Published online April 26, 2018
JOURNAL OF PLANT REGISTRATIONS

CULTIVAR

Registration of 'Bolles' Hard Red Spring Wheat with High Grain Protein Concentration and Superior Baking Quality

J. A. Anderson,* J. J. Wiersma, G. L. Linkert, S. K. Reynolds, J. A. Kolmer, Y. Jin, M. Rouse, R. Dill-Macky, M. J. Smith, G. A. Hareland, and J.-B. Ohm

Abstract

The hard red spring wheat (*Triticum aestivum* L.) market class in the United States commands the highest prices on the worldwide wheat markets because of its high protein concentration, strong gluten, and good baking properties. 'Bolles' (Reg. No. CV-1140, PI 678430) hard red spring wheat was released by the University of Minnesota Agricultural Experiment Station in 2015 and combines very high grain protein concentration, strong gluten, and good baking characteristics, along with competitive grain yields and good resistance to the diseases Fusarium head blight, leaf rust, stripe rust, and stem rust. Bolles is a mid-late maturity, semidwarf cultivar that should improve the overall end-use quality of the hard red spring wheat crop in its region of adaptation in the north-central United States.

Hard red spring wheat (*Triticum aestivum* L.) produced in the United States is highly valued on the world market for its high protein concentration and strong gluten, characteristics that make it a preferred class of wheat for yeast-leavened products either alone or in blends with other wheat classes (US Wheat Associates, 2017). Hard red spring wheat regularly has premiums and discounts at the first point of sale based on grain protein concentration (Minneapolis Grain Exchange, 2017). 'Bolles' (Reg. No. CV-1140, PI 678430) hard red spring wheat was developed by the University of Minnesota Agricultural Experiment Station and released in 2015. Bolles was released on the basis of its high grain protein concentration, end-use quality characteristics, competitive grain yields, and good disease resistance.

Bolles is an F_6–derived selection from the cross MN02268-1/MN01333-A-1, two experimental lines from the University of Minnesota breeding program that were not released. MN002268-1 has the pedigree MN99077 ('BacUp' [Busch et al., 1998]/'HJ98' [Busch et al., 2000])/MN97518 (SBE0303-18/MN92320), and MN01333-A-1 has the pedigree MN97008 (2375/MN91123)/MN97695 (MN92387/SBE0303-23). The cultivar name is to bring recognition to the first flour mill in Minnesota, built in the winter of 1845–1846 by Lemuel Bolles in Afton, MN.

Methods

Early Generation Development

The cross of MN02268-1/MN01333-A-1 was made in 2004 and designated 04X163. The F_1 generation was grown in a greenhouse, and approximately 700 F_2 seeds were grown in a St. Paul, MN, field in 2005. This field included inoculated spreader rows of wheat lines highly susceptible to leaf rust (caused by *Puccinia triticina* Eriks.) and stem rust (caused by *P. graminis* Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn.). A single spike from 25 plants with appropriate maturity, plant height, and leaf and

Journal of Plant Registrations 12:215–221 (2018).
doi:10.3198/jpr2017.08.0050crc
Received 17 Aug. 2017.
Accepted 4 Dec. 2017.
Registration by CSSA.
5585 Guilford Rd., Madison, WI 53711 USA
*Corresponding author (ander319@umn.edu)

J.A. Anderson, J.J. Wiersma, G.L. Linkert, and S.K. Reynolds, Dep. of Agronomy & Plant Genetics, Univ. of Minnesota, St. Paul, MN 55108; J.A. Kolmer, Y. Jin, and M. Rouse, USDA-ARS, St. Paul, MN 55108; R. Dill-Macky and M.J. Smith, Dep. of Plant Pathology, Univ. of Minnesota, St. Paul, MN 55108; G.A. Hareland and J.-B. Ohm, USDA-ARS, Red River Valley Agricultural Research Center, Cereal Crops Research Unit, Hard Spring and Durum Wheat Quality Lab., Fargo, ND 58102.

Abbreviations: DON, deoxynivalenol; FHB, Fusarium head blight; PYT, preliminary yield trial; VSK, visually scabby kernels.

stem rust resistances were harvested. After threshing the spikes individually, seed from 6 of the 25 spikes was discarded due to pale color or shriveled grains. Seed of the remaining 19 spikes was sown as $F_{2:3}$ headrows in St. Paul in 2006, and 14 rows were selected on the basis of appropriate plant height and resistance to leaf and stem rust.

Line Selection and Evaluation

In 2007, 4 $F_{3:4}$ headrows from each of the 14 selected F_3 rows were grown in St. Paul, and 5 of the 14 were selected on the basis of their straw strength. One spike from each of the selected rows was sown in a winter nursery in New Zealand for seed increase in 2008. All of the five rows were harvested in bulk in New Zealand, and one was designated as MN08165 and entered into unreplicated preliminary yield trials (PYTs) sown in Crookston and St. Paul, MN. These and all subsequent yield trials were sown in plots with a size of 4.5 to 5.5 m^2 and row spacing of 0.15 to 0.20 m.

MN08165 was entered in a two-replication advanced yield trial grown in Crookston, Morris, Stephen, and St. Paul, MN, in 2009. The reselected line, MN08165-8, was grown at 9 locations in 2010 and 10 to 15 locations from 2011 to 2014 in Minnesota statewide performance tests. MN08165-8 was tested in a Tri-State regional nursery having three to four sites in Minnesota, North Dakota, and South Dakota in 2011 and 2012. Six of the total of 21 regional environments were excluded from analysis because of low average grain yield (<1335 kg ha^{-1}) or grain volume weight (<68.4 kg hL^{-1}).

A sample of the harvested grain from two to three locations each year, beginning in 2008, was analyzed for dough mixing and bread-baking properties (AACCI, 2000) at the USDA-ARS Spring Wheat Quality Laboratory in Fargo, ND. Experimental bread making was performed by a straight-dough method using 25-g flour samples (AACCI approved method 10-10.03). Preharvest sprouting was evaluated by harvesting 10 intact spikes at physiological maturity from each of two replicates grown at Crookston and St. Paul from 2009 to 2014. Spikes were air dried for 5 d and stored at −20°C for 4 to 16 wk. Spikes were placed in a dew chamber (>90% relative humidity) at 22°C for 7 d and rated for degree of sprouting on a scale of 0 (no visible sprouting) to 9 (extensive sprouting over entire spike).

MN08165-8 was grown in inoculated, mist-irrigated Fusarium head blight (FHB, caused primarily by *Fusarium graminearum* Schwabe) nurseries at Crookston and St. Paul each year starting in 2008. The Crookston FHB nursery used *Fusarium graminearum*-colonized corn kernel inoculum and the St. Paul nursery used a spray-applied macroconidial suspension of *F. graminearum* following the methods of Fuentes-Granados et al. (2005). The FHB data collected included heading date, disease incidence and severity recorded 18 to 21 d after anthesis, seed weight from a 30-spike sample, visually scabby kernels (VSK), grain volume weight of the VSK sample using a 15.7-mL cylinder measuring 20 mm in diameter and 50 mm in height, and the deoxynivalenol (DON) concentration of mature seed (Fuentes-Granados et al., 2005).

MN08165-8 and all other experimental lines at the PYT stage or later were grown as single 1-m-long rows, 0.3 m apart, in an inoculated rust nursery in St. Paul, beginning in 2008. This nursery contained a mixture of leaf and stem rust-susceptible spreader rows, sown perpendicular to the experimental lines in every other alley. The alternate alleys were sown with winter wheat. Spreader rows were inoculated with prevalent leaf rust and stem rust pathogen races following the methods of Roelfs et al. (1992). MN08165-8 was tested for seedling reaction to leaf rust races KFBJG, MBDSD, MHDSB, MLDSD, TBBGJ, TCRKG, TDBGG, TFBJQ, THBJG, and TNRJG following the methods of Oelke and Kolmer (2004) and stem rust races GFMNC, MCCFC, QCCSM, QFCSC, QTHJC, RCRSC, RKQQC, TPMKC, and TTTTF following the methods of Jin and Singh (2006). MN08165-8 was evaluated for reaction to stem rust race TTKST (Ug99 race group) in stem rust nurseries in Debre Zeit, Ethiopia and/or Njoro, Kenya in 2012 to 2016 as described in Jin et al. (2007). The 2015–2016 African stem rust nursery data, collected after the release of MN08165-8 as Bolles, are also presented because they better represent the response of Bolles and check cultivars.

Seed Purification and Increase

A purification process was initiated in 2008 when 10 random spikes of MN08165 were harvested from the PYT in St. Paul. Eight of the 10 random heads were grown in St. Paul in 2009. One of the eight, designated MN08165-8, was selected for advancement because it was phenotypically representative of the line. Ten heads harvested from MN08165-8 were planted in New Zealand in fall 2009 as single rows. Five of the most uniform of the 10 rows of MN08165-8 were harvested in New Zealand, bulked together, and used to sow a seed increase in St. Paul in spring 2010. Two hundred random heads were harvested from the seed increase. A total of 160 of the 200 random headrows were grown in St. Paul in 2011. Seven of the 160 rows were discarded because they were either 1 d earlier heading (three rows), had a single plant with at least one spike 10 cm or more above other plants in the row (two rows), or were segregating for plant height or architecture (two rows). One or two heads were harvested from the remaining 153 selections and used to sow 160 headrows in 2012 at St. Paul. Thirteen of the 160 rows were discarded because they had one or more taller tillers (12 rows), or were segregating for plant height or architecture (one row). All 147 rows were combine-harvested in bulk, and 1.5 kg of the resulting seed was used to sow a seed increase in St. Paul in 2013. Approximately 0.3% of plants in the 2013 increase produced one spike at least 10 cm above the canopy and were removed. Approximately 145 kg of seed was produced from the seed increase and 68 kg of the seed increase was sown near Brawley, CA, for further seed increase during the winter of 2013–2014. A total of 6145 kg cleaned seed was produced from the California increase, and further seed increase was arranged by the Minnesota Crop Improvement Association.

Statistical Analyses

All statistical analyses were done using JMP Pro 13.0.0 (SAS Institute, Raleigh, NC). Data were subjected to analysis of variance across environments with each location-year combination considered a separate environment. A mixed model was used with genotypes as fixed factors and environments, replications within environments, and genotype × environment interaction as random factors. The LSD test ($\alpha = 0.05$) was used to compare least squares means for the genotype effects.

Characteristics

Agronomic and Botanical Description

Bolles has erect juvenile plant growth, a recurved flag leaf, white glumes with an oblique shoulder, and an acuminate beak. The spike is awned, middense, and tapering. The kernel is red and ovate in shape with angular cheeks and a midnarrow, middeep crease. The brush on the kernel is not collared and is medium in length. Bolles is a mid-late maturity cultivar, averaging 2.4 d later in heading compared with other cultivars in Minnesota locations from 2012 to 2014 (Table 1). This is similar to 'LCS Albany'. Bolles is taller than average at 81.7 cm, measured from soil level to the tip of the spike, excluding awns (Table 1). This height is not significantly different than 'Prosper' (83.4 cm) but is significantly taller than 'RB07' (78.5 cm). Bolles has average straw strength with a score of 1.24 on a 0-to-9 scale (where 0 = no lodging and 9 = flat) across 12 locations where differential lodging occurred from 2012 to 2014 (Table 1). This level of straw strength is significantly better than Prosper (2.24) but significantly worse than 'Rollag' (0.53).

Field Performance

In 41 Minnesota yield trials from 2012 to 2014, Bolles's average grain yield was 5066 kg ha^{-1}, significantly higher than 'Glenn' (4584 kg ha^{-1}), a cultivar that also has high grain protein and excellent baking quality. Bolles's grain yield was significantly lower than cultivars that have lower grain protein concentration, including LCS Albany (5707 kg ha^{-1}) and Prosper (5433 kg ha^{-1}). In these same trials, the protein concentration of Bolles was 156.6 kg hL^{-1}, significantly higher than all of the 16 comparison cultivars. The most likely source of this high protein concentration is the cultivar BacUp (Busch et al., 1998). When evaluated in 15 environments in Minnesota, North Dakota, and South Dakota in 2011 and 2012 in Tri-State regional nurseries, Bolles's grain yield (3471 kg ha^{-1}) was significantly higher than Glenn (3206 kg ha^{-1}) but not significantly different than the check 'Verde' (3456 kg ha^{-1}) (Table 2).

Bolles is rated as resistant to preharvest sprouting. In six tests conducted from 2012 to 2014, Bolles had a preharvest sprouting rating of 0.65, below the average of 0.98 for all cultivars evaluated in the same tests (Table 1).

Disease Resistance

Bolles has been evaluated in FHB nurseries since 2008 and has moderate resistance to this disease, assigned a rating of 4 on a 1-to-9 scale (where 1 = resistant to 9 = susceptible) for commercially available cultivars. Compared with other cultivars, Bolles has better than average FHB severity, FHB index, percentage VSK and DON, and seed weight and grain volume weight (Table 3). Bolles does not possesses the major FHB resistance quantitative trait locus *Fhb1* (Liu et al., 2008b).

Bolles is resistant to leaf rust, showing resistant infection types when inoculated as seedlings to leaf rust pathogen races KFBJG, MBDSD, MHDSB, MLDSD, TBBGJ, TCRKG,

Table 1. Performance of Bolles and other hard red spring wheat cultivars in Minnesota, 2012–2014.

Cultivar†	Reference	Grain yield	Grain volume wt.	Grain protein	Days to heading	Plant height	Straw strength	Preharvest sprouting
		kg ha^{-1}	kg hL^{-1}	g kg^{-1}	d from 1 June	cm	0–9‡	0–9§
LCS Albany	PI 658002	5707	77.5	131.9	26.4	77.8	1.21	2.09
Prosper	Mergoum et al., 2013	5433	77.5	138.0	25.0	83.4	2.24	0.74
Faller	Mergoum et al., 2008	5345	77.3	137.7	24.9	83.2	0.94	0.54
Forefront	Glover et al., 2013	5171	78.3	147.1	20.5	87.9	1.76	1.75
Samson	PI 652923	5114	76.1	142.8	22.1	72.8	0.57	2.37
SY Soren	PI 662048	5079	77.9	146.7	22.7	73.1	0.78	0.51
Bolles	–	5066	77.2	156.6	26.1	81.7	1.24	0.65
Knudson¶	PI 619609	5040	77.2	137.9	23.6	78.6	1.68	0.94
Elgin-ND	Mergoum et al., 2016	4924	76.9	145.4	24.1	86.6	2.34	0.77
RB07	Anderson et al., 2009	4921	77.4	145.7	22.1	78.5	1.58	0.65
WB-Mayville	PI 661061	4909	76.9	148.8	21.8	72.9	0.47	1.17
Barlow	Mergoum et al., 2011	4858	78.2	147.6	21.5	83.8	1.81	0.85
Linkert	Anderson et al., 2018	4813	77.7	152.4	23.3	73.3	0.28	0.90
Vantage	PI 653518	4800	79.3	153.5	27.6	77.5	0.22	1.28
Rollag	Anderson et al., 2015	4794	78.4	150.3	22.8	75.3	0.53	0.34
Glenn	Mergoum et al., 2006	4584	79.6	149.5	21.5	84.1	1.18	0.23
Marshall¶	Busch et al., 1983	4557	75.9	135.4	27.1	77.8	1.10	0.89
Mean		5007	77.6	145.1	23.7	79.3	1.17	0.98
LSD (0.05)		143	0.6	131.9	0.3	2.0	0.70	1.00
No. of environments		41	36	36	13	16	12	6

† Cultivars are sorted on the basis of grain yield.

‡ 0 = no lodging; 9 = flat.

§ 0 = no visible sprouting; 9 = extensive sprouting over entire spike.

¶ Long-term check.

TDBGG, TFBJQ, THBJG, and TNRJG (Table 4). Importantly, Bolles is resistant to the *Lr21*-virulent races (TFBGQ and TFBJQ) that were identified in the region in 2010 (Kolmer and Anderson, 2011). In naturally infected sites from 2008 to 2014, Bolles showed good resistance to stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Eriks.). The results of DNA marker testing (Lagudah et al., 2009) indicate that Bolles does not contain the adult plant resistance gene *Lr34/Yr18*.

Bolles is highly resistant to the prevalent stem rust pathogen race QFCSC and other races that are important in North America (QTHJC, RCRSC, RKQQC, TPMKC, and TTTTF) at both the seedling (Table 5) and adult plant stages. Since the beginning of US field evaluations of MN08165 in 2008, natural infection by stem rust on Bolles has not been observed. Bolles has shown susceptible reactions to TTKSK (syn. Ug99) when evaluated in seedling screens in the greenhouse and moderately

Table 2. Performance of Bolles and other hard red spring wheat cultivars in the Tri-State Regional Hard Red Spring Wheat Nursery, 2011–2012.

Cultivar†	Reference	Yield	Grain volume wt.	Protein	Heading	Height
		kg ha^{-1}	kg hL^{-1}	g kg^{-1}	d from 1 June	cm
Prevail	Glover et al. 2017	3691	76.4	148.6	19.6	79.2
Select	Glover et al. 2011	3540	78.0	147.6	16.9	82.1
Bolles	–	3471	75.6	164.7	23.5	79.7
Verde‡	Busch et al. 1996	3456	75.2	148.5	21.8	79.1
RB07	Anderson et al., 2009	3434	76.0	153.7	19.7	76.0
Faller	Mergoum et al., 2008	3433	75.5	149.8	22.7	79.5
Glenn	Mergoum et al., 2006	3206	79.4	159.3	18.9	84.5
Mean		3462	76.6	153.2	20.4	80.0
LSD (0.05)		247	0.8	7.6	0.9	2.1
No. of environments		15	15	9	12	14

† Cultivars are sorted on the basis of grain yield.

‡ Long-term check.

Table 3. Performance of Bolles and other hard red spring wheat cultivars and checks in inoculated Fusarium head blight nurseries, 2012–2014.

Line†	Heading	Incidence	Severity	Disease index	Spike seed wt.	Grain volume wt.	Visually scabby kernels	Deoxynivalenol
	d after 1 June	%			g	kg hL^{-1}	%	μg g^{-1}
Forefront	33.7	64.4	14.9	10.6	0.88	70.6	8.6	2.3
Alsen‡§	37.3	86.9	21.2	19.2	0.79	72.4	7.2	3.6
Rollag	36.8	89.2	21.0	19.3	0.90	71.7	7.0	3.6
LCS Albany	39.7	82.5	25.9	21.8	0.89	72.2	7.9	4.0
Glenn	34.9	84.9	23.4	20.5	0.85	74.0	8.5	4.4
RB07	36.2	87.5	30.9	27.9	0.84	68.5	12.8	5.0
Norden	37.3	91.1	36.8	34.7	0.87	72.0	9.8	5.2
BacUp‡	33.8	82.2	21.5	18.8	0.83	70.6	12.9	5.5
SY Soren	36.3	95.3	37.0	35.7	0.80	68.5	12.5	5.8
Bolles	38.6	91.7	30.3	28.1	0.96	70.5	10.8	6.0
Faller	37.9	82.4	24.1	20.7	0.97	70.9	8.8	6.5
Elgin-ND	37.3	90.1	29.8	27.3	0.95	70.5	10.5	6.7
Roblin¶	33.9	98.9	71.4	70.9	0.80	63.1	40.6	7.1
Linkert	37.4	89.7	35.4	33.2	0.87	69.2	13.0	7.5
Prosper	37.8	87.5	29.7	27.1	0.97	70.1	10.3	7.7
MN00269¶	41.2	98.6	63.7	63.0	0.77	58.5	31.9	8.1
WB-Mayville	36.4	94.2	58.8	57.0	0.82	63.4	25.9	8.5
Marshall#	39.6	91.4	38.1	36.7	0.80	67.8	16.4	9.3
Knudson	37.7	93.3	41.9	40.0	0.86	66.8	23.8	10.0
Wheaton¶§	38.8	95.6	70.8	69.1	0.76	58.3	56.7	13.5
Mean	37.1	88.9	36.3	34.1	0.86	68.5	16.8	6.5
LSD (0.05)	1.0	9.1	10.2	11.8	0.13	2.7	8.8	3.3
No. of environments	7	6	6	6	5	6	6	6

† Lines are sorted by deoxynivalenol content.

‡ Moderately resistant check.

§ Alsen, Frohberg et al. (2006); Wheaton, Busch et al. (1984)

¶ Susceptible check.

Long-term check.

susceptible reactions in field stem rust nurseries in Ethiopia and Kenya (Table 5).

End-Use Quality

Bolles has excellent end-use quality, having superior grain and flour protein concentration (Tables 1 and 6). Bolles's dough has good water absorption prior to baking (bake absorption, Table 6) at 562 g kg^{-1}. Bolles has a long bake mix time, 3.1 min, significantly longer than all but 4 of the 16 comparison cultivars (Table 6). The loaf volume of Bolles is very high, 208 mL, significantly higher than all but three of the comparison cultivars. The Farinograph stability of Bolles was 19.3 min, averaged over grain samples from four environments. This is near the mean, 19.5 min, of the comparison cultivars. Bolles contains the 2* and 5+10 subunits of the *Glu-A1* and *Glu-D1* loci, respectively (Liu et al., 2008a). These subunits have been positively correlated with bread-making quality (Payne, 1987).

Availability

The Minnesota Agricultural Experiment Station, St. Paul, MN 55108, will maintain breeder seed of Bolles. Foundation seed will be produced and maintained by the Minnesota Crop Improvement Association, 1900 Hendon Ave., St. Paul, MN 55108. Bolles has been approved for US Plant Variety Protection (PVP no. 201600163) with the seed certification option. A seed sample has been deposited in the USDA-ARS National Center for Genetic Resources Preservation, where it will become available for distribution after expiration of PVP. Small quantities of seed for research purposes may be obtained from the corresponding author for at least five years from the date of this publication.

Acknowledgments

Bolles was developed with financial support from the Minnesota Agricultural Experiment Station, the Minnesota Wheat Research and Promotion Council, and the US Department of Agriculture Agricultural Research Service under Agreement Nos. 59-0790-9-025 and 59-0206-9-070 and the Agriculture and Food Research Initiative Competitive

Table 4. Leaf rust reaction of Bolles and other hard red spring cultivars in seedling greenhouse tests and the field in 2011 and 2012 and postulation of *Lr* genes.

Line	Gene postulation	KFBJG†	MBDSD	MHDSB	MLDSD	TBBGJ	TCRKG	TDBGG	TFBJQ	THBJG	TNRJG	Field	
												2011	2012
Bolles	+	0;‡	;	;	0;	;	;	;	;	;	;	1R§	1R
Forefront	Lr34,+	0;	;2^{-}	;12	;2^{-}	;12^{-}	;	;2	;2^{-}	;1^{+}	;	5R	20MR
Linkert	Lr34,+	0;	;	;	;1	;	;	;1^{-}	;1^{-}	;	;	5R	10RMR
Norden	Lr34,+	3;	;1^{-}	;1^{-}	;	3^{+}2^{+}	;12^{-}	3^{+}	2^{+}	2^{+}	;	5R	10R
Prevail	Lr16, Lr34	;	;1	2^{+}	;1^{-}	;	;2^{-}	;1^{-}	;1^{-}	;1^{-}	;	–	5R
Prosper	Lr21	;1^{-}	0;	;	0;	;	;1^{-}	;1^{-}	3^{+}	;12^{-}	;	5MR	10S
Rollag	Lr34,+	;	;2^{-}	;	;2^{-}	;	;	;	;2^{-}	;1	;	30MS	5R
Select	Lr18, Lr34	;	;	;	0;	;12^{-}	3^{+}	;	;2	;	;1	30MRMS	10R
SY-Soren	Lr34,+	;	;2	;	22^{+}	;	;	;1^{-}	;2	;	;	10MR	5RMR
Velva	Lr21	;	0;	;	0;	;1^{-}	;	;2^{-}	32^{+}	;	;	TR	20MRMS
WB-Mayville	Lr1, Lr23, Lr34	;	;23	;	2^{+}3	32^{+}	;2	3^{+}	2^{+}	;2^{+}3	32^{+};	10MR	10RMR

† Reaction of individual leaf rust races is based on seedlings.

‡ Seedling infection types: 0 = immune response, no sign of infection; ";" = hypersensitive chlorotic or necrotic flecks; 1 = small uredinia surrounded by necrosis; 2 = small uredinia surrounded by chlorosis; 3 = moderate size uredinia without necrosis or chlorosis; 4 = large uredinia without necrosis or chlorosis; "+" = uredinia larger than normal; "–" = uredinia smaller than normal. A range of infection types is indicated by more than one infection type, with the predominant type listed first. Infection types described by Oelke and Kolmer (2004).

§ MR, moderately resistant; MS, moderately susceptible; R, resistant; S, susceptible.

Table 5. Wheat stem rust reaction of Bolles, hard red spring cultivars, and susceptible checks.

Line	QFCSC†	QTHJC	MCCFC	RCRSC	RKQQC	TPMKC	TTTTF	TTKSK (Ug99)	Kenya Oct. 2012	Ethiopia May 2013	Kenya May 2013	Kenya May 2015	Ethiopia May 2015	Kenya May 2016	Ethiopia May 2016
Bolles	;1-‡	1	1-	1-;	1	11+	1-	3	30 MSMR§	60 MSMR	30 MSMR	20 S	25 S	20 M	50 MSS
Tom¶	0	;2-	0;	0	;1-	1-;	0;	3–1;	5 MRMS	45 MSS	15 MRMS	15 M	45 S	5 M	40 MSMR
RB07	0;	1–1	0;	0	31	;1-	0;	3+	25 MS	55 SMS	25 MSS	15 MS	20 S	40 SMS	15 MS
Sabin¶	0;	1-	0;	0	;	0;	0;	3	50 MSS	60 SMS	35 MSS	25 MS	25 S	10 M	20 MSS
LMPG-6	4	4	4	4	4	4	4	3	60 S	50 S	40 S	60 S	50 S	40 M	40 SMS
Red Bobs¶	–	–	–	–	–	–	–	–	50 S	50 S	40 S	55 MSS	65 MS	30 MSS	60 S

† Reaction of individual leaf rust races is based on seedlings. Isolates corresponding to stem rust pathogen races described in Rouse et al. (2011).

‡ Seedling infection types: 0 = immune response, no sign of infection; ";" = hypersensitive chlorotic or necrotic flecks; 1 = small uredinia surrounded by necrosis; 2 = small uredinia surrounded by chlorosis; 3 = moderate size uredinia without necrosis or chlorosis; 4 = large uredinia without necrosis or chlorosis; "+" = uredinia larger than normal; "–" = uredinia smaller than normal. A range of infection types is indicated by more than one infection type, with the predominant type listed first. Infection types described by Jin et al. (2007).

§ Stem rust severity and infection response recorded as described in Jin et al. (2007). MR, moderately resistant; MS, moderately susceptible; R, resistant; S, susceptible.

¶ Red Bobs, Cltr 6255; Sabin, Anderson et al. (2012a); Tom, Anderson et al. (2012b).

Table 6. Grain end-use quality of Bolles and other hard red spring wheat cultivars grown in Minnesota, 2011–2013.

Cultivar†	Kernel weight	Grain protein‡	Flour protein‡	Bake mix	Bake absorption	Loaf volume	Farinograph absorption	Farinograph stability
	mg kernel^{-1}	g kg^{-1}	g kg^{-1}	min	g kg^{-1}	mL	g kg^{-1}	min
Bolles	33.3	159.1	151.1	3.1	562.0	208	664.0	19.3
RB07	28.6	145.0	134.7	2.5	544.8	203	637.8	15.9
Samson	31.2	140.4	128.9	2.8	537.2	201	605.8	21.4
Glenn	30.9	148.9	137.3	3.3	561.6	200	652.0	29.4
Elgin-ND	29.7	146.6	138.0	2.2	561.8	198	661.3	18.6
Vantage	30.6	151.3	144.7	2.5	546.0	198	654.3	14.8
Prosper	35.9	137.0	128.4	2.3	542.6	195	634.5	15.8
Barlow	31.4	145.6	135.7	2.3	565.0	194	664.8	16.2
SY-Soren	28.7	145.4	135.4	2.6	549.4	194	639.8	24.6
Linkert	33.8	150.6	140.9	3.1	554.6	190	650.8	25.8
Forefront	30.7	145.4	133.1	2.6	539.2	190	633.3	19.9
Faller	35.3	137.1	129.4	2.2	546.8	189	630.3	20.0
Knudson	32.5	136.7	126.9	3.5	551.8	187	634.5	30.4
WB-Mayville	34.1	146.9	134.9	2.5	558.0	187	658.5	28.2
LCS Albany	27.2	131.4	122.1	2.3	541.0	186	609.0	9.0
Rollag	31.4	149.6	139.0	2.1	562.2	185	684.3	9.0
Marshall§	28.4	132.6	120.7	2.1	519.6	184	608.8	12.1
Mean	31.5	142.8	132.9	2.6	550.8	192	640.7	19.5
LSD (0.05)	1.2	3.4	4.0	0.3	10.2	9	17.4	6.8
No. of environments	5	7	7	5	5	7	4	4

† Cultivars are sorted by loaf volume.

‡ 12% moisture basis.

§ Long-term check.

Grant 2011-68002-30029 (Triticeae-CAP). This is a cooperative project with the US Wheat & Barley Scab Initiative. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the US Department of Agriculture.

References

AACC International. 2000. Approved methods of the American Association of Cereal Chemists International. 10th ed. AACC International, St. Paul, MN.

Anderson, J.A., G.L. Linkert, R.H. Busch, J.J. Wiersma, J.A. Kolmer, Y. Jin, R. Dill-Macky, J.V. Wiersma, G.A. Hareland, and D.V. McVey. 2009. Registration of 'RB07' wheat. J. Plant Reg. 3:175–180. doi:10.3198/jpr2008.08.0478crc

Anderson, J.A., J.J. Wiersma, G.L. Linkert, J.A. Kolmer, Y. Jin, R. Dill-Macky, J.V. Wiersma, G.A. Hareland, and R.H. Busch. 2012a. Registration of 'Sabin' wheat. J. Plant Reg. 6:174–179. doi:10.3198/jpr2011.06.0344crc

Anderson, J.A., J.J. Wiersma, G.L. Linkert, J.A. Kolmer, Y. Jin, R. Dill-Macky, J.V. Wiersma, G.A. Hareland, and R.H. Busch. 2012b. Registration of 'Tom' wheat. J. Plant Reg. 6:180–185. doi:10.3198/jpr2011.06.0339crc

Anderson, J.A., J.J. Wiersma, G.L. Linkert, S. Reynolds, J.A. Kolmer, Y. Jin, R. Dill-Macky, and G.A. Hareland. 2015. Registration of 'Rollag' spring wheat. J. Plant Reg. 9:201–207. doi:10.3198/jpr2014.07.0048crc

Anderson, J.A., J.J. Wiersma, G.L. Linkert, S. Reynolds, J.A. Kolmer, Y. Jin, M. Rouse, R. Dill-Macky, G.A. Hareland, and J.-B. Ohm. 2018. Registration of 'Linkert' spring wheat with good straw strength and adult plant resistance to the Ug99 family of stem rust races. J. Plant Reg. doi:10.3198/jpr2017.07.0046crc

Busch, R.H., D.V. McVey, G.L. Linkert, J.V. Wiersma, R. Dill-Macky, G.A. Hareland, I. Edwards, and H.J. Schmidt. 2000. Registration of 'HJ98' wheat. Crop Sci. 40:296–297. doi:10.2135/cropsci2000.0011rcv

Busch, R.H., D.V. McVey, G.L. Linkert, J.V. Wiersma, D.D. Warnes, R.D. Wilcoxson, R. Dill-Macky, G.A. Hareland, I. Edwards, and H.J. Schmidt. 1998. Registration of 'BacUp' wheat. Crop Sci. 38:550. doi:10.2135/cropsci1998.0011183X003800020073x

Busch, R.H., D.V. McVey, G.L. Linkert, J.V. Wiersma, D.O. Warnes, R.D. Wilcoxson, G.A. Hareland, I. Edwards, and H. Schmidt. 1996. Registration of Verde wheat. Crop Sci. 36:1418. doi:10.2135/cropsci1996.0011183X003600050072x

Busch, R., D. McVey, T. Rauch, J. Baumer, and F. Elsayed. 1984. Registration of Wheaton wheat. Crop Sci. 24:622. doi:10.2135/cropsci1984.0011183X002400030054x

Busch, R., D. McVey, V. Youngs, R. Heiner, and F. Elsayed. 1983. Registration of Marshall wheat. Crop Sci. 23:187. doi:10.2135/cropsci1983.0011183X002300010074x

Frohberg, R.C., R.W. Stack, and M. Mergoum. 2006. Registration of 'Alsen' wheat. Crop Sci. 46:2311–2312. doi:10.2135/cropsci2005.12.0501

Fuentes-Granados, R.G., H.R. Mickelson, R.H. Busch, R. Dill-Macky, C.K. Evans, W.G. Thompson, J.V. Wiersma, W. Xie, Y. Dong, and J.A. Anderson. 2005. Resource allocation and cultivar stability in breeding for Fusarium head blight resistance in spring wheat. Crop Sci. 45:1965–1972. doi:10.2135/cropsci2004.0589

Glover, K.D., J.L. Kleinjan, Y. Jin, L.E. Osborne, J.A. Ingemansen, E.B. Turnipseed, and J.B. Ohm. 2017. J. Plant Reg. 11:55–60. doi:10.3198/jpr2016.05.0026crc

Glover, K., J.C. Rudd, R.N. Devkota, R.G. Hall, Y. Jin, L.E. Osborne, J.A. Ingemansen, J.R. Rickertsen, and G.A. Hareland. 2011. Registration of 'Select' wheat. J. Plant Reg. 5:196–201. doi:10.3198/jpr2010.08.0477crc

Glover, K.D., J.C. Rudd, R.N. Devkota, R.G. Hall, Y. Jin, L.E. Osborne, J.A. Ingemansen, E.B. Turnipseed, J.R. Rickertsen, and G.A. Hareland. 2013. Registration of 'Forefront' wheat. J. Plant Reg. 7:184–190. doi:10.3198/jpr2012.07.0007crc

Jin, Y., and R.P. Singh. 2006. Resistance in US wheat to recent eastern African isolates of *Puccinia graminis* f. sp. *tritici* with virulence to resistance gene Sr31. Plant Dis. 90:476–480. doi:10.1094/PD-90-0476

Jin, Y., R.P. Singh, R.W. Ward, R. Wanyera, M. Kinyua, P. Njau, T. Fetch, Z.A. Pretorius, and A. Yahyaoui. 2007. Characterization of seedling infection types and adult plant infection responses of monogenic Sr gene lines to race TTKS of *Puccinia graminis* f. sp. *tritici*. Plant Dis. 91:1096–1099. doi:10.1094/PDIS-91-9-1096

Kolmer, J., and J. Anderson. 2011. First detection in North America of virulence in wheat leaf rust (*Puccinia triticina*) to seedling plants of wheat with Lr21. Plant Dis. 95:1032. doi:10.1094/PDIS-04-11-0275

Lagudah, E.S., S.G. Krattinger, S.A. Herrera-Foessel, R.P. Singh, J. Huerta-Espino, W. Spielmeyer, G. Brown-Guedira, L. Selter, and B. Keller. 2009. Gene-specific markers for the wheat gene *Lr34/Yr18* which confers resistance to multiple fungal pathogens. Theor. Appl. Genet. 119:889–898.

Liu, S., S. Chao, and J.A. Anderson. 2008a. New DNA markers for high molecular weight glutenin subunits in wheat. Theor. Appl. Genet. 118:177–183.

Liu, S., M.O. Pumphrey, B.S. Gill, H.N. Trick, J.X. Zhang, J. Dolezel, B. Chalhoub, and J.A. Anderson. 2008b. Toward positional cloning of *Fhb1*, a major QTL for Fusarium head blight resistance in wheat. Cereal Res. Commun. 36(Suppl. 6):195–201. doi:10.1556/CRC.36.2008.Suppl.B.15

Mergoum, M., R.C. Frohberg, T. Olson, T.L. Friesen, J.B. Rasmussen, and R.W. Stack. 2006. Registration of 'Glenn' wheat. Crop Sci. 46:473–474. doi:10.2135/cropsci2005.0287

Mergoum, M., R.C. Frohberg, R.W. Stack, J.W. Rasmussen, and T.L. Friesen. 2008. Registration of 'Faller' spring wheat. J. Plant Reg. 2:224–229. doi:10.3198/jpr2008.03.0166crc

Mergoum, M., R.C. Frohberg, R.W. Stack, S. Simsek, T.B. Adhikari, J.W. Rasmussen, M.S. Alamri, T.L. Friesen, and J. Anderson. 2013. 'Prosper': A high-yielding hard red spring wheat cultivar adapted to the North Central Plains of the USA. J. Plant Reg. 7:75–80. doi:10.3198/jpr2012.05.0271crc

Mergoum, M., S. Simsek, R. Frohberg, J. Rasmussen, T. Friesen, and T. Adhikari. 2011. 'Barlow': A high-quality and high-yielding hard red spring wheat cultivar adapted to the North Central Plains of the USA. J. Plant Reg. 5:62. doi:10.3198/jpr2010.05.0259crc

Mergoum, M., S. Simsek, S. Zhong, M. Acevedo, T.L. Friesen, M.S. Alamri, S. Xu, and Z. Liu. 2016. 'Elgin-ND' spring wheat: A newly adapted cultivar to the North-Central Plains of the United States with high agronomic and quality performance. J. Plant Reg. 10:130–134. doi:10.3198/jpr2015.07.0044crc

Minneapolis Grain Exchange. 2017. North American HRSW Basis (13%, 14%, 15% proteins), 1985–Present*. Minneapolis Grain Exchange. http://www.mgex.com/spring_wheat.html (accessed 15 Aug. 2017).

Oelke, L.M., and J.A. Kolmer. 2004. Characterization of leaf rust resistance in hard red spring wheat cultivars. Plant Dis. 88:1127–1133. doi:10.1094/PDIS.2004.88.10.1127

Payne, P.I. 1987. Genetics of wheat storage proteins and the effect of allelic variation on bread-making quality. Annu. Rev. Plant Physiol. Plant Mol. Biol. 38:141–153. doi:10.1146/annurev.pp.38.060187.001041

Roelfs, A.P., R.P. Singh, and E.E. Saari. 1992. Rust diseases of wheat: Concept and methods of disease management. CIMMYT, Mexico, D.F.

Rouse, M.N., E.L. Olson, B.S. Gill, M.O. Pumphrey, and Y. Jin. 2011. Stem rust resistance in *Aegilops tauschii* germplasm. Crop Sci. 51:2074–2078. doi:10.2135/cropsci2010.12.0719

US Wheat Associates. 2017. Wheat classes. US Wheat Associates. http://www.uswheat.org/wheatClasses (accessed 15 Aug. 2017).