi and M. Laddada

Institut National de la Recherche Agronomique d'Algérie, El-Khroub, Algeria

There are many biotic constraints to wheat production in Algeria. Rusts, and in particular yellow rust (*Puccinia striiformis*), are among the most prevalent diseases that occur mostly all over the northern part of the country. Yellow (stripe) rust appeared as an epidemic in 2004, affecting more than 600 000 ha of bread wheat with a severity exceeding 70%. The seed yields from affected fields of a susceptible variety ranged from 0.5 to 5.2 q/ha, and while resistant cultivars yielded from 32 to 48 q/ha. Overall yield loss was estimated at 65%, representing around 7.8 million quintals. Application of fungicides has now become a common practice in many farmer fields. Yellow rust has become sporadic due the exploitation of effective resistance genes in different forms and combinations that came from CIMMYT material. Durable resistance was probably due to many genes, such *Yr18*, *Yr9*, *Yr27* and *Yr1*. This material was extensively used in our breeding programmes, but farmers are not using these cultivars for many reasons. Recently, we saw a spread of a new virulence for some genes and this is a typical example of the potential risk from wheat rusts.

Durum wheat varieties showed better resistance than bread wheat and barley. Yellow rust is still present every year sporadically in most humid areas.

Virulence of yellow rust and resistance of registered wheat varieties in Turkey in the period 2000–2008

L. Çetin, Z. Mert, K. Akan, F. Düşünceli and S. Yazar

Central Research Institute for Field Crops, Ankara, Turkey

Wheat is the most important cereal crop in Turkey and yellow rust *(Puccinia striiformis* f.sp. *tritici*) is one of the major biotic stresses affecting wheat yield worldwide. Yellow rust causes significant losses especially in seasons with cool and wet spring conditions through decreasing photosynthesis capacity and grain weight. In this study, the reactions to yellow rust of some varieties registered by Central Research Institute for Field Crops (CRIFC) were determined in seven growing seasons between 2000 and 2008, in Ankara

conditions. During this period, no epidemic of yellow rust developed under natural conditions. Thus, all testing was conducted under artificial inoculation. Each year, the plants were inoculated by a bulk of yellow rust uredospores with a virulence spectrum against *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr2+*, *YrSD* and *YrA*. According to the results, the majority of registered bread and durum wheat varieties and candidates were susceptible to yellow rust. However, some recently developed varieties, namely Yakar 99 and Demir 2000, were immune to the disease, while other lines, such as Ikizce 96, Mızrak, Aksel 2000, Bayraktar 2000, and Atlı 2002, were resistant, with maximum Coefficient of Infection (CI) scores <20.

Yellow rust pathotypes on barley and triticale in Kazakhstan

Sh.S. Rsaliyev,[1] Zh.S. Tileubayeva[2], and Yu.I. Zelenskiy[2]

1. Research Institute for Biological Safety Problems, Kazakhstan; 2. CIMMYT, Kazakhstan

In Kazakhstan, yellow rust develops on leaves of some barley and triticale varieties. For instance, Steploe 1, a spring barley variety, is annually affected by the wheat form of yellow rust (*Puccinia striiformis* f.sp. *tritici*), while cvs Ak Zhol, Arna, Assem, Shynar and Yassy are absolutely resistant. In some years signs of the disease were noted on cvs Mereke 150 and Yubileiniy 100 (Kazakh Institute of Farming). In 2009, severe yellow rust was observed on barley at Krasnovodopad Experimental Station. Some triticale varieties were also affected by the wheat form of yellow rust. In experiments aimed at evaluating winter triticale for resistance to yellow rust, uredia appeared on leaves of some susceptible varieties, but disease progress rate was low and mean severity was 10 to 30%. Similar infection development was observed on cvs Avangard and Taza triticale. Spores were sampled from affected barley and triticale hosts and pathotyped in isolation rooms of the greenhouse. The research resulted in differentiation of yellow rust pathotype 7E156 from Altaiskoye 2 and Kurskoye Stepnoye triticale; 79E143 and 15E159 pathotypes from Avangard triticale; and pathotype 47E143 from Taza triticale. Pathotype 7E159 of *P. striiformis* f.sp. *tritici* was isolated from Steploe 1 barley. It should be noted that yellow rust pathotypes of narrow specialization only for barley and triticale were not detected. All pathotypes isolated from these cultivars are widespread on susceptible wheat plants. Therefore, pathotypes 7E156, 7E159, 15E159, 47E143 and 79E143 of *P. striiformis* f.sp. *tritici*, isolated from barley and triticale hosts, are classified as universal pathotypes that affect susceptible cereals.

Inheritance of yellow rust resistance in wheat cultivar Sönmez

K. Akan,[1] Z. Mert,[1], L. Çetin,[1] F. Düşünceli,[1], N. Bolat,[2] M. Çakmak[2] and S. Belen[2]

1. Central Research Institute for Field Crops, Ankara, Turkey;
2. Anatolian Agricultural Research Institute, Eskisehir, Turkey

Yellow rust, caused by the fungus *Puccinia striiformis* f.sp. *tritici,* is one of the most damaging diseases affecting yield and quality in wheat in Turkey and worldwide. Among all the control measures of yellow rust, genetic resistance is the most economical and practical mean of control, causing no additional cost to the farmer. Use of genetic resistance and development of resistant cultivars are very important to control the disease. Additionally, genetic resistance is an environmentally safe control measure. The most widely utilized resistance mechanism for yellow rust is a race-specific type (generally under mono- or polygenic control). At present, more than 30 resistance genes have been described. Sönmez 2001 is a wheat cultivar with resistance to yellow rust that was released for the central Anatolia region. The objective of the present study was to determine the inheritance of resistance in cv. Sönmez 2001 bread wheat. Resistances at adult and seedling stages of segregating F_2 plants obtained from a Sönmez 2001 × Aytın 98 cross were determined under artificial disease conditions produced using appropriate inoculation methods in the field and greenhouse. For the adult plant stage test, the F_2 plants and the parents were sown by hand in rows 2-m long in October 2006. The F_2 plants for the seedling stage test, the parents and the susceptible checks were sown in small pots and kept in the greenhouse until scored in March 2007. A yellow rust population virulent on *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr2+*, *YrSD* and *YrA* was used for inoculation of both seedling and adult plants. Analysis using a Chi-squared test confirmed that resistance is controlled by a minor gene in cv. Sönmez 2001.

Inheritance of resistance to 4E0A+ race of stripe [yellow] rust at the seedling stage

M. Taherian and M. Armin

Islamic Azad University of Sabzevar, Islamic Republic of Iran

To study the inheritance of stripe [yellow] rust resistance and to estimate its genetic components in wheat, F_1, F_2, BC_1 and BC_2 generations derived from crosses between two resistant cultivars and one susceptible cultivar (Falat), along with parental lines, were evaluated in the greenhouse in a randomized complete block design with three replications. The plant materials were inoculated with pathotype 4E0A+ of stripe rust. In all plants, resistance parameters, including latent period and infection type, were recorded after appearance of pustules on leaves. Generational mean analysis revealed that additive, dominance and epistasis play major roles in extending the latent period and ameliorating the infection type. In addition to the significant additive effect, the dominant gene effect was the most important in controlling these two characteristics. Broad sense heritability and narrow sense heritability estimates for latent period were 0.65 and 0.54. For infection types, these parameters were estimated as 0.57 and 0.25, respectively.

Molecular mapping of a new gene for resistance to stripe [yellow] rust in durum wheat PI 480148 and gene transfer into common wheat

L. Xu,[1,2] P. Cheng,[1] M. Wang,[1] Z. Kang,[2] S. Hulbert[1] and X. Chen[1,3]

1. Department of Plant Pathology, Washington State University, Pullman, USA;
2. College of Plant Protection, Northwest A&F University, Yangling, China;
3. USDA-ARS, Wheat Genetics, Quality, Physiology and Disease Research Unit, Pullman, WA, USA

Stripe [yellow] rust, caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*), is one of the most damaging diseases of wheat worldwide. It is essential to identify new genes for effective resistance against the disease. Durum wheat germplasm has excellent resistance to stripe rust, but not many genes for resistance have been identified from durum wheat genotypes. Durum wheat PI 480148, originally from Ethiopia, was resistant in all seedling tests with several USA races under controlled greenhouse conditions and at multiple locations under natural

infection of the pathogen for four years. To map the resistance gene(s) in the genotype and transfer it into common wheat, a cross was made between PI 480148 and susceptible common wheat genotype Avocet Susceptible. Resistant F_3 plants with 42 chromosomes were selected through Feulgen-staining of root tip cells and testing with *Pst* races. When tested with *Pst*-100, the most predominant race in the USA for the last six years, 157 F_4 plants from a single F_3 hexaploid plant segregated into a 3:1 ratio for resistance vs susceptible plants, which identified a single dominant gene from PI 480148. Using the $F_{3:4}$ population and the resistance gene-analogue polymorphism (RGAP) and simple sequence repeat (SSR) markers, the gene was mapped to the long arm of chromosome 2B. An RGAP marker and an SSR marker (*Xwmc441*) were closely linked to the resistance gene with a genetic distance of 2.7 and 5.6 cM, respectively. The effective resistance of the gene to an Australian isolate virulent to *Yr5*, which is located on 2BL and resistant to all *Pst* races in the USA so far, indicated that the gene is different from *Yr5* and should be a new and useful gene for resistance to stripe rust. Resistant common wheat lines with plant types similar to Avocet Susceptible were selected for use in breeding programmes to develop common wheat cultivars with the resistance gene.

Evaluation of germplasm for resistance to yellow rust in Ankara in the period 2000–2008

K. Akan, Z. Mert, L. Çetin and F. Düşünceli

Central Research Institute for Field Crops, Ankara, Turkey

Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is an important fungal disease of wheat. The disease caused significant economic losses in the Cukurova region in 1995. Losses were estimated at 500 000 t. Use of genetic resistance and development of resistant cultivars are very important to control the disease. In this respect, we evaluated the resistance of adult plants of genotypes from breeding programme against yellow rust under artificial inoculation in Ankara conditions during the period 2000–2008. The experiment was conducted at the Central Research Institute for Field Crops (CRIFC) in Ikizce-Haymana and Yenimahalle sites in Ankara, Turkey. Each genotype was planted as a single row 1-m long. The trial was sown in October each year. The experiment was conducted under natural conditions, supplemented by mist irrigation. Cvs Little Club, Michigan Amber, Türkmen, Gerek 79, Seri 82 and Gün 91 were sown around the experimental field. In addition, Little Club was sown after every 10 entries and used as control and susceptible check in the

trial. Yellow rust uredospores collected the previous year in Haymana were preserved in liquid nitrogen until a spore suspension was prepared with mineral oil (Soltrol 170). Uniform epidemics resulted from the artificial inoculations. Thus, disease severity of susceptible genotypes reached 90S to 100S at scoring time. Disease severity was first scored in June. A minimum of two readings were done and the highest score was used for selection of the genotypes. At adult plant stage, infection type (IT) of each entry was evaluated and percentage leaf area affected (disease severity) was also scored using the modified Cobb's scale. Then Coefficients of Infection (CI) were calculated by combining IT and disease severity. In total, 204 bread and 48 durum winter wheat genotypes were resistant to yellow rust. For spring wheat genotypes, 77 bread and 19 durum entries were resistant to yellow rust. Additionally, we found that 176 winter bread wheat genotypes were resistant to both yellow and leaf rust, 57 winter bread wheat genotypes were resistant to both bunt and yellow rust, and 80 winter bread wheat genotypes were resistant to both loose smut and yellow rust. Based on these results, we can use these genotypes as resistant germplasm for registration or crossing programmes.

Determination of yellow rust resistance in some International Winter Wheat Improvement Programme (IWWIP) nurseries in central Anatolia

Z. Mert,[1] K. Akan,[1] L. Çetin,[1] F. Düşünceli,[1] A. Morgunov,[2] M. Keser[3] and B. Akın[2]

1. Central Research Institute for Field Crops, Yenimahalle, Ankara, Turkey; 2. CIMMYT Office, Ankara, Turkey. 3. ICARDA Office, Ankara, Turkey

Yellow rust caused by *Puccinia striiformis* f.sp. *tritici* is one of the important diseases on cereal crops worldwide, causing yield and quality loss in wheat under epidemic conditions. Genetic resistance is the most economical and environmentally safe control measure, so use of genetic resistance and development of resistant cultivars are very important to control the disease. The International Winter Wheat Improvement Programme (IWWIP) main objective is to develop winter and facultative wheat germplasm for the Central and West Asia region. IWWIP also facilitates winter wheat germplasm exchange for the global breeding community. The purpose of the study was to determine the resistance at the adult plant stage of some genotypes from IWWIP against yellow rust under artificial epidemic conditions in Ankara in the 2007/08 growing season. The experiment was conducted at the Research Station of the Central Research Institute for Field Crops (CRIFC) in Haymana, Ankara. A total of 2156 wheat cultivar and lines were used in 15 nurseries. Each wheat cultivar or line was sown by hand in a row 1-m long in October 2007. Cv. Little

Club and other susceptible wheat cvs Michigan Amber, Türkmen, Gerek 79, Seri 82 and Gün 91 were sown around the experimental field as controls and susceptible checks in the trial. Yellow rust uredospores collected the previous year from Haymana station had been preserved in liquid nitrogen (-196°C). A spore suspension was prepared with mineral oil (Soltrol 170) and sprayed on the plants. A modified Cobb's scale and Coefficient of Infection (CI) were used for evaluation. Uniform epidemic conditions were achieved. The first scoring was recorded on 20 June 2008, when the susceptible genotypes showed a 90S–100S score. At least two reading were done, and the highest scores were used for selection of the genotypes. 1284 (60%) of genotypes were immune. At the same time, 150 genotypes (7%) gave CI values of 1 to 5, and 327 lines (15%) had a CI value of 6 to 20.

Identification of winter wheat breeding lines and cultivars resistant to yellow rust in south-eastern Kazakhstan

G. Essenbekova

Institute of Plant Biology and Biotechnology, Almaty, Kazakhstan

Severe yellow rust *(Puccinia striiformis* f.sp. *tritici)* epidemics occurred on wheat a few times in the period from 1975 to 1995 in the mountain regions of south and south-east Kazakhstan and in Kyrgyzstan. However, severe disease development was frequent in the last few years. In the period 2000–2002, yellow rust reduced the production of bread wheat to 50–60%. The main objective of our work was to identify reliable donor sources for resistance to yellow rust and to find new wheat germplasm combining high yield, good end-use quality and resistance to the main diseases. As a result of this work, effective yellow rust-resistant genes and donors were identified and included in the breeding programmes for wheat improvement. The 23 donors with a high level of yellow rust resistance identified and the most advanced lines were tested as the last steps of the breeding process. Depending on disease pressure, reactions to yellow rust by the wheat material tested were variable. In 2007, with low disease occurrence, wheat commercial cvs Almaly, Arap, Kupava, Knyazhna, Adyr, Bezostaya 1, Umanka and Naz, and breeding lines BWKLDN 33, MK 3732–7thFAWWON, MK 3744 and MK 3832 were scored resistant. Moderate levels of disease severity were expressed on cvs Bermet (10MR) and Taza (10MS). Cultivars found susceptible were: Zhetisu (15S), Octyabrina (30S), Sharora (40S), Krasnovodopadskaya 25 (40S), Steklovidnaya 24 (50S), Karlygash (60S), Sanzar 8 (60S) and Avocet (80S). In 2009, because of an exceptional disease outbreak, most of the cultivars and

lines tested were severely attacked by stripe [yellow] rust: Bermet (100S), Taza (90S), Zhetisu (50S), Octyabrina (50S), Sharora (100S), Krasnovodopadskaya 25 (50S), Steklovidnaya 24 (90S), Karlygash (100S), Sanzar 8 (70S) and Avocet (100S). The lines that expressed moderate reactions in 2007 were fully susceptible. Under 2009 epidemic conditions, cvs Mereke and Tungish, and breeding lines BWKLDN 33, MK 3732-7thFAWWON and MK 3796 expressed high levels of resistance to stripe rust.

Resistance of winter soft wheat cultivars to yellow rust and effective resistance genes in southern Russia

G. Volkova, Y. Shumilov, L. Kovalenko and O. Babak

All-Russia Research Institute of Biological Plant Protection of the Russian Academy of Agricultural Sciences, Russia

Yellow rust, a damaging disease of wheat, has lately increased in occurrence in southern Russia. The disease is widely distributed worldwide. Its control has been based mainly on the use of resistant cultivars. Thus, the aim of our work was to characterize the types of resistance found in 44 winter wheat cultivars grown in southern Russia and elsewhere, and to identify effective genes for resistance. The criteria utilized for resistance evaluation under field conditions were the reaction type, the disease severity (%), the area under disease progress curve (AUDPC) and 1000-kernel weight loss. Our results indicate that 18 winter wheat cvs were in the group with race-specific resistance + adult plant resistance, including Amazonka, Veda and Viza; 26 winter wheat cvs were found to have race-non-specific (partial) yellow rust resistance; 16 cvs expressed high race-non-specific resistance; and 10 cvs were moderately resistant. The use of cvs Vita, Deviz and Delta, having a high level of non-specific resistance, and the moderately resistant cultivars Aksinit, Bat'ko and Garant in southern Russia is important, since yellow rust build up occurs in this region. The cultivation of such cultivars will reduce virulence accumulation in the pathogen population, decrease pathogen selection pressure and consequently minimize the risk of disease outbreak. The evaluation of the genes for resistance to yellow rust was conducted for three years. It was found that genes *Yr5*, *Yr10* and *YrSP*, expressing zero infection type, were effective during the three years of evaluation. The same results were obtained for genes *Yr8*, *Yr15*, *Yr17*, *Yr24*, *Yr26* and *Yr27*. These genes express infection types from 1 to 2. The effective genes should be recommended for the use in rust-resistant cultivar selection in southern Russia.

Selection of wheat cultivars for resistance to yellow rust in Uzbekistan

V.E. Khokhlacheva, B.A. Khasanov, R.M. Bajanova, S.K. Baboev and A.U. Mavjudova

Institute of Genetics and Plant Experimental Biology of AS Ruz, Uzbek Academy of Sciences, Kibray, Tashkent, Uzbekistan

Airstream circulation influences the spread of wheat yellow rust caused by *Puccinia striiformis* f.sp. *tritici* in Central Asia. In Uzbekistan, yellow rust epidemics occur every 3 to 5 years. The race composition of the yellow rust population has also been changing. The prevalent races are 0E0, 2E0, 5E0 and 160E16. The most rational method of control of yellow rust is the use of resistant cultivars. Thus, in our work, we evaluated the reactions to yellow rust of nine wheat cultivars and up to 100 lines in the laboratory and in the field. In the field, the nurseries were planted in different climatic areas of Uzbekistan. The results showed that 77 lines and varieties were resistant in the seedling stage and 51 lines and varieties were resistant in the adult stage. In the past, cvs Kroshka, Kupava, Knyagna, Polovchanka, Bozsuv 1, Emnbosh, Bayaut, Umanka and Ulugbek 600 were moderately resistant to yellow rust (5MR–10MR). In 2009, all commercial cultivars grown in Uzbekistan were severely damaged by yellow rust. This may indicate that the races of yellow rust have changed in Uzbekistan. Only one new variety of bread wheat, cv. Ravi, cultivated in a farmer's 3-ha field, was not damaged. This variety came from CIMMYT germplasm in 2001. The monitoring of yellow rust throughout Uzbekistan during the 2009 season showed that almost all commercial cultivars of bread wheat were damaged by yellow rust, with severity ranging from 50 to 100%. In some situations, fungicides were applied in the beginning of flowering stage, sometimes twice, but the disease re-appeared in many place This year, yellow rust has damaged soft wheat not only in irrigated fields but also in rainfed areas. In the screening conducted in 2009, we found that 24 new wheat cultivars were severely infected (40S–90S), 8 were moderately susceptible (5–10MS) and 18 were moderately resistant (5–15MR) to yellow rust. The screening of 3rd IYRTN-09 has shown that cultivars with (*Yr3*1+APR), (W; *Yr1*) or (S; *Yr6*+1) genes and Avocet single-gene lines with *YrA, Yr1*, *Yr6*, *Yr9*, *Yr18, Yr28, Yr31* and *YrCV* were ineffective against yellow rust. Avocet single-gene lines with *Yr5*, *Yr8*, *Yr10*, *Yr15*, *Yr17*, *Yr27* and *YrSP* were effective against the disease. These lines were scored from 5 to 30MR.

Detection and distribution of wheat yellow rust in north-eastern Syria and efficacy of some fungicides for rust control

O. Youssef,[1] O. Sulieman,[2] Y. Halim[1] and S. Sultan[1]

1. General Commission for Scientific Agricultural Research (GCSAR), AL Qamishli Agricultural Research Centre, Al Qamishli, Syria; 2. General Commission for Scientific Agricultural Research (GCSAR), Administration of Plant Protection Research, Douma, Damascus, Syria

Fields survey results of yellow rust on wheat in north-eastern Syria during three growing seasons (2006/07, 2007/08 and 2008/09) showed occurrence of the disease in some regions during the 2006/07 growing season. Incidence did not exceed 15% of the fields surveyed and the disease severity was relatively low, estimated at 10%. Yellow rust was not observed during the second season (2007/08); however, in 2008/09 the disease was observed in the irrigated areas, where incidence reached 80%; the severity varied from 20MS to 60S. The highest infection was observed in the Ras-Alain region on cultivar Sham 8. Results from chemical control for the disease in 2008/09 showed that two fungicides (Artia and Atmy) gave effective control of the disease. The average yellow rust severity was 15MS for Artia and 10MS for Atmy. Chemical control results showed an increase in kernel number per head and 1000-kernel weight (TKW). The highest yield (4.792 t/ha) was recorded following treatment with Artia. A yield of 4.57 t/ha was registered with Atmy, while the yield of the control treatment was 4.3 t/ha.

Yellow rust development features in south and south-east Kazakhstan. Yellow rust resistance of winter wheats carrying *Yr* genes

M Koishibayev[1] and M. Yessimbekova[2]

1. Kazakh Research Institute of Plant Protection and Quarantine; 2. Kazakh Research Institute of Farming and Crop Production

Yellow rust (YR) dissemination and development on winter wheat was monitored in the south and south-east of Kazakhstan in 2006–2009. Disease development varied significantly across years depending on weather

conditions. In 2006 and 2008, due to dry conditions in April and May, the disease manifested at a late crop stage and developed weakly. In 2007 in Almaty Oblast at the milk stage, some winter wheat varieties in multi-location yield trials carried out by Agrosemconsult were susceptible at 50 to 75%. In the highland areas of Zhambyl Oblast, winter wheat (cv. Naz) and spring wheat (cv. Kazakhstanskaya 19) were weakly infected with yellow and brown rusts (5–10%) at the milk stage. Barley was characterized with moderate disease infection (10–25% or more).

YR spread significantly on winter wheat in South Kazakhstan Oblast in early May 2009. At the heading stage, disease dissemination was as high as 40–50%, with leaf damage often at 5–10%, and 10–25% in several cases. The second monitoring survey of winter wheats carried out one month later at the milk to milk and wax stage at Krasnovodopadskaya Breeding Station showed that cvs Yuzhnaya 12, Pamyat 47 and Krasnovodopadskaya 210 were susceptible, with infection as high as 75–100%. Demonstration yield trials conducted by the South-East Agricultural Research Institute suggested high susceptibility in cvs Zhetissu, Steklovidnaya 24 and Pamyat 47 (70–80%), while cv. Almaty, nominally yellow rust-resistant, was susceptible a rate of 40–60%. No yellow rust was identified on winter wheat at the flag leaf and early heading stages during disease monitoring in the Zhambyl foothill area. In the 2nd decade of June, at the milk stage, yellow rust manifested moderately at 25–50% on cvs Steklovidnaya 24 and Bogarnaya 56, and low disease levels were observed on cvs Bezostaya 1 and Naz. In Almaty Oblast, early symptoms of yellow rust were identified in the 3rd decade of May at the heading stage of winter wheat, with leaf damage of 1–5%. The disease dramatically progressed on cv. Bezostaya 1, reaching 75–100% leaf damage in the 3rd decade of June, at the milk stage.

Approximately 800 genotypes of winter wheat early generation (elite) and hybrid lines representing the following nurseries from near abroad and foreign countries were screened: WWEERYT; YET-IRR; EYT-SA; 2 ПОП ЦАЗ; 13 ПМП; 9th, 5th and 11th FAWWON; FWWYT 22; IW×SWSNL; RBWYT(SAA); and 3rd WDEERYT, as well as locally developed varieties. Wheat genotypes from a YRT nursery (116) as well as Central Asian varieties (80) were screened. A severe yellow rust infection was observed on experimental fields of Genetic Resources Department of the Farming and Crop Research and Production Centre (FCRPC) located in a lowland area. The most susceptible varieties were damaged at 50–75%, while cv. Morocco's infection level was 100%. Lines demonstrating resistance to yellow rust included Any 126, Mirbashir, Tarragui, Seri 82, Shiras, Pyshtaz, Kinai, Gun 91, Sultan 95, Sanzar, Polovchanka and Ulugbek 600. Group resistance to two types of rust (yellow and brown) was shown by cvs Pirchachin, Tarragi, Polovchanka, Noroeste, Ananuac 75, Super Ser# 2, Babax# 1, Super Kauz, Tonichi 85 and a number of complex wheat hybrids carrying slow-rusting genes. Winter wheats when planted in spring were characterized with high tillering and no rusts. At the milk stage, winter

wheat varieties and hybrid lines planted in multi-locational yield trials in Almaty Oblast by Agrosemconsult were screened. A number of genotypes (17 of 56) were resistant or infected insignificantly, including new cvs Almaly and Yegemen developed by FCRPC.

Effective YR resistance genes for winter wheat breeding were identified. Many genes were found to be highly effective under moderate infection challenge. Genes *YrA, Yr1, Yr6* and *YrA* proved to have low effectiveness.

Yellow rust in wheat in Azerbaijan

Fargana Alibakhshiyeva

FAO Project

Wheat as a main food crop plays an important role in food security in Azerbaijan. The area under wheat has increased during recent years. Wheat yield is below its potential due to several biotic and abiotic factors affecting growth and development of plants. Among biotic factors, yellow rust and leaf rust seriously damage wheat in the Caucasian countries, as well as in Azerbaijan. Yellow rust is a very dangerous disease that significantly reduces grain yield in both bread and durum wheat. Yellow rust of wheat is widespread in Azerbaijan under irrigated and rainfed conditions. Severe epidemics of yellow rust occur when the humidity is conducive. Serious damage from yellow rust in Azerbaijan has occurred in Calilabad, Gobustan and Terter regions. In these regions, yellow rust epidemics may reduce wheat yields by up to 80%. Field observations, monitoring and surveys conducted in the farmers' fields since 2007 have demonstrated that in Azerbaijan development of yellow rust starts in the beginning of March when wheat is in the booting stage, and the pathogen affects wheat until the flowering stage. Because of that, the farmers prefer early maturing and yellow rust-resistant wheat cultivars. Field observations showed that cvs Mirbashir 128, Aran, Bezostaya and Azametli 95 were resistant to yellow rust. The results of the surveys and investigations showed that maximum damage in 2007was 60%. In comparison with 2007, yellow rust in 2008 and 2009 was only 10%. An increasing tendency for epidemics of yellow rust has been observed in all the agro-ecological zones of Azerbaijan. While in 2008 humidity was low and weather conditions in April and May were very dry, in the spring of 2009 humidity was very high, and even resistant varieties have been affected by yellow rust.

Regulation of development of yellow rust of wheat using physiologically active substances

H. Kushiev

Gulistan State University, Uzbekistan

The study of biochemical processes in the interaction between pathogens and their hosts is important for understanding the mechanisms of resistance of plants to their pathogens. Having compared data on a number of tannin agents in healthy and diseased wheat plants, we drew a conclusion that tannin agents (phenolic compounds) and their accumulation in cell vegetative bodies play an important role in protection of plants against infections. In our investigation, we studied the production of phenolic compounds, particularly tannins, on cultivars of wheat susceptible and resistant to *Puccinia striiformis.* The quantity of tannins was similar for both susceptible and resistant cultivars before the appearance of external symptoms within the first phase of disease development. However, drastic changes occurred in tannin production after the appearance of external disease symptoms. Thus, the quantity of tannins in the susceptible plants stayed at the same level, while the quantity of tannin in the resistant plants doubled compared with the first phase of disease development. Considering these findings, we studied the effect of glycyrrhizine acid on rust development. The application of this acid inhibited the development of *Puccinia striiformis*. Copper salts of glycyrrhizine acids have stimulated the accumulation of tannin in cell vegetative bodies of wheat. These findings indicate that the development of *Puccinia striiformis* could be regulated using glycyrrhizine acids.

Artificial inoculation techniques in screening for resistance to yellow rust

A. Yahyaoui, M. Al Ahmed, Z. Alamdar, K. Nazari and M. Naimi

ICARDA, Aleppo, Syria

Screening for host resistance is one of the major activities undertaken by ICARDA wheat pathology and breeding programmes. Breeding nurseries are screened for yellow rust resistance under artificial inoculation in greenhouse and field conditions. Proper techniques to ensure adequate infection levels are important in the selection process to identify resistance to yellow rust. At ICARDA, all breeding nurseries are evaluated each year at seedling and adult growth stages in the greenhouse and under field conditions. Yellow rust inoculum from Syrian yellow rust populations is increased and maintained in the laboratory for inoculation. Single pustules are multiplied and used for race analysis. Inoculation with single races is conducted at seedling growth stages in a controlled environment for selected wheat germplasm. Mixed and single-spore cultures are vacuum dried and stored at -80°C for long-term storage or maintained in a refrigerator at 10°C for short-term storage (6–12 months). To ensure proper infection, stored spores are increased on the universal susceptible cv. Morocco, then used for field and greenhouse inoculations. Yellow rust inoculum is composed of prevalent races that occur in Syria and are used as bulk inoculum to eventually expose wheat genotypes to varied pathogen virulences.