Races of *Puccinia graminis* f. sp. *tritici* with Combined Virulence to *Sr13* and *Sr9e* in a Field Stem Rust Screening Nursery in Ethiopia

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Abstract

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North American durum lines, selected for resistance to TTKSK (Ug99) and related races of *Puccinia graminis* f. sp. *tritici* in Kenya, became susceptible in Debre Zeit, Ethiopia, suggesting the presence of stem rust races that were virulent to the TTKSK-effective genes in durum. The objective of this study was to characterize races of *P. graminis* f. sp. *tritici* present in the Debre Zeit, Ethiopia stem rust nursery. Three races of *P. graminis* f. sp. *tritici* were identified from 34 isolates: JRCQC, TRTTF, and TTKSK. Both races JRCQC and TRTTF possess virulence on stem rust resistance genes *Sr13* and *Sr9e*, which may explain why many TTKSK-resistant durum lines tested in Kenya became susceptible in Debre Zeit. The *Sr9e-Sr13* virulence combination is of particular concern because these two genes constitute major components of stem rust resistance in North American durum cultivars. In addition to *Sr9e* and *Sr13* virulence, race TRTTF is virulent to at least three stem rust resistance genes that are effective to race TTKSK, including *Sr36*, *SrTmp*, and resistance conferred by the 1AL.1RS rye translocation. Race TRTTF is the first known race with virulence to the stem rust resistance carried by the 1AL.1RS translocation, which represents one of the few effective genes against TTKSK in winter wheat cultivars in the United States. Durum entries exhibiting resistant to moderately susceptible infection response at the Debre Zeit nursery in 2009 were evaluated for reaction to races JRCQC, TRTTF, and TTKSK at the seedling stage. In all, 47 entries were resistant to the three races evaluated at the seedling stage, whereas 26 entries exhibited a susceptible reaction. These results suggest the presence of both major and adult plant resistance genes, which would be useful in durum-wheat-breeding programs. A thorough survey of virulence in the population of *P. graminis* f. sp. *tritici* in Ethiopia will allow characterization of the geographic distribution of the races identified in the Debre Zeit field nursery.

Stem rust, caused by *Puccinia graminis* f. sp. *tritici*, is one of the most destructive diseases of bread wheat (*Triticum aestivum*), durum wheat (*T. turgidum* subsp. *durum*), and barley (*Hordeum vulgare*). Races that recently emerged in eastern Africa (TTKSK [Ug99] and its variants) possess broad virulence to wheat cultivars worldwide, and only a few genes in adapted cultivars are effective against these races (7,8,21). Durum wheat in North America generally has a higher frequency of resistance to race TTKSK than common wheat based on field evaluations conducted in Njoro, Kenya in 2005 and 2006 (R. Singh and Y. Jin, *unpublished*). Pozniak et al. (14) described that over 80% of the durum varieties and breeding lines from breeding programs in the United States and Canada evaluated in a field trial in Njoro exhibited a moderately resistant or resistant response to stem rust. Singh et al. (18) also reported that durum lines from Egypt and the International Maize and Wheat Improvement Center (CIMMYT) exhibited a high level of resistance to races TTKSK and TTKST in the Njoro's field nursery. However, when durum lines from the United States and CIMMYT were selected for resistance in Kenya and subsequently were evaluated in Debre Zeit, Ethiopia, many became susceptible to stem rust (R. Singh and Y. Jin, *unpublished*). Thus, we hypothesized that races of *P. graminis* f. sp. *tritici* in the Debre Zeit nursery possess virulence that overcomes the TTKSK resistance in North American durum germplasm. The objective of this study was to identify the race or races of *P. graminis* f. sp. *tritici* present in the Debre Zeit, Ethiopia nursery that are virulent on durum lines with TTKSK resistance.

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Materials and Methods

Stem rust nursery. The 2009 durum stem rust field nursery was established by the Ethiopian Institute of Agricultural Research at the Debre Zeit Research Center in Ethiopia. The nursery site was located at 08°46′N, 39°00′E, and 1,900 m in elevation. Entries were planted in double 1-m-row plots on 15 July 2009. Wheat 'Red Bobs' (CItr 6255) was included at an interval of 50 lines as a susceptible control. Continuous rows of stem rust spreader (mixture of susceptible cultivars) were planted perpendicular to all entries to facilitate inoculum build-up and uniform dissemination. The spreader rows were planted the same day as the wheat entries and were artificially inoculated by needle injection three times at a weekly interval, starting at stem elongation (stage = Zadoks 31) (23). Urediniospores were suspended in distilled water plus one drop of Tween 20 per 0.5 liters of suspension, and delivered with a hypodermic syringe into the stem tissue. Inoculum was composed of race TTKSK and a bulk of Ethiopian isolates (with unknown race identities) at a ratio of 50/50. Race TTKSK was originally collected from wheat 'PBW343' (carrying *Sr31*) at Debre Zeit, and the bulk of Ethiopian isolates was collected from durum lines at the Debre Zeit Research Center.

Sample collection and storage. Forty-one samples of infected stems were collected from durum and common wheat lines with known *Sr* genes in the stem rust field nursery in 2009. Each sample consisted of 10 to 15 pieces of stem tissue of about 10 cm in length bearing moderately susceptible to susceptible pustules. Stem and leaf sheath tissue were kept in glassine bags and air dried for 2 days at room temperature in the dark. Dried samples were mailed to the United States using an international express courier service with a transit time of 5 days. Shipping protocol was followed according to United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service permit conditions for handling international cultures of *P. graminis* f. sp. *tritici*. Upon arrival at the Cereal Disease Laboratory, samples were stored in a –80°C freezer. In December, urediniospores from each stem sample were collected into three to four gelatin capsules (size 00) and stored at –80°C.

Race identification. The North American stem rust differential set (15,16) that was modified to further delineate races in the TTKS race group (9) was used for race identification. One capsule per sample was removed from the –80°C freezer and exposed to a heat-shock treatment (water bath at 45°C for 15 min), then placed in a rehydration chamber (80% relative humidity maintained by a KOH solution) for a period of 4 h (9). Five seedlings from each of the 20 differential lines were inoculated with a bulk collection of spores on fully expanded primary leaves at 8 to 9 days after planting. Experimental procedures for inoculation, incubation, and disease assessment were done as described by Jin et al. (8). Single-pustule isolates were derived from individual plants after preliminary evaluation on the differential lines. Six to eight pustules were isolated from each original collection. Incubation and collection of urediniospores from each single pustule was done as described by Jin et al. (9). The pure cultures derived from single-pustule inoculation were increased on 'McNair 701' wheat (CItr 15288) and stored at –80°C. Each single-pustule isolate was evaluated two to three times on differential lines before a race was designated. Race designation was done based on the letter code proposed by Roelfs and Martens (16). Representative isolates from each race were further characterized on 17 additional monogenic lines carrying the following genes: *Sr22, Sr25, Sr26, Sr27, Sr32, Sr33, Sr35, Sr37, Sr39, Sr40, Sr42, Sr44, Sr46, Sr47, Sr50, SrSatu,* and the 1A.1R rye translocation. Cultivars and lines carrying *Sr13* and *Sr9e* alone or in combination and both resistant (Iumillo [PI 210973]) and susceptible (Rusty [PI 639869]) checks were also included in the evaluation of each isolate.

Seedling evaluation of wheat germplasm. One thousand durum entries deposited at the USDA Agricultural Research Service, National Small Grain Collection (Aberdeen, ID) were evaluated for resistance in field test at the 2009 durum stem rust field nursery in Debre Zeit. Disease assessment was done at the soft-dough stage of plant growth. Plants were evaluated for their infection response (pustule type and size) (17) and stem rust severity following the modified Cobb scale (13). In all, 137 durum wheat lines characterized as resistant with a maximum 30% stem rust severity and maximum moderately susceptible infection response were evaluated at the seedling stage with *P. graminis* f. sp. *tritici* races identified from this nursery following procedures described above. Seedling evaluation was repeated once.

Results and Discussion

We obtained 34 single-pustule isolates from the 41 samples collected in 2009 from the Debre Zeit nursery. Three races of *P. graminis* f. sp. *tritici* were identified: JRCQC, TRTTF, and TTKSK (Table 1). The race most frequently observed was TTKSK (18 isolates), followed by JRCQC (12 isolates) and TRTTF (4 isolates). The high frequency of race TTKSK was likely due to artificial inoculation of *P. graminis* f. sp. *tritici* collected from PBW 343 in the 2009 Debre Zeit field nursery. The virulence profile of race TTKSK from Debre Zeit was identical to that of race TTKSK isolates found in Kenya (9,10).

Race JRCQC produced high infection types (ITs) on differential lines carrying *Sr6, Sr9a, Sr9d, Sr9e, Sr9g*, *Sr11, Sr13/17, Sr21,* and *SrMcN* (Table 1). Race JRCQC produced a high IT on differential line Combination VII, which carries *Sr13* in addition to *Sr17* and was virulent on other *Sr13*-lines (Table 2). Thus, this race possesses relatively rare virulence to both *Sr9e* and *Sr13*, a combination believed to be the main component of stem rust resistance in contemporary North American durum cultivars (11). Race JRCQC produced an IT = X- on W2691Sr10 (tester for *Sr10*). W2691Sr10 generally produces IT = 0; to ;1 when inoculated with avirulent North American stem rust isolates, and IT = X is infrequent except for a few isolates from the Pacific Northwest (Y. Jin, *unpublished*). It is not known, however, whether the "X" type was due to *Sr10* or a different gene in the W2691Sr10 background. Race JRCQC was avirulent to additional stem rust resistance genes tested in this study, except presumably *Sr42* in Norin 40 (Table 2).

Race TRTTF was first identified from a stem rust collection from Yemen in 2006 (Y. Jin and A. Yahyaoui, *unpublished*), and was further isolated from stem rust collections in Ethiopia and Yemen in subsequent years (T. Fetch, *unpublished*). Race TRTTF is virulent on most of the stem rust resistance genes in the differential set, including *Sr9e* (Table 1). Virulence on *Sr13* was determined based on high IT (IT 3+) on Combination VII, which carries *Sr13* in addition to *Sr17* (Table 1). Virulence on *Sr9e* and *Sr13* was also confirmed in monogenic lines Vernal (*Sr9e*) and Khapstein/9*LMPG (*Sr13*), respectively (Table 2). However, the low ITs observed on K253/3*Steinwedel/8*LMPG (*Sr9e*) and Leeds (*Sr9e* + *Sr13*) (Table 2) indicate that these lines may carry an additional

Table 1. Infection types (ITs) observed on stem rust differentials using races JRCQC, TRTTF, and TTKSK of *Puccinia graminis* f. sp. *tritici* collected from the 2009 Debre Zeit (Ethiopia) field nursery[a]

Gene	Line	JRCQC (09ETH08-3)	TRTTF (09ETH06-1)	TTKSK (09ETH05-3)
Sr5	ISr5-Ra	;1	4	4
Sr21	CnS_T_mono_deriv	4	4	3+
Sr9e	Vernstein	4	3+	4
Sr7b	ISr7b-Ra	2	3+	4
Sr11	ISr11-Ra	4	4	3+
Sr6	ISr6-Ra	3+	3+	4
Sr8a	ISr8a-Ra	22+	2	4
Sr9g	CnSr9g	4	4	4
Sr36	W2691SrTt-1	0	3+	0
Sr9b	W2691Sr9b	2+	4	4
Sr30	BtSr30Wst	22-	4	4
Sr17 (+*Sr13*)	Combination VII	3	3+	22+
Sr9a	ISr9a-Ra	3+	4	3+
Sr9d	ISr9d-Ra	4	4	4
Sr10	W2691Sr10	1+3;	4	4
SrTmp	CnsSrTmp	2-	4	2+
Sr24	LcSr24Ag	2-	2	2-
Sr31	Sr31/6*LMPG	2-	2-	4
Sr38	Trident	;1	4	4
McN	McNair 701	4	4	4

[a] ITs were accessed on seedlings at 14 days post inoculation using a 0-to-4 scale according to Stakman et al. (19), where ITs of 0, ;, 1, 2, or combinations are considered to be low ITs and ITs of 3 or higher are considered to be high. "N" or "C" denotes excessive necrosis or chlorosis, respectively.

resistance gene or genes that are effective against race TRTTF. Race TRTTF has a virulence profile similar to race RRTTF (avirulent on *Sr9e*), identified from stem rust collections in Ethiopia and Yemen in 2007 (4) and Pakistan in 2009 (6). Interestingly, both races have a uredinial morphology that is distinct from other common stem rust isolates in that the epidermal tissue over the uredinia has a delayed breakage and the color of uredinia is darker than normal (Fig. 1).

In addition to virulence to *Sr13* and *Sr9e*, race TRTTF exhibited a high IT (IT 3) to stem rust resistance conferred by the 1AL.1RS translocation (Table 2). This is the first known race with virulence to the stem rust resistance gene carried by this rye translocation, which represents one of the few effective genes to Ug99 in winter wheat cultivars in the United States (7). Race TRTTF, in combination with TTKSK, differentiates the stem rust resistance gene on 1AL.1RS from other stem rust resistance genes present on 1RS; namely, *Sr31* and *Sr50* (3,12). Additional data are needed to determine the genetic relationship between 1A.1R resistance and both *Sr31* and *Sr50*. In the United States, current bread wheat breeding lines and cultivars with resistance to race TTKSK possess resistance genes including *Sr24*, *Sr36*, *SrTmp*, and resistance on the 1A.1R translocation (7). Though race TRTTF is avirulent to *Sr31*,

Table 2. Infection types (ITs) observed on additional resistant lines using races JRCQC and TRTTF of *Puccinia graminis* f. sp. *tritici* identified from the 2009 Debre Zeit (Ethiopia) field nursery[a]

Gene	Line	JRCQC (09ETH08-3)	TRTTF (09ETH06-1)
Resistant check	Iumillo	;N	11+;N
Susceptible check	Rusty	3+	4
Sr13	Khapstein/9*LMPG	3	3+
Sr9e	Vernal	3+	3
Sr9e	K253/3*Steinwedel/8*LMPG	4	2+
Sr13 + *Sr9e*	Leeds	4	;
Sr22	SwSr22T.B.	2-	2-
Sr25	LcSr25Ars	2+	2+3-
Sr26	Eagle	2	2-
Sr27	WRT 238-5	;	2-
Sr32	ER 5155	2	2+
Sr33	Tetra Canthatch/Ae. Squarrosa	;2=	2
Sr35	Mq(2)5*G2919	0	0
Sr37	W3563	31;	13+;
Sr39	RL6082	0;	2-
Sr40	RL6088	2-	2
Sr42	Norin 40	33+	4
Sr44	TAF 2	;N1	3+;N1
Sr46	AUS 18913	;1	2-;
Sr47	DAS15	;2=	2-
SrSatu	Satu	0;	0;
1A.1R	TAM 107	2-	3
Sr50	Fed*3/Gabo*51BL.1RS-1-1	2-;	;1-

[a] ITs observed on seedlings at 14 days post inoculation using a 0-to-4 scale according to Stakman et al. (19), where ITs of 0, ;, 1, 2, or combinations are considered to be low ITs and ITs of 3 or higher are considered to be high. "N" or "C" denotes excessive necrosis or chlorosis, respectively.

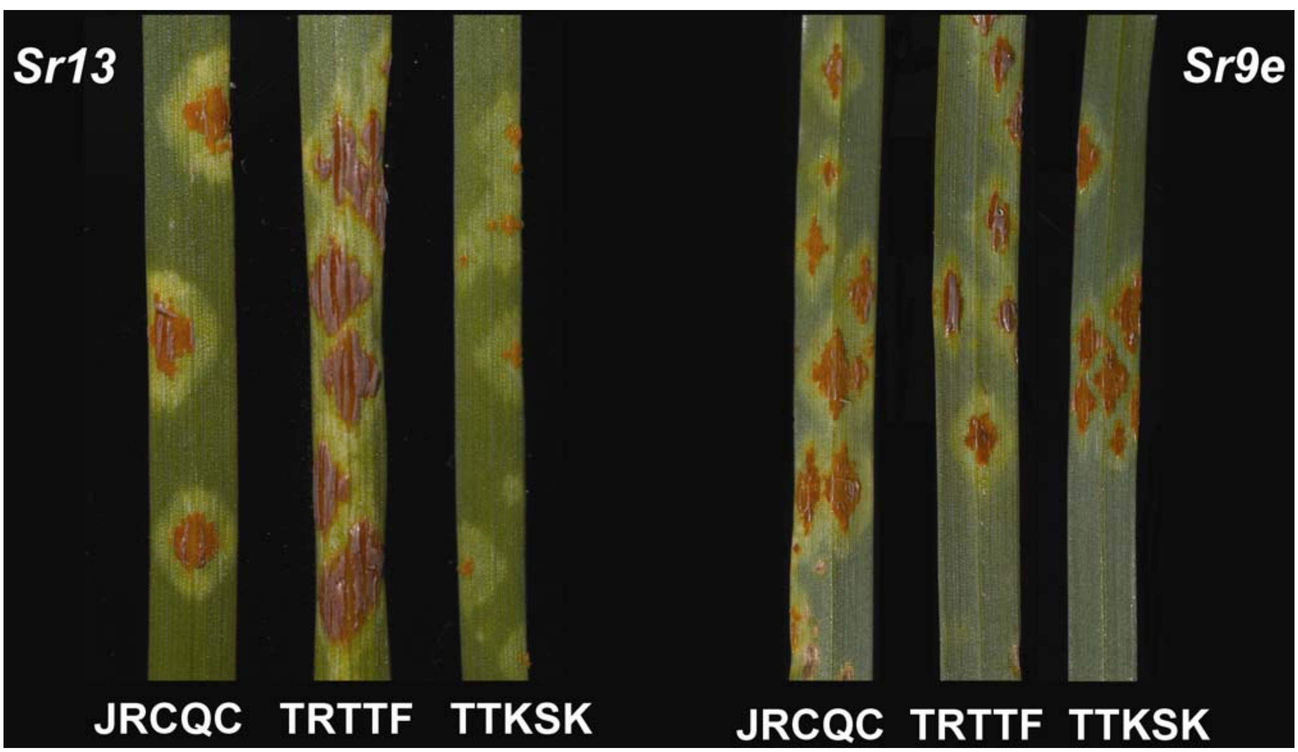

Fig. 1. Infection types produced by races JRCQC, TRTTF, and TTKSK of *Puccinia graminis* f. sp. *tritici* on Combination VII (*Sr13*) and Vernstein (*Sr9e*).

Table 3. Disease reaction of durum wheat (*Triticum turgidum* subsp. *durum*) selected for resistant to moderately resistant to *Puccinia graminis* f. sp. *tritici* at the adult stage in field evaluations in Debre Zeit (Ethiopia) and at the seedling stage against races JRCQC, TRTTF, and TTKSK

			Adult[a]	Seedling[b]		
Line ID	**Type[c]**	**Origin**	**Debre Zeit 2009**	**JRCQC (09ETH08-3)**	**TRTTF (09ETH061)**	**TTKSK (04KEN156-4)**
CItr 6519	Cultivar	North Dakota	10 R	0;	4	;CN / 3+
CItr 7287	Cultivar	North Dakota	20 MS	32	4	3
CItr 8123	Landrace	Ethiopia	40 MR-MS	13+;	;2-N	2- / 2+2
CItr 8214	Cultivar	North Dakota	10 MS-MR	3+ / 3+;N	2+	3+
CItr 8634	Landrace	Ethiopia	20 MR	3+;1	4	3+
CItr 11477	Cultivar	North Dakota	20 MS	;13	3	2
CItr 11541	Cultivar	North Dakota	20 MS	4	4	3+
CItr 13245	Cultivar	North Dakota	10 R-MR	;	2-	3+
CItr 13247	Cultivar	North Dakota	15 MS	3+;	2+	3+
CItr 13333	Cultivar	North Dakota	5 R-MR	2+	;1	2- / 3+
CItr 13335	Cultivar	North Dakota	5 R	2	2	2-
CItr 13338	Breeding	Manitoba	10 MR-MS	0; / 2+	2-;	;CN / 2-
CItr 13768	Cultivar	North Dakota	20 MS-MR	3+	0;	2-N
CItr 14091	Cultivated	Unknown	5 MR-MS	3	2+3- / 22+	X / 3+
CItr 14434	Landrace	Ethiopia	20 R-MR	4;N / ;N	4	33-
CItr 14965	Cultivated	Unknown	10 MR	;N3+	3+	3+
CItr 15326	Cultivar	North Dakota	20 MR	;N	0;	2-
CItr 15769	Breeding	North Dakota	15 MR-MS	;N	;2-	2-2
CItr 15814	Breeding	North Dakota	T MR-MS	;3	;N	3+
CItr 15892	Cultivar	North Dakota	15 MR-MS	;N	;	2-
CItr 17282	Cultivar	North Dakota	5 R-MR	;1+	;	3 / 2-
CItr 17283	Cultivar	North Dakota	15 MR-R	;N / 3	;2-	2-
CItr 17284	Cultivar	North Dakota	5 MR	;1-	;N	2-
CItr 17337	Cultivar	Saskatchewan	15 MR	2	;1N	2-
CItr 17637	Landrace	Ethiopia	30 MS	33+ / 2	22-	22+ / 33+
CItr 17748	Cultivar	North Dakota	10 MR	;1-	;	3+
CItr 17789	Cultivar	North Dakota	10 R-MR	;1+N	;N	2-
PI 45441	Cultivated	South Africa	15 MR-MS	32+;	2+3-	2
PI 56251	Landrace	Portugal	20 MS	2+	3- / 2	2 / 3+
PI 61111	Landrace	Georgia	20 MS	3+3;	3+	3+
PI 61123	Landrace	Kazakhstan	10 MS	2+	4	3+
PI 61127	Cultivar	Kyrgyzstan	15 MS	3-	4	3+
PI 61176	Landrace	Russian Fed.	15 MS	4	3	3+
PI 61351	Cultivated	Hokkaido	15 MS	3+1+;	3+	3+
PI 61873	Cultivated	Morocco	50 MS-MR	2-	2	2 / 3+
PI 70718	Landrace	Iraq	20 MS	3+	3-;	3+
PI 94694	Landrace	Egypt	15 MS	3-2+	3+	22- / 2+3-
PI 94726	Landrace	Italy	0 / 20 R	2-	2	2-
PI 94761	Wild	Georgia	T R	33+	4	;CN
PI 113395	Landrace	Egypt	10 MR	2+;N3	22+;	3-;
PI 113398	Landrace	Egypt	10 R-MR	0;	3+	3
PI 166336	Landrace	Turkey	15 MR-MS	3+ / 0	3+	3
PI 167270	Landrace	Turkey	5 MR	3+;N	3+	;
PI 168916	Breeding	Mexico	5 R	4	22+ / 3	2
PI 168922	Breeding	Mexico	5 MS-MR	2+ / ;N / 0	4	2
PI 178048	Landrace	Turkey	5 MS	2+;	3+	;
PI 178156	Landrace	Turkey	10 MS	3+ / ;	3+	;CN
PI 182668	Cultivated	Lebanon	5 MS	;1+	2+3-	3-
PI 184540	Cultivated	Portugal	10 MS-MR	2+1;	3+ / 3;N	2-
PI 184641	Landrace	Portugal	15 MS	2+	4	4
PI 185300	Breeding	Santa Fe	25 MS	2++	4	2-2
PI 191183	Landrace	Spain	15 MS	;N3+	3+	2-
PI 191645	Cultivated	Sao Paulo	20 MR-MS	2=	2	2
PI 192051	Landrace	Portugal	5 R	2=;	4	2-;N
PI 192399	Landrace	Italy	15 MS	1-;	2-;	2+3-
PI 192711	Cultivated	Gotland	5 MS / 40 S	1;3	;1	;CN
PI 193920	Landrace	Portugal	30 MS-MR	2-	3+ / 2	2-; / 3-
PI 208910	Landrace	Iraq	30 MS	3+	3	3
PI 210944	Landrace	Cyprus	15 MS-MR	2-; / 33+	4	3+
PI 234386	Landrace	Jordan	30 MS	3-2 / 4	4	3+
PI 253801	Landrace	Iraq	30 MS	;13+	2+3-	3+
PI 264947	Cultivated	Italy	10 MS	2+2	3-2;	4
PI 272476	Breeding	Hungary	30 MR-MS	2-;	2	2-
PI 272545	Breeding	Hungary	30 MS	3+1	4	3+

(*continued on next page*)

[a] Plants evaluated for infection response (17) and severity following the modified Cobb scale (13). R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, and T = traces.

[b] Infection types (ITs) observed on seedlings at 14 days post inoculation using a 0-to-4 scale according to Stakman et al. (19), where ITs of 0, ;, 1, 2, or combinations are considered to be low ITs and ITs of 3 or higher are considered to be high. "N" or "C" denotes excessive necrosis or chlorosis, respectively; / indicates that an accession was heterogeneous (the predominant type was given first); and – denotes missing data, frequently caused by poor viability of seed.

[c] Classification according to the United States Department of Agriculture–Agricultural Research Service, National Small Grain Collection (Aberdeen, ID). Cultivated = uncertainty about the improvement status.

Table 3. (*continued from preceding page*)

Line ID	Type[c]	Origin	Adult[a] Debre Zeit 2009	Seedling[b] JRCQC (09ETH08-3)	TRTTF (09ETH061)	TTKSK (04KEN156-4)
PI 272553	Cultivated	Hungary	40 MS-MR	;N / 3	X	2-
PI 274681	Cultivated	Poland	T S	;	-	3-c
PI 278352	Cultivated	Italy	T R	1+13-	2	2+3-
PI 278380	Cultivated	Malta	15 MS	;N4	;1	3
PI278503	Cultivated	Spain	10 MS	31	1+	2-
PI 283854	Cultivated	India	10 MS	4;	4	3+
PI 286539	Cultivar	Ecuador	5 MR	;1	2	22+
PI 295967	Cultivar	Israel	15 MS-MR	3+	23-;	3
PI 298547	Landrace	Ethiopia	15 MR	;N	;1	2=
PI 316092	Breeding	Australia	20 MS	2-	2-	2-
PI 316096	Cultivar	Australia	15 MS	3	3+	3
PI 320128	Landrace	Ethiopia	20 MR-MS	;2=	;	2- / 2
PI 324928	Breeding	Argentina	15 MR	1;	2+3-	3
PI 326315	Cultivar	Azerbaijan	T S	31;	3+	3+
PI 347217	Landrace	Iran	60 MS-MR	2-	4	2 / 3+
PI 352317	Breeding	Switzerland	15 MR	;1	2-	2-
PI 352463	Cultivar	Switzerland	20 MR	3+	2	33-
PI 352512	Wild	Switzerland	5 R	3	2+	2+
PI 361149	Landrace	India	10 MR	-	;N1	2-
PI 366110	Landrace	Egypt	20 MR	3+	4	33+
PI 367224	Breeding	Italy	10 R-MR	1	2;	3-2+
PI 383416	Breeding	France	5 R-MR	0;	2	2++
PI 384111	Landrace	Ethiopia	15 MR	3-2+	2-	2-
PI 422412	Cultivar	Australia	30 MS	;1	2	2-
PI 428539	Cultivar	France	T R	0;	;	2-;
PI 428541	Cultivar	France	10 MS-MR	0;	3-2;	3-3
PI 428549	Cultivar	France	T R	2-;	;1	2-
PI 430747	Landrace	Yemen	40 MS-MR	3-3	22+	2-
PI 434919	Landrace	Egypt	30 MS	2-; / 3	3+	3
PI 434952	Landrace	Egypt	30 MS-MR	3+	3+	3+
PI 477881	Landrace	Peru	10 MR	33+	3-2+	3+3
PI 478298	Cultivar	North Dakota	15 MR-MS	;N	;N	2- / 3+
PI 478304	Breeding	North Dakota	5 MR-MS	3+/ 22+ /;N	;N	2-
PI 478306	Cultivar	Washington	5 MS	2+	;N	2-
PI 479916	Landrace	Ethiopia	20 MR-MS	2-;	2-N	2- / 3
PI 479921	Landrace	Ethiopia	15 MR	-	2-N	2-
PI 479923	Landrace	Ethiopia	20 MR-R	;N	2-;N	2-2
PI 479956	Landrace	Ethiopia	15 MR-R	;2= / 22- / 3	;N2-	2-2
PI 479959	Landrace	Ethiopia	40 MR-MS	2=;	;N2-	2-N
PI 480006	Landrace	Ethiopia	20 R-MR	;N1	;N2-	2-
PI 480401	Landrace	Ethiopia	10 MS-MR	;1	3-	22+ / 2-
PI 487290	Landrace	Jordan	15 MS	3+	4	3+
PI 497927	Breeding	North Dakota	5 MR	31	0;	2-;
PI 506469	Cultivar	Colorado	T R	;3+1	;	2-
PI 506470	Cultivar	Colorado	5 MR-MS	;11+	0;	3+ / 2-;
PI 510694	Breeding	North Dakota	10 MR-MS	-	;N	2-
PI 510696	Cultivar	North Dakota	5 MR-MS	;N	;N	2-
PI 519170	Breeding	La Araucania	10 MS	3;	X-	;3-
PI 519171	Breeding	La Araucania	5 MR	;1+	2	3-2+
PI 519445	Breeding	North Dakota	T R	22+	;N1	2-
PI 519559	Breeding	Syria	5 MS	;N1+	2-;	2-;
PI 519619	Breeding	Syria	5 MS	4	22-	2-
PI 519639	Breeding	Syria	5 MS	3+	-	2-;N
PI 519642	Breeding	Kenya	5 MS	4	22-	2-
PI 519811	Cultivar	Italy	10 MS	3+;	3+ / 2-	3
PI 519832	Cultivar	Lebanon	15 MR	;N	3-	2-
PI 520299	Breeding	North Dakota	5 MS	2-	;N	2-
PI 520300	Cultivar	California	5 MR-MS	3+	;N	2-;
PI 520392	Breeding	Mexico	15 MS	2	2-	22+
PI 520413	Breeding	Syria	10 MR-R	3+2	2+	3
PI 520518	Breeding	North Dakota	5 R-MR	;N1	;	-
PI 525395	Cultivated	Morocco	15 MS	3+3	3+	3
PI 537310	Cultivar	Saskatchewan	10 MR	2+	;1	2-
PI 572862	Landrace	Azerbaijan	20 MR-MS	32	2	3-2+
PI 573005	Cultivar	Arizona	10 MR-MS	2+2	2	2-N
PI 576787	Landrace	Algeria	25 MS	3+	4	-
PI 585010	Landrace	Ethiopia	50 MS-MR	3+;N	2-	-
PI 585020	Cultivated	Saudi Arabia	20 MS	3-2+	22+	22+
PI 601250	Cultivar	Arizona	15 R-MR	1;N	2	2-
PI 614658	Cultivar	United States	30 MS	3+	;	2-N; / 2+
PI 623997	Landrace	Iran	20 MS	3+	3+	3
PI 624854	Landrace	Iran	15 MS-MR	4	X-	3
PI 636501	Breeding	North Dakota	15 MS-MR	1+;	;	3- / 2-

it is virulent to *Sr36, SrTmp* and the 1A.1R translocation that are effective against race TTKSK (Tables 1 and 2). Additional studies are needed to determine the percentage of bread wheat cultivars and breeding lines resistant to race TRTTF.

Stem rust isolates with virulence to *Sr9e* and *Sr13* were first reported in Ethiopia in 1988 and 1989, respectively (5). They appear to be widespread, because Admassu et al. (2) described races with virulence to these two genes in the major wheat-growing regions in Ethiopia. Races JRCQC and TRTTF, described in this report, possess combined virulence on *Sr13* and *Sr9e*. This virulence combination may explain why the TTKSK-resistant durum entries in Njoro (Kenya) were susceptible in Debre Zeit (Ethiopia). Lines with *Sr13* conferred a moderately resistant to moderately susceptible response when tested against race TTKSK in the Njoro nursery (8). However, lines and cultivars carrying *Sr9e* (Vernal, K253/3*Steinwedel/8*LMPG, Vernstein) and *Sr13* (Khapstein/9*LMPG) exhibited a susceptible response in the Debre Zeit field (*data not shown*). The virulence combination to *Sr9e* and *Sr13* is of particular concern because these two genes constitute major components of stem rust resistance in North American durum cultivars (11). Identification of novel resistance genes effective against races JRCQC, TRTTF, and TTKS is required to broaden the pool of resistance genes in durum wheat. The description of race TRTTF with virulence to several TTKSK-effective resistance genes should remind breeders and pathologists of the danger of deploying race-specific genes alone. Resistance gene combinations are necessary to provide long-lasting resistance to wheat stem rust.

A set of durum germplasm (137 entries) selected for resistant to moderately susceptible responses from the 2009 field nursery in Debre Zeit was evaluated for reaction to races JRCQC, TRTTF, and TTKSK at the seedling stage (Table 3). The numbers of accessions exhibiting low ITs to race JRCQC, TRTTF, and TTKSK were 96 (70%), 89 (65%), and 84 (61%), respectively. Many of these lines appear to have race-specific genes and only 47 (34%) accessions were resistant to all three races used in this study. These resistant lines could serve as sources of stem rust resistance for wheat-breeding programs. The genetics of resistance to races JRCQC and TRTTF in selected lines are being investigated. Twenty-six lines (19%) that were resistant to moderately resistant in the field were susceptible to the three races at the seedling stage, suggesting that adult plant resistance might be present in these accessions. Most of the accessions (66%) susceptible at the seedling stage were landraces and other cultivated materials (with uncertainty about the improvement status) from the Middle East and Caucasus regions, and landraces from North and East Africa (Table 3).

Race-typing experiments of isolates collected from Kenyan fields in recent years yielded only races belonging to the TTKS lineage (9,10,22). However, surveys conducted in Ethiopia in the last 20 years had more diversity of *P. graminis* f. sp. *tritici* races (1,2,20). Continuous and thorough race surveys in Ethiopia are required to have a clear picture of the virulence dynamics in the population of *P. graminis* f. sp. *tritici* in the country. Identifying and monitoring movement of races with virulence to effective and widely used resistance genes is critical for defining breeding strategies for stem rust resistance in durum and bread wheat. Our results highlight the relevance of evaluating durum wheat lines for stem rust resistance in Ethiopia due to the presence of combined virulence to genes *Sr9e* and *Sr13* in the *P. graminis* f. sp. *tritici* population.

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