CULTIVAR

Registration of 'Mattern' Waxy (Amylose-free) Winter Wheat

R. A. Graybosch,* P. S. Baenziger, D. K. Santra, T. Regassa, Y. Jin, J. Kolmer, S. Wegulo, Guihua Bai, Paul St. Amand, Xianming Chen, B. Seabourn, F. Dowell, R. Bowden, and D.M. Marshall

ABSTRACT

'Mattern' (Reg. No. CV-1092, PI 665947) hard winter waxy wheat (*Triticum aestivum* L.) was developed cooperatively by the USDA–ARS and the Nebraska Agricultural Experiment Station and released in 2012. Mattern has red grain color and waxy (amylose-free) endosperm starch. It was released primarily for its unique end-use quality attributes and for grain yield competitive with currently grown Nebraska-adapted cultivars. The waxy starch is conditioned by the presence of three naturally occurring mutations that eliminate production of the enzyme granule-bound starch synthase. Granule-bound starch synthase synthesizes amylose in typical wheats and other cereal crops. Mattern was tested experimentally as NX04Y2107 and was selected from the cross NW98S061/99Y1442.

Journal of Plant Registrations 8:43–48 (2014).
doi: 10.3198/jpr2013.08.0045crc
Received 9 Aug. 2013. Registration by CSSA.
5585 Guilford Rd., Madison, WI 53711 USA
*Corresponding author (bob.graybosch@ars.usda.gov)

Wild-type wheat (*Triticum aestivum* L.) endosperm starch is composed of approximately 25 to 30% amylose and 70 to 75% amylopectin. In cereals, mutations in the genetic loci encoding the granule-bound starch synthase (GBSS, also known as the "waxy protein") can eliminate or reduce amylose production, resulting in starch consisting of nearly 100% amylopectin (Nelson and Rines, 1962). The term *waxy* is not related to plant waxes; rather, it derives from the appearance of cut kernels of waxy maize (*Zea mays* L.), the texture of which "suggests that of the hardest waxes" (Collins, 1909). Although waxy types of maize and other diploid cereals have been known to science for more than 100 years (Collins, 1909), naturally occurring waxy forms of hexaploid wheat have only been available for the past two decades. In the early 1990s, Nakamura and colleagues in Japan identified GBSS mutants based on electrophoretic mobilities; they combined mutants from each of the three wheat genomes to produce the world's first waxy hexaploid wheats (Nakamura et al., 1993; 1995). Subsequently, nonfunctional mutations at the *Wx-A1* and *Wx-B1* loci were found to be common within the U.S. Great Plains wheat germplasm base (Graybosch et al., 1998). Mutations at the *Wx-D1* locus are rare; the most commonly used *Wx-D1* mutation traces to the Chinese landrace Bai Huo (Nakamura et al., 1993). Subsequent to the work of Nakamura and colleagues, novel waxy mutations were induced via mutagenesis (Keeling et al., 2000) or isolated using TILLING (Slade et al., 2005).

Wheat starch consisting only of amylopectin differs in functional properties compared with wild-type starches (Graybosch, 1998). Addition of either native or chemically modified waxy wheat flour or starch can alter the functional properties of a number of food products (Akashi et al., 2000; Hatta et al., 2000). Waxy wheat kernels may be used to produce novel whole grain products (Wilson et al., 2003). Starch from waxy wheat is more efficient than wild-type starch in ethanol production systems (Zhao et al., 2009) and provides

R.A. Graybosch, Y. Jin, J. Kolmer, G. Bai, P. St. Amand, X. Chen, B. Seabourn, F. Dowell, R. Bowden, and D.M. Marshall, USDA–ARS; R.A. Graybosch, 137 Keim Hall, Univ. of Nebraska–East Campus, Lincoln, NE 68583; P.S. Baenziger, D.K. Santra, T. Regassa, and S. Wegulo, Univ. of Nebraska– Lincoln.

Abbreviations: GBSS, granule-bound starch synthase; NRPN, Northern Regional Performance Nursery.

unique functional properties when used as a substrate for the production of modified food starches (Hansen et al., 2010). To date, only one waxy wheat cultivar, 'Waxy-Pen', adapted to the Pacific Northwest has been publically available in the United States (Morris and King, 2007). To satisfy the demand from commercial entities for waxy wheat adapted to the Great Plains, the USDA–ARS, in cooperation with the University of Nebraska, developed and released the hard waxy winter wheat 'Mattern' (Reg. No. CV-1092, PI 665947). Mattern was named to honor the memory of Paul J. Mattern, long-time cereal chemist at the University of Nebraska, Lincoln, mentor of many, and a friend to all.

Methods

Early-Generation Population Development

Mattern, tested experimentally as NX04Y2107, was selected from the cross NW98S061/99Y1442. NW98S061 is a hard white winter wheat breeding line developed by the USDA–ARS at Lincoln, NE, with the pedigree 'Jagger'/'Nekota'. 99Y1442 is a waxy experimental line, also developed by the USDA–ARS, Lincoln, NE, with the pedigree Bai Huo/'Kanto107'//'Ike'/3/96MD7413-10. 96MD7413-10 is a partial waxy breeding line developed by the USDA–ARS, with the pedigree NE90616/Ike. NE90616 is a breeding line developed by the University of Nebraska, with the pedigree 'Arapahoe'/'Colt'-83-composite. Bai Huo is the donor of the null *Wx-D1b* null mutant. Null alleles (*Wx-A1b* and *Wx-B1b*) are present in Kanto107, Ike, and 96MD7413-10. The last cross in the development of Mattern was made in spring 2000 in the University of Nebraska Agronomy Greenhouse Facility. The F_1 generation was grown in the field at Yuma, AZ, in 2001, and the F_2 to F_3 generations were advanced using the bulk breeding method in the field at Lincoln in 2002 and 2003. In 2003, single head selections were made from the F_3 bulk populations and screened for the presence of waxy seed using I_2KI staining (Pedersen et al., 2004). Heads uniform for the waxy starch trait were planted as single-plant progeny rows in Yuma and harvested in spring 2004. The line to be designated Mattern, derived from one Yuma-grown progeny row, subsequently was entered in a preliminary nursery with three replications planted at Mead, NE. A second, single observation nursery was seeded at Lincoln. On the basis of preliminary yield data and disease responses, Mattern was moved to advanced yield testing.

Evaluation and Selection of Advanced Lines

In 2006, Mattern was entered in an advanced yield trial at four Nebraska locations, Lincoln, Mead, Alliance and North Platte, and at Hays, KS. The trial was planted as a three-replication, randomized complete block design and included numerous waxy experimental lines and the control cultivars 'Trego', 'Wesley', 'Antelope', and 'Millennium'. In 2007, Mattern was tested in a similar replicated yield trial at three locations (Lincoln, Mead, and North Platte) in Nebraska. Grain yields and opportunistic disease responses were recorded. In 2008 and 2011, Mattern was entered in the USDA–ARS coordinated Northern Regional Performance Nursery (NRPN) (http://www.ars.usda.gov/Research/docs.htm?docid=11932) planted at numerous locations in Kansas, Nebraska, Wyoming, South Dakota, North Dakota, Minnesota, and Alberta. Control cultivars in the 2008 NRPN were Wesley, Antelope, and 'Jerry'; in 2011, the controls were Wesley, 'Overland', and Jerry. The trial was seeded in replicated, randomized complete block designs, typically with three replications. Mattern also was tested in the University of Nebraska Fall Sown Variety trial in 2008, 2009, 2011, and 2012. The trial contains 30 to 40 advanced experimental lines and cultivars, planted in 12 to 15 locations across the state each year. For simplicity, grain yield results for Mattern are presented in comparison to control cultivars only for the NRPN and University of Nebraska trials. Disease responses and DNA marker profile were reported by cooperators of the NRPN (http://www.ars.usda.gov/Research/docs.htm?docid=11932); end-use quality characteristics were reported separately by the USDA–ARS Hard Winter Wheat Quality Laboratory (http://www.ars.usda.gov/Main/docs.htm?docid=14298). Quality characteristics were assessed using composite samples from locations within three Great Plains Winter Wheat Production Zones, as defined by Peterson (1992), from the 2008 and 2011 NRPN. High-molecular-weight glutenin subunit composition was determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis as per Blechl and Anderson (1996) and verified using DNA markers (http://www.ars.usda.gov/Research/docs.htm?docid=11932).

Seed Purification and Increase

In 2010, an automated single kernel near-infrared system (Dowell et al., 2009) was used to purify Mattern by removal of non-waxy (wild-type) seed. After the 2011 harvest, this procedure was repeated. Approximately 40 kg of Mattern breeder seed was obtained after removal of nonwaxy seed and was used to seed a foundation seed increase at Yuma. Up to 2.5% variant plants (nonwaxy) may be encountered in subsequent generations. Taller (5–10 cm) variant plants occur at a frequency of approximately 1.0%. After the 2011 harvest, Mattern was noted to be segregating for red and white grain color. A Satake (Stafford, TX) ScanMaster IE 200 Automated Seed Sorter housed at the Seed Science Center, Iowa State University, was used to remove white-grained seed and produce red-seeded breeder seed.

Characteristics

Agronomic and Botanical Description

Mattern is a winter wheat, requiring vernalization to induce flowering. Coleoptile and auricle anythocyanin is lacking. The plant color is blue-green with a waxy bloom. Anthers are yellow, the head is middense and strap-shaped at maturity and awned. Glumes are white with an oblique shoulder. Glume pubescence is absent. The seed are ovate in shape, red, and possess a rounded cheek. The brush is short and the crease is wide. Seed texture is hard. The endosperm starch lacks amylose, and stains reddish-brown with addition of I_2KI solution. Grain volume weights and days to heading of Mattern are nearly identical to those of Wesley. Mattern plant heights typically exceed those of Wesley by 2 to 6 cm (Table 1). Results with DNA marker *Xwmc331*

indicate that Mattern carries the Al4DL allele, derived from 'Atlas 66', conditioning tolerance to aluminum toxicity (Ma et al., 2005).

Grain Yield and Quality Characteristics

In the 2006 advanced yield trial, Mattern was the highest-yielding entry, averaging 3977 kg ha^{-1} over the five locations. Check cultivars and their respective averages in the same trial were Trego, 3484 kg ha^{-1}; Antelope, 3436 kg ha^{-1}; Wesley, 3360 kg ha^{-1}; and Millennium, 3211 kg ha^{-1}. In the 2007 trial, respective mean grain yields were Mattern, 5288 kg ha^{-1}; Antelope, 4107 kg ha^{-1}; Millennium, 5055 kg ha^{-1}; Trego, 4908 kg ha^{-1}; and Wesley, 4780 kg ha^{-1}. Based on its performance in these trials, Mattern was entered in USDA–ARS coordinated NRPNs in 2008 and 2011 and in the Nebraska State Variety Trials in 2008, 2009, 2011, and 2012.

In the 2008 NRPN, grain yield of Mattern did not differ significantly from two check cultivars—the Nebraska-adapted lines Wesley and Antelope—and its yield was significantly greater than the North Dakota–developed cultivar Jerry (Table 1). In the 2011 NRPN, grain yield of Mattern again was not significantly different from Wesley and did not differ from that of Jerry, but it was significantly lower than Overland, the highest-yielding entry in the trial. In 4 yr (53 total site×year combinations) in the Nebraska State Variety Trials, grain yields of Mattern did not differ significantly from Overland, Wesley, and 'Camelot' (Table 1).

Disease and Insect Resistance

Mattern is moderately resistant to field infections of *Soil-borne wheat mosaic virus* and *Wheat spindle streak mosaic virus*, but it is susceptible to *Wheat streak mosaic virus*. It is highly resistant to infections of stem rust (caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn.) based on results of field nursery tests inoculated with a composite of stem rust races (RCRSC, QFCSC, QTHJC, RKQQC, and TPMKC). In adult plant screens near Nairobi. Kenya, it was rated 70S in 2008 and ranged from 30S to 60S in 2009, and 15S to 30MS in 2011, where S = susceptible and MS = moderately susceptible. In greenhouse seedling tests, it was highly resistant to races TPMKC, QFCSC, RCRSC, and RKQQC but susceptible to races TTTTF and TTKSK; Mattern is postulated as carrying *Sr38*. It is also postulated to carry leaf rust (caused by *P. triticina* Eriks.)–resistant genes

Table 1. Grain yield and agronomic properties of wheat cultivar Mattern compared with check cultivars from advanced breeding trials.

Trial (no. of locations)	Entry	Grain yield	Volume weight	Days from 1 Jan. to heading	Plant height
		kg ha^{-1}	kg hL^{-1}	d	cm
2008 NRPN† (15)	Mattern	4366	72.9	143	80
	Wesley	4133	72.8	142	75
	Antelope	4191	74.8	144	77
	Jerry	3873	72.3	148	90
	LSD (0.05)‡	398			
2011 NRPN (12)	Mattern	3814	71.8	166	87
	Wesley	3944	71.2	166	82
	Overland	4430	73.9	168	90
	Jerry	3530	72.0	171	93
	LSD (0.05)	399			
2008 NE (13)	Mattern	4246	74.4		86
	Camelot	4242	75.3		87
	Overland	4444	76.0		89
	Wesley	4127	73.9		80
	LSD (0.05)	557	2.2		6
2009 NE (14)	Mattern	4187	73.4		86
	Camelot	4280	74.6		88
	Overland	4222	75.2		87
	Wesley	4282	73.9		80
	LSD (0.05)	548	3.2		7
2011 NE (11)	Mattern	4698	72.1		86
	Camelot	4667	73.1		88
	Overland	5000	75.1		90
	Wesley	4877	73.4		80
	LSD (0.05)	565	2.7		7
2012 NE (15)	Mattern	4262	76.1		84
	Camelot	3915	75.7		89
	Overland	4202	77.9		88
	Wesley	3949	76.3		82
	LSD (0.05)	496	2.3		6

† NRPN, USDA–ARS coordinated Northern Regional Performance Nursery.

‡ LSD (0.05) given for all trial entries. Means presented only for selected control cultivars.

Lr14a and *Lr17* and also carries DNA markers indicating the presence of gene cluster *Lr37/Sr38/Yr17*; however, Mattern is moderately susceptible to susceptible to current prevalent Great Plains leaf rust races. It is susceptible to greenhouse seedling infections with stripe rust (caused by *P. striiformis* Westend. f. sp. *tritici* Eriks.) but is moderately resistant to resistant to adult plant infections by races PST-100, PST-114, and PST-127. Field responses to stripe rust vary, ranging from resistant in the eastern United States to moderately susceptible to moderately resistant in the Great Plains to susceptible in the Pacific Northwest. Based on its variable field responses, it is possible Mattern carries a form of high-temperature adult plant resistance to stripe rust.

End-Use Quality

Mean grain volume weights and grain protein concentration of Mattern, based on composite samples of three production zones of the 2008 and 2011 NRPN, did not differ from the controls (Table 2). Single-kernel hardness testing classified Mattern as a hard wheat, with hardness values similar to Wesley, Overland, and Jerry and significantly higher than that of Antelope. Milling yield of Mattern was significantly lower than those of the three controls, an attribute typical of waxy wheat (Graybosch et al., 2003). Mattern carries alleles at the *Glu-1* loci conditioning the production of high-molecular-weight glutenin subunits 1Ax 2*, 1Bx 7, 1By 9, 1Dx 5, and 1Dy 10. DNA markers (http://www.ars.usda.gov/Research/docs.htm?docid=11932) verified the presence of alleles encoding 1Ax 2*, 1Bx 7, 1Dx 5, and 1Dy 10. Mixograph flour water absorption of Mattern also did not differ from control cultivars in 2008; in 2011, however, it was significantly higher (Table 3). Loaf volumes of Mattern did not differ from controls; however, after resting 24 h, loaf volume collapsed. Flour pasting properties, as measured by the Rapid Visco Analyzer

Table 2. Grain quality characteristics of wheat cultivar Mattern compared with check cultivars from the Northern Regional Performance Nursery, 2008 and 2011.

Production zone†	Entry	Grain volume weight	Kernel hardness	Grain protein	Milling yield
		kg hL^{-1}	units	g kg^{-1}	g kg^{-1}
		2008			
NCP	Mattern	75.5	67	129	644
	Antelope	77.5	53	128	703
	Wesley	73.8	59	132	725
	Jerry	76.2	58	131	723
NHP	Mattern	77.4	62	144	660
	Antelope	77.7	60	133	695
	Wesley	75.7	61	143	720
	Jerry	75.2	64	145	706
NP	Mattern	77.0	68	131	644
	Antelope	78.1	60	134	681
	Wesley	77.9	66	139	720
	Jerry	75.2	67	126	698
Means	Mattern	76.6	65	134	649
	Antelope	77.8	57	131	693
	Wesley	75.8	62	138	722
	Jerry	75.5	63	134	709
	LSD (0.05)	ns	7.3	ns	18
		2011			
NCP	Mattern	73.9	60	129	612
	Overland	74.8	60	126	717
	Wesley	74.8	51	135	710
	Jerry	73.0	49	134	710
NHP	Mattern	77.0	61	104	584
	Overland	76.2	50	96	708
	Wesley	74.8	50	104	703
	Jerry	73.0	56	112	697
NP	Mattern	75.3	69	119	671
	Overland	76.6	68	106	703
	Wesley	73.5	67	117	688
	Jerry	74.7	61	117	692
Means	Mattern	75.4	63	117	622
	Overland	75.9	59	109	709
	Wesley	74.7	56	118	701
	Jerry	74.3	55	121	700
	LSD (0.05)	ns	ns	ns	45

† Production zones: NCP, North Central Plains; NHP, Northern High Plains; NP, Northern Plains.

(Perten Instruments), differed markedly from the controls and from typical wheats in general (Table 3). Peak time was reached nearly 3 min earlier; peak and final viscosities were significantly lower than the controls (Table 3). In 2008, viscosities were only slightly reduced relative to controls. In 2011, viscosities were markedly reduced. This inconsistency may relate to the different cooking properties of waxy starch and could indicate that their assessment requires different procedures than those used to asses wild-type wheat starch properties. The observed low stirring numbers are typical of waxy wheats, are independent of α-amylase activity (Graybosch et al., 2000), and do not indicate preharvest sprouting.

Availability

The Nebraska Foundation Seed Division, University of Nebraska–Lincoln, Lincoln, NE 68583 will produce, distribute, and license seed of Mattern for identity preserved markets. The U.S. Department of Agriculture will not have seed for commercial distribution. The seed classes will be breeder, foundation, registered, and certified. Mattern has been submitted for U.S. Plant Variety Protection under P. L. 10577 with the certification option.

Acknowledgments

Mattern was developed with partial financial support from the Nebraska Wheat Development, Utilization, and Marketing Board.

Table 3. Flour quality characteristics of wheat cultivar Mattern compared with check cultivars from the Northern Regional Performance Nursery, 2008 and 2011.

Production zone†	Entry	MG‡ water absorption	MG mixing time	MG tolerance score§	Stirring number	RVA peak time	RVA peak viscosity	RVA final viscosity	Loaf volume
		g kg^{-1}	min	0–5	RVU	min	RVU¶	RVU	mL
					2008				
NCP	Mattern	635	3.1	3	86	6.3	157	56	1055
	Antelope	617	4.4	3	131	6.2	223	261	845
	Wesley	618	5.5	4	123	6.3	223	276	950
	Jerry	623	3.6	3	133	6.3	216	279	895
NHP	Mattern	643	2.5	2	97	4.0	198	140	900
	Antelope	635	4.0	3	134	6.4	226	289	895
	Wesley	637	5.0	4	128	6.3	214	287	950
	Jerry	653	4.4	4	142	6.3	208	297	970
NWP	Mattern	645	2.8	3	113	3.9	188	133	960
	Antelope	633	3.9	4	141	6.4	225	284	750
	Wesley	631	5.6	5	121	6.3	206	270	835
	Jerry	625	5.4	5	114	6.3	222	296	720
Means	Mattern	641	2.8	2.7	99	4.7	181	110	971
	Antelope	628	4.1	3.3	135	6.3	225	278	830
	Wesley	629	5.4	4.3	124	6.3	215	278	911
	Jerry	634	4.5	4.0	130	6.3	216	291	861
	LSD (0.05)	ns	1.0	1.3	20	1.3	23	48	ns
					2011				
NCP	Mattern	686	4.1	4	52	3.4	75	17	760
	Overland	611	2.4	2	130	6.2	212	256	730
	Wesley	631	6.4	4	127	6.2	208	254	950
	Jerry	617	4.4	3	126	6	170	193	785
NHP	Mattern	622	3.6	3	110	3.7	210	120	860
	Overland	546	3.6	1	137	6.3	236	280	700
	Wesley	572	4.6	4	140	6.3	242	289	760
	Jerry	580	3.9	3	157	6.3	234	300	800
NP	Mattern	680	4	3	24	3.3	41	9	920
	Overland	590	3.4	2	138	6.2	205	234	785
	Wesley	601	5.1	3	134	6.2	194	230	880
	Jerry	602	4.5	3	123	5.9	160	180	715
Means	Mattern	663	3.9	3.3	62	3.5	109	49	847
	Overland	582	3.1	1.7	135	6.2	218	257	738
	Wesley	601	5.4	3.7	134	6.2	215	258	863
	Jerry	600	4.3	3.0	135	6.1	188	224	767
	LSD (0.05)	56	1.1	0.9	46	0.3	96	92	ns

† Production zones: NCP, North Central Plains; NHP, Northern High Plains; NWP, Northwest Plains; NP, Northern Plains.

‡ MG, mixograph; RVA, Rapid Visco Analyzer.

§ MG tolerance score: 0 = no tolerance to over-mixing, 5 = excessive tolerance.

¶ RVU: rapid visco units.

Funding for R.A. Graybosch is derived from USDA–ARS Project Number 5440-21000-031-00, Genetic Improvement of Winter Wheat for End-Use Quality and Disease Resistance. The authors wish to acknowledge the technical assistance of Lori Divis, Vern Hansen, Gregory Dorn, Mitchell Montgomery, Elizabeth Maghirang, and Janelle Millhouse, and the vision and support of Cal Konzak. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

References

Akashi, H., S. Endo, K. Hatta, K. Hayakawa, T. Hoshino, S. Ishigami, S. Ito, T. Nakamura, S. Tago, K. Tanaka, M. Yamamori, and R. Yoshikawa. 2000. Flour blends for breads, cakes, or noodles, and foods prepared from the flour blends. U.S. Patent 6042867. Date issued: 28 March.

Blechl, A.E., and O.D. Anderson. 1996. Expression of a novel high-molecular-weight glutenin subunit gene in transgenic wheat. Nat. Biotechnol. 14:875–879. doi:10.1038/nbt0796-875

Collins, G.N. 1909. A new type of Indian corn from China. Bureau of Plant Industry Bull. 161. U.S. Gov. Print. Office, Washington, DC.

Dowell, F.E., E.B. Maghirang, R.A. Graybosch, W.A. Berzonsky, and S.R. Delwiche. 2009. Selecting and sorting waxy wheat kernels using near-infrared spectroscopy. Cereal Chem. 86:251–255. doi:10.1094/CCHEM-86-3-0251

Graybosch, R.A. 1998. Waxy wheats: Origin, properties and prospects. Trends Food Sci. Technol. 9:135–142. doi:10.1016/S0924-2244(98)00034-X

Graybosch, R.A., G. Guo, and D.R. Shelton. 2000. Aberrant falling numbers of waxy wheats independent of alpha-amylase activity. Cereal Chem. 77:1–3. doi:10.1094/CCHEM.2000.77.1.1

Graybosch, R.A., C.J. Peterson, L.E. Hansen, S. Rahman, A. Hill, and J. Skerritt. 1998. Identification and characterization of U.S. wheats carrying null alleles at the wx loci. Cereal Chem. 75:162–165. doi:10.1094/CCHEM.1998.75.1.162

Graybosch, R.A., E. Souza, W. Berzonsky, P.S. Baenziger, and O.K. Chung. 2003. Functional properties of waxy wheat flours: Genotypic and environmental effects. J. Cereal Sci. 38:69–76. doi:10.1016/S0733-5210(02)00139-X

Hansen, L.E., D.S. Jackson, R.L. Wehling, and R.A. Graybosch. 2010. Functionality of chemically modified wild-type, partial waxy and waxy starches from tetraploid wheats. J. Cereal Sci. 51:409–414. doi:10.1016/j.jcs.2010.02.010

Hatta, K., K. Hayakawa, T. Hoshino, S. Ishigami, S. Ito, Y. Kawamura, H. Miyamura, M. Mizukami, Y. Murayama, T. Nakamura, S. Tago, Y. Tanaka, K. Tanaka, M. Yamamori, and R. Yoshikawa. 2000. Flour blends for deep fried foods, steamed Chinese manju, dough sheets, okonomi-yaki, and takoyaki. U.S. Patent 6,139,894. Date issued: 31 October.

Keeling, P.L., F.G. Dunlap, and M. Chang. 2000. Waxy wheat starch type having waxy proteins in granule. U.S. Patent 6,143,963. Date issued: 7 November.

Ma, H.X., G.H. Bai, B.F. Carver, and L.L. Zhou. 2005. Molecular mapping of a quantitative trait locus for aluminum tolerance in wheat cultivar Atlas 66. Theor. Appl. Genet. 112:51–57. doi:10.1007/s00122-005-0101-5

Morris, C.F., and G.E. King. 2007. Registration of 'Waxy-Pen' soft white spring waxy wheat. J. Plant Reg. 1:23–24. doi:10.3198/jpr2006.08.0551crc

Nakamura, T., M. Yamamori, H. Hirano, and S. Hidaka. 1993. Identification of three Wx proteins in wheat. Biochem. Genet. 31:75–86. doi:10.1007/BF02399821

Nakamura, T., M. Yamamori, H. Hirano, S. Hidaka, and T. Nagamine. 1995. Production of waxy (amylose-free) wheats. Mol. Gen. Genet. 248:253–259. doi:10.1007/BF02191591

Nelson, O.E., and H.W. Rines. 1962. The enzymatic deficiency in the waxy mutant of maize. Biochem. Biophys. Res. Commun. 9:297–300. doi:10.1016/0006-291X(62)90043-8

Pedersen, J.F., S.R. Bean, D.L. Funnell, and R.A. Graybosch. 2004. Rapid iodine staining techniques for identifying the waxy phenotype in sorghum grain and waxy genotype in sorghum pollen. Crop Sci. 44:764–767.

Peterson, C.J. 1992. Similarities among test sites based on cultivar performance in the hard red winter wheat region. Crop Sci. 32:907–912. doi:10.2135/cropsci1992.0011183X003200040014x

Slade, A.J., S.I. Fuerstenberg, D. Loeffler, M.N. Steine, and D. Facciotti. 2005. A reverse genetic, nontransgenic approach to wheat crop improvement by TILLING. Nat. Biotechnol. 23:75–81. doi:10.1038/nbt1043

Wilson, L.A., J.W. Colyn, G. Lai, and C. Morris. 2003. Waxy wheat products and processes for producing same. U.S. Patent 2,003,0008,049. Date issued: 9 January.

Zhao, R., X. Wu, B.W. Seabourn, S. Bean, L. Guan, Y. Shi, J.D. Wilson, R. Madl, and D. Wang. 2009. Comparison of waxy vs. nonwaxy wheats in fuel ethanol fermentation. Cereal Chem. 86:145–156. doi:10.1094/CCHEM-86-2-0145