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CULTIVAR

Registration of 'Shelly' Hard Red Spring Wheat

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Abstract

Grain yield is generally the most important criterion growers use to select which cultivar to grow. 'Shelly' (Reg. No. CV-1150, PI 681618) hard red spring wheat (*Triticum aestivum* L.) was released by the University of Minnesota Agricultural Experiment Station in 2016 because it combines very high grain yield with acceptable lodging resistance, grain protein concentration and end-use quality characteristics, and good resistance to the diseases Fusarium head blight, leaf rust, stripe rust, and stem rust. Shelly is a mid-late maturity, semidwarf cultivar that is well adapted to the north-central United States and is among the highest-yielding cultivars currently available.

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'Shelly' (Reg. No. CV-1150, PI 681618) hard red spring wheat (*Triticum aestivum* L.) was developed by the University of Minnesota Agricultural Experiment Station and released in 2016. Shelly was released on the basis of its high grain yield, acceptable lodging resistance, protein concentration, end-use quality characteristics, and good disease resistance.

Shelly, tested as MN11325-7, is an F_6–derived selection from the cross 'Faller'//00H04*J3/MN03130-1-62. Faller (Mergoum et al., 2008) was released by North Dakota State University in 2007 and was the most popular cultivar grown in Minnesota from 2009 to 2013. 00H04*J3 is an unreleased line from the Agriculture and Agri-Food Canada spring wheat breeding program in Manitoba, Canada, and was entered in the 2005 Uniform Regional Hard Red Spring Nursery (URHRSWN) and exhibited good Fusarium head blight (FHB; caused primarily by *Fusarium graminearum* Schwabe) resistance in the nursery. It has the pedigree Mono 3B/FHB37. MN03130-1-62 is an unreleased University of Minnesota experimental line with good overall performance that has the pedigree MN97695-4/MN97448-17.

Shelly is named after the town of Shelly, MN, which is in its area of adaptation in northwest Minnesota.

Methods

Early Generation Development

The cross of 00H04*J3/MN03130-1-62 was made in 2007 and designated 07X001. The topcross to Faller was performed in 2007 and designated 07X278. The TC_1F_1 generation was grown in a greenhouse and approximately 700 F_2 seeds were

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Abbreviations: FHB, Fusarium head blight; MR, moderately resistant; MS, moderately susceptible; R, resistant; S, susceptible; URHRSWN, Uniform Regional Hard Red Spring Wheat Nursery; VSK, visually scabby kernels.

grown in a St. Paul, MN, field in 2008. 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 each of approximately 20 plants with appropriate maturity, plant height, and leaf and stem rust resistances was harvested. After bulk threshing the selected spikes, 100 F_3 seeds were sown in a winter nursery in New Zealand for generation advance, and approximately one spike per plant was harvested.

Line Selection and Evaluation

In 2009, 72 $F_{3:4}$ headrows were grown at Crookston and St. Paul, MN (36 at each location), and 12 of the 72 rows were selected based on appropriate plant height, maturity, and leaf and stem rust resistance. Seven spikes were harvested from each of the 12 selected rows.

In 2010, F_5 heads from each F_4 selection were evaluated as four-row observation plots at St. Paul and in single row plots in inoculated and mist-irrigated FHB nurseries located at Crookston and St. Paul. Six of the 12 F_5 families were selected on the basis of good FHB resistance and suitable plant height and straw strength. One spike from each of the six selections was sown in a winter nursery near Yuma, AZ. Five of the six rows were harvested in Arizona in 2011, one of which was designated MN11325 and grown in unreplicated preliminary yield trials at Crookston and Morris, MN, in 2011. 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.

MN11325 was entered in an unreplicated advanced yield trial, grown at 10 Minnesota locations in 2012. The reselected line, MN11325-7 (see "Seed Purification and Increase" section), was grown at 10 locations in 2013 and 15 locations in 2014 to 2016 in Minnesota statewide performance tests. MN11325-7 was tested in the 2104 and 2015 URHRSWN with sites in Minnesota, Montana, North Dakota, South Dakota, and Canada. Data from 13 locations of the URHRSWN in Minnesota, North Dakota, and South Dakota were included in the analysis.

A sample of the harvested grain from two to three locations each year, beginning in 2011, was analyzed for dough mixing and bread-baking properties (AACCI, 2000) at the USDA-ARS Hard Spring and Durum Wheat Quality Laboratory in Fargo, ND. Experimental bread making was performed by a straight-dough method using 25-g flour samples (Approved Method 10-10.03; AACCI, 2000). Preharvest sprouting was evaluated by harvesting 10 intact spikes at physiological maturity from each of two replicates grown at Crookston and St. Paul from 2014 to 2016. 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).

MN11325-7 was grown in inoculated, mist-irrigated FHB nurseries at Crookston and St. Paul each year starting in 2011. The Crookston FHB nursery used *Fusarium graminearum*–colonized corn kernel inoculum, and the St. Paul nursery used a spray-applied suspension of *F. graminearum* macroconidia following the methods of Fuentes-Granados et al. (2005). The FHB data collected included heading date, FHB disease incidence, and severity recorded 18 to 21 d after anthesis; FHB index was calculated as FHB incidence × FHB severity. A 30-spike sample was harvested and threshed from each plot and used to determine total seed weight of the 30-spike sample, percentage visually scabby (symptomatic) 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 finally, the deoxynivalenol concentration (Fuentes-Granados et al., 2005).

MN11325-7, along with all other experimental lines at the preliminary yield trial stage or later, was grown as single 1-m-long rows, 0.3 m apart, in an inoculated rust nursery in St. Paul beginning in 2011. This nursery utilized a mixture of leaf and stem rust–susceptible lines used as spreader rows, sown in rows perpendicular to the experimental lines in every other alley to facilitate disease development. 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). MN11325-7 was tested for seedling reaction to leaf rust pathogen races KFBJG, MBDSD, MBTNB, MCTNB, MJBJG, PBLRG, TBBGS, TCRKG, TFBGQ, TNBGJ, and TNRJJ following the methods of Oelke and Kolmer (2004) and stem rust pathogen races GFMNC, MCCFC, QCCSM, QFCSC, QTHJC, RCRSC, RKQQC, TKKTP, TKTTF, TPMKC, TRTTF, TTKSK, TTKST, TTKTT, TTTSK, and TTTTF following the methods of Jin and Singh (2006). MN11325-7 was evaluated for reaction to stem rust in nurseries in Debre Zeit, Ethiopia (predominantly race TTKSK; Ug99), and/or Njoro, Kenya (predominantly race TTKST, a member of the Ug99 race group with additional virulence to stem rust resistance gene *Sr24*), in 2014 to 2016 as described in Jin et al. (2007).

Seed Purification and Increase

A purification process was initiated in 2011 when 10 random spikes of MN11325 were harvested from the preliminary yield trial in St. Paul. Seed from 8 of the 10 random heads was grown in St. Paul in 2012. One of the eight rows, designated MN11325-7, was selected for advancement because it was uniform and phenotypically representative of the line. The seed from two spikes harvested from MN11325-7 were sown as single rows in a winter nursery near Yuma, AZ in November 2012. One of the two rows of MN11325-7 was harvested and seed used to sow an advanced yield trial at 10 Minnesota locations and a seed increase plot in 2013. The seed increase in 2013 was inspected for off-types and taller plants on 27 June, 2 July, and before harvest on 25 July. No off-types or taller plants were found, and 1 kg of the harvested seed was used to sow a seed increase at St. Paul in 2014. From approximately 30,000 plants, 57 were rogued because they contained one or more tillers that were more than 10 cm taller than the canopy. The 45 kg of breeder seed harvested from the 2014 increase was then sown in November 2014 near Brawley, CA, for further seed increase. Seed produced from the California increase was sown in Minnesota in spring 2015 as foundation seed, arranged by the Minnesota Crop Improvement Association.

Statistical Analyses

All statistical analyses were done using JMP Pro 13.2.0 (SAS Institute, 2018). 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

Shelly has erect juvenile plant growth, a recurved flag leaf, red auricles, white glumes with an apiculate shoulder, and an acuminate beak. The spike is awned, mid-dense, and tapering. The kernel is red and ovate in shape with angular cheeks and a mid-narrow, mid-deep crease. The brush on the kernel is not collared and is medium-long. Shelly is a mid-late maturity cultivar, averaging 2.2 d later in heading than other cultivars in Minnesota locations from 2014 to 2016 (Table 1), similar to Faller. Shelly is shorter than average, at 79.2 cm, measured from soil level to the tip of the spike, excluding awns (Table 1). Shelly is significantly shorter than Faller (86.5 cm). Shelly has average lodging resistance with a score of 1.72 on a scale of 0 to 9 (where 0 = no lodging and 9 = flat) across 29 locations where differential lodging occurred from 2014 to 2016 (Table 1). This level of straw strength is not significantly different than Faller (2.21), but significantly worse than 'Linkert' (Anderson et al., 2018b) (0.16).

Field Performance

In 42 Minnesota yield trials from 2014 to 2016, Shelly's average grain yield was 5923 kg ha^{-1}, significantly less than 'LCS Albany' (PI 658002) (6085 kg ha^{-1}). Shelly's grain yield was not significantly different from 'SY Rowyn' (PI 667772) (5830 kg ha^{-1}) or Faller (5779 kg ha^{-1}) but was significantly higher than the remaining 13 cultivars in Table 1. The protein concentration of Shelly was 137.7 g kg^{-1}, significantly lower than 10 of the 16 comparison cultivars in Table 1. However, Shelly's protein concentration was significantly higher than Faller (134.4 kg ha^{-1}) and the higher-yielding LCS Albany (131.7 kg ha^{-1}).

When evaluated in 24 Minnesota, North Dakota, and South Dakota environments in the 2014 and 2015 regional nursery, Shelly's grain yield (5163 kg ha^{-1}) was significantly higher than that of the checks '2375' (PI 601477) (4597 kg ha^{-1}) and 'Verde' (Busch et al., 1996) (4500 kg ha^{-1}) but not significantly different from 'Surpass' (PI 678862) (5015 kg ha^{-1}) (Table 2).

Shelly is rated as resistant to preharvest sprouting. In five tests conducted from 2014 to 2016, Shelly had a preharvest sprouting rating of 0.24, below the average of 0.68 for all cultivars evaluated in the same tests but not significantly different from 13 of the 15 comparison cultivars (Table 1).

Disease Resistance

Shelly has been evaluated in FHB nurseries since 2011 and has moderate resistance to this disease; it has been assigned a

Table 1. Performance of Shelly and other hard red spring wheat cultivars in Minnesota, 2014–2016.

Cultivar†	Cultivar reference	Grain yield	Grain volume wt.	Grain protein	Days to heading	Plant height	Lodging	Preharvest sprouting
		kg ha^{-1}	kg hL^{-1}	g kg^{-1}	d from planting	cm	0–9‡	0–9§
LCS Albany	PI 658002	6085	77.4	131.7	64.0	80.8	1.88	1.65
Shelly	–	5923	77.4	137.7	63.0	79.2	1.72	0.24
SY Rowyn	PI 667772	5830	78.0	137.4	59.6	77.8	2.41	0.75
Faller	Mergoum et al., 2008	5779	77.0	134.0	62.8	86.5	2.21	0.21
Prevail	Glover et al., 2017	5761	77.7	139.4	59.1	84.8	1.55	1.32
SY Ingmar	PI 672586	5725	78.2	145.5	62.0	80.6	1.34	0.64
Forefront	Glover et al., 2013	5531	78.2	146.0	58.2	95.8	2.93	0.96
SY Soren	PI 662048	5528	77.2	146.1	60.2	77.5	1.14	0.30
Bolles	Anderson et al., 2018a	5466	76.8	158.3	63.5	84.1	1.33	0.46
Norden	Anderson et al., 2018c	5454	79.0	139.8	61.5	80.8	0.60	0.39
Knudson¶	PI 619609	5447	77.0	135.5	61.3	81.1	2.17	0.85
WB-Mayville	PI 661061	5406	76.5	146.7	59.4	76.5	0.49	1.11
Linkert	Anderson et al., 2018b	5372	77.7	149.9	60.4	75.8	0.16	0.73
RB07	Anderson et al., 2009	5364	77.2	143.6	59.8	81.8	1.94	0.44
Rollag	Anderson et al., 2015	5331	78.5	148.4	60.2	77.9	0.74	0.48
Elgin-ND	Mergoum et al., 2016	5267	76.8	145.4	60.4	92.6	3.08	0.80
Glenn¶	Mergoum et al., 2006	5090	79.7	149.3	58.6	90.6	1.50	0.15
Mean		5551	77.7	143.2	60.8	82.6	1.60	0.68
LSD (0.05)		154	0.6	2.1	0.7	2.5	0.54	0.84
No. of environments		42	31	33	12	13	29	5

† 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.

rating of 4 on a scale of 1 to 9 (1 = resistant to 9 = susceptible) for commercially available cultivars. Compared with other cultivars, Shelly has lower-than-average FHB severity, FHB index, VSK, and deoxynivalenol and higher seed weight and grain volume weight (Table 3). Shelly contains the major FHB resistance quantitative trait locus *Fhb1* (Liu et al., 2008b).

Shelly is moderately resistant to leaf rust, showing resistant (R) infection types when inoculated as seedlings to *P. triticina* races KFBJG, MBDSD, MBTNB, MCTNB, MJBJG,

Table 2. Performance of Shelly and hard red spring cultivars in the Uniform Regional Hard Red Spring Wheat Nursery, 2014–2015.

Cultivar†	Cultivar reference	Grain yield	Grain v olume wt.	Grain protein	Heading	Plant height	Lodging
		kg ha^{-1}	kg hL^{-1}	g kg^{-1}	d from 1 June	cm	0–9‡
Shelly	–	5163	76.2	138.3	33.2	77.7	1.0
Surpass	PI 678862	5015	75.9	142.6	29.0	85.1	2.7
2375§	PI 601477	4597	76.2	143.3	30.7	86.7	3.8
Verde§	Busch et al., 1996	4500	74.8	138.5	31.9	84.0	1.5
Keene§	PI 598224	4055	75.2	146.2	32.0	100.7	2.9
Marquis§	CItr 3641	3221	74.3	146.2	35.2	107.7	5.5
Chris§	Heiner and Johnston, 1967	3218	74.0	152.8	34.0	103.9	6.2
Mean		4253	75.2	144.0	32.3	92.3	3.4
LSD (0.05)		264	0.6	3.4	0.9	2.6	0.9
No. of environments		24	24	16	23	24	13

† Cultivars are sorted on the basis of grain yield.

‡ 0 = no lodging; 9 = flat.

§ Long-term check.

Table 3. Performance of Shelly and hard red spring cultivars and checks in inoculated Fusarium head blight nurseries, 2014–2016.

Line†	Heading	FHB			30-spike seed sample			
		Incidence	Severity	Index	Spike seed wt.	Grain volume wt.	Visually scabby kernels	Deoxynivalenol
	d after 1 June	%	%	%	g spike^{-1}	kg hL^{-1}	%	µg g^{-1}
Rollag	34.4	82.1	18.8	18.1	0.64	73.7	5.8	1.6
Forefront	31.1	61.7	20.2	14.8	0.73	72.0	9.7	1.7
SY Rowyn	32.6	71.7	17.6	11.9	0.69	73.4	9.3	2.1
Alsen‡#	34.3	78.8	19.8	18.3	0.56	73.4	5.7	2.1
LCS Albany	37.3	65.4	23.7	16.0	0.67	73.5	8.0	2.3
Norden	34.6	88.3	28.7	25.0	0.61	73.8	8.5	2.8
SY Ingmar	35.6	87.1	30.2	25.9	0.59	72.3	8.0	2.8
Prevail	33.1	72.9	31.2	24.8	0.71	71.4	12.1	3.0
SY Soren	33.9	92.9	41.7	33.6	0.54	70.0	11.2	3.0
RB07	33.6	80.8	30.4	26.1	0.52	69.6	13.6	3.0
Shelly	36.7	80.2	20.2	18.1	0.76	71.4	9.2	3.1
Glenn§	32.5	78.8	21.1	16.1	0.60	75.4	8.3	3.2
Bolles	36.3	80.4	28.6	27.1	0.67	69.2	12.3	3.4
Elgin-ND	33.5	87.3	27.4	21.9	0.66	71.8	10.8	3.4
Faller	36.3	74.6	22.6	17.9	0.73	72.6	8.3	3.7
BacUp‡#	31.2	83.5	25.5	20.1	0.58	73.8	8.8	4.2
Linkert	34.7	86.7	35.9	31.2	0.63	71.5	12.7	4.6
MN00269¶	38.0	98.3	62.6	59.0	0.34	58.7	32.1	4.9
Knudson§	35.3	88.3	35.5	31.7	0.58	70.4	21.4	5.6
Roblin¶	32.7	98.3	62.4	58.6	0.53	63.0	41.3	5.6
Wheaton¶#	37.0	93.3	61.0	63.1	0.35	59.0	51.4	6.4
WB-Mayville	33.5	92.5	50.3	46.4	0.54	67.0	27.8	6.7
Mean	34.5	82.9	32.5	28.4	0.60	70.5	15.3	3.6
LSD (0.05)	1.4	15.0	13.1	10.1	0.11	3.6	7.3	2.2
No. of environments	6	4	4	6	5	5	6	5

† Cultivars are sorted by deoxynivalenol content in grain.

‡ Moderately resistant check.

§ Long-term check.

¶ Susceptible check.

Alsen, Frohberg et al. (2006); BacUp, Busch et al. (1998); Wheaton, Busch et al. (1984).

PBLRG, TBBGS, TCRKG, TNBGJ, and TNRJJ and a susceptible (S) infection type to race TFBGQ (Table 4). The race TFBGQ was first identified in Minnesota in 2010 (Kolmer and Anderson, 2011) and is virulent on *Lr21*. Shelly and one of its parents, Faller, contain *Lr21* as indicated by their susceptibility to race TFBGQ and diagnostic DNA marker profile using marker D14 (Wheat Genetics Resource Center, 2018). Race TFBGQ has been included in the inoculum mixture for the St. Paul leaf rust nursery, resulting in high levels of disease on Shelly (50S and 40S), comparable to Faller (Table 4). However, in naturally infected trials at Lamberton, Le Center, and Waseca, MN, in 2017, Shelly's leaf rust (trace moderately susceptible [MS], 0, and trace moderate [M], respectively) was considerably less severe than Faller's (40S, 10S, and 60S, respectively), indicating that Shelly has additional, unknown leaf rust resistance genes relative to Faller. Shelly has shown good resistance to stripe rust (caused by *P. striiformis* f. sp. *tritici*) under field conditions. At two Minnesota locations in 2015 Shelly had stripe rust severities of trace R and trace moderately resistant (MR), while Faller, one of the more susceptible cultivars in the same trial, had severities of 30S and 20S. The results of DNA marker testing (Lagudah et al., 2009) indicate that Shelly does not contain the adult plant resistance locus *Lr34/Yr18/Sr57* that is common in the University of Minnesota spring wheat breeding program germplasm.

Shelly is highly resistant to the prevalent stem rust pathogen race (QFCSC) of *P. graminis* f. sp. *tritici* and most other races that are important in North America (QTHJC, RCRSC, RKQQC, TPMKC) with the exception that it is susceptible to race TTTTF at the seedling stage (Table 5). Since the beginning of US field evaluations of MN11325 in 2011, natural infection by stem rust on Shelly has not been observed. Shelly has shown susceptible reactions to TTKSK (syn. Ug99) and related races when evaluated in seedling screens in the greenhouse and moderately susceptible reactions in field stem rust nurseries in Ethiopia and Kenya (Table 6).

End-Use Quality

Shelly has acceptable end-use quality but is significantly lower than average for several key parameters (Table 7) based on analysis from six environments from 2014 to 2016. Shelly has above average kernel weight of 35.1 mg kernel^{-1}. In these six environments, the grain protein of Shelly (136.2 g kg^{-1}) was comparable to Faller (136.6 kg ha^{-1}) but significantly lower than the average of the comparison cultivars. The water absorption prior to baking (bake absorption, Table 6) at 571.8 g kg^{-1} was lower than the average of the comparable cultivars. Shelly has relatively long bake mix times (5.2 min.), not significantly different from the high-quality cultivars Linkert (5.5 min.), 'Glenn' (Mergoum et al., 2006) (5.4 min.), and 'Bolles' (Anderson et al., 2018a) (5.3 min.) (Table 7). The loaf volume (183 mL) of Shelly was second lowest among the comparison cultivars. Shelly contains the 2* and 5+10 subunits of the *Glu-A1* and *Glu-D1* loci, respectively (Liu et al., 2008a) that are positively correlated with breadmaking quality (Payne, 1987).

Availability

The Minnesota Agricultural Experiment Station, St. Paul, MN 55108, will maintain breeder seed of Shelly. Foundation seed will be produced and maintained by the Minnesota Crop Improvement Association, 1900 Hendon Ave.,

Table 4. Leaf rust reactions of Shelly and hard red spring cultivars.

Cultivar	Gene postulation	Race†‡											St. Paul field§	
		KFBJG	MBDSD	MBTNB	MCTNB	MJBJG	PBLRG	TBBGS	TCRKG	TFBGQ	TNBGJ	TNRJJ	2015	2016
Bolles	unknown	0	;	;	;	;1–	;	;	;	;1–	;	;	TR	5R
Eglin-ND	Lr21 and unknown	;	0;	0;	0;	0;	0;	2–	;	;22+	;2	;1–	10MRMS	10RMS
Faller	Lr21	;2	0;	0;	0;	0;	0;	3+	2+		;2–	;12–	80S	40MSS
Forefront	unknown	;	;1-	;1–	;1–	;	1+	;1–	;1–	;	;1–	;	10RMR	30MRMS
Glenn	Lr21	;	0;	0;	0	0;	0;	22+;3	;1–	3+	;	;	60S	30MSS
Knudson	unknown	;	;12-	0;	;	;	;12–	;	;	;12–	;2–	;	5R	30MRMS
LCS Albany	Lr24	3+	;	0;	0;	3–	;	;	0;	3+	;2–	3+	TR	30MSS
Linkert	unknown	;	;	0;	0;	;2	0;	0;	;	;	;1–	;	50RMR	50S
Norden	unknown	;	;1	;	;12–	;23	;	;2	;	;23	;1–	;	5R	10MR
Prevail	unknown	;	;1+	;	;	;1–	;22+	;2	;	;2	;	;	5R	30MSS
RB07	unknown	;1–	;22+	;23	;1–	;1–	2+3	;2	32+	3+;	;2–	;22+	10MRMS	20MRMS
Rollag	unknown	;	;	;	;	;22+	;	;	;	;12	;2–	;	20MRMS	40MSS
Shelly	Lr21 and unknown	;1	0	0;	0;	0;	;	;	;2–	32+	;	;2–	50S	40S
SY Ingmar	unknown	;	0;	0;	0;	0;	;	;	;	;2	;	;2–	TR	5R
SY Rowyn	Lr16, Lr24	0	2	0;	0;	3+	;2	;1–	;	;2	;	0	20RMR	30MRMS
SY Soren	unknown	;	;12	0;	0;	;1	;23	;	;	;2-	;1–	;	5R	30MRMS
WB-Mayville	Lr1, Lr10	0	3+	–	0	32+;	3+	;2-	32+;	32+;	3+	3+	5R	20MRMS

† 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; TR, trace resistant.

Table 5. Wheat stem rust reactions of Shelly, other hard red spring cultivars, and susceptible check LMPG-6 following inoculation with domestic *P. graminis* f. sp. *tritici* races.

Line	Race†‡									St. Paul field§	
	GFMNC	MCCFC	QCCSM	QFCSC	QTHJC	RCRSC	RKQQC	TPMKC	TTTTF		
	12WA147-2	59KS19	75WA165-2A	06ND76C	75ND717C	77ND82A	99KS76A-1	74MN1409	01MN84A-1-2	2015	2016
Bolles	1–	2–	2–	1–	2–	;1–1	2	2	;1–LIF	TR	20R
Elgin-ND	;	2–/0;	2–;	;	2	1–1	2/3	2–	;1	10R-MR	20R/30MR
Faller	;	1–	;1–	;	2–	;1–	2–	2–	0;	10MR	5R
Forefront	0	;	;	0;	3	;	3	2	;1	30MS-S	60MS
Glenn	;	;1–	;1–	;	2	1–;	2	2–	;1–	5R	10R
Knudson	;	;	;	;	1–	1–;	2	2	4	20MR	10RMR
LCS Albany	2–	;2–	;	;1–	2	2–	2–	2–	2–	20R-MR	10R
Linkert	;1–	1–	1–	;1–	2–	;	2–	2–	0;	0	0
LMPG-6¶	3	3	4	3	3	3	4	3	4	–	–
Norden	0	0;	0;	0;	2–	0;	;2–	0;	0;	TR	TR
Prevail	0;	;	;	0;	23–?	0;	3	0;	;1	50MS-S	50MS
RB07	0	;	;	0;	2–	0	3	;	;1 LIF	20MR	30RMR
Rollag	–	;1–	1–;	0	2–	;1–	2	2	;1/1; LIF	10MR	10R
Shelly	;1–	;1–	2–;	;	2	2–	2	2–	4	10R	20R
SY Ingmar	0	0;	0;	0	;1–	;1-	1–1/3–1	;1– LIF	13–	TR/20MR	TR
SY Rowyn	0	0;	;	0	12;	;2=	1	1–N	3–1	0	TR
SY Soren	0	0	;	0	1	;	12	0;	;13–	0	TR
WB-Mayville	2–;	0;	;1–	;	2=	2=;	2	2-	4	20MR	30MR

† 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). LIF, low infection type; MR, moderately resistant; MS, moderately susceptible; R, resistant; S, susceptible; TR, trace resistant.

¶ Susceptible check.

Table 6. Wheat stem rust reactions of Shelly, other hard red spring cultivars, and susceptible check LMPG-6 following inoculation with exotic *P. graminis* f. sp. *tritici* races and field evaluation in Ethiopia and Kenya.

Line	Race†‡								African field§		
	TKKTP	TKTTF	TKTTF	TRTTF	TTKSK	TTKST	TTKTT	TTTSK	Kenya	Ethiopia	Kenya
	13GER16-1	13ETH18-1	13GER17-2	06YEM34-1	04KEN156/04	06KEN19V3	14KEN58-1	07KEN24-4	May 2015	May 2016	May 2016
Bolles	–	0;1	–	3	3+	3+	3+	;1+	25S	50MRMSS	20M
Elgin-ND	2+3	;1+	3+	3	3+	3+/2	3+	;1	–	–	–
Faller	–	1+3–	–	3	3	3	3+	;11+	30MSS	30SMS	20M
Forefront	–	;1	–	22+	3+	2	3+	;1	55MSS	50MSS	40M
Glenn	2+3	;1+	3+	3	3+	3	3+	0;	–	–	–
Knudson	–	3+	–	2–	3+	2	2	2+3	25MSS	–	–
LCS Albany	2–	2–;	2	;2–	2–	2–	2–	2–	–	–	–
Linkert	–	;1	–	2+3	3	3	3+	0;	10M	25SMS	10MS
LMPG-6¶	3+	3+	3+	3	3	3+	3+	3	60S	40SMS	40M
Norden	;2–	;	;1+	3–	3	3+	2–	0;	25M	40MSMR	10M
Prevail	3	;11+	3+	3–	3+	3+	3+	;1	45MSS	50MSS	30M
RB07	3	;1+	3+	3–	3	3+	3+	;1+	15MS	40SMS	15MS
Rollag	3+	;1	4	3–	3	3+	3+	;1+3–	20MS	35SMS	20MS
Shelly	–	3+	–	3+	3	3+	3	2+3	20S	50S	30MSS
SY Ingmar	2+3	;	3	2–	3	2	33+	;1	–	–	–
SY Rowyn	2+3	;1	3	2–	3	2	3+	;1	–	–	–
SY Soren	2+3	;1	3	2–	3	2	3+	;1	–	–	–
WB-Mayville	2+	3	2+	2–	3	2	3+	2+3	–	–	–

† 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.

¶ Susceptible check.

Table 7. Grain end-use quality of Shelly and other hard red spring wheat cultivars grown in Minnesota, 2014–2016.

Cultivar†	Kernel weight	Grain protein‡	Flour protein‡	Bake mix time	Bake absorption	Loaf volume
	mg kernel^{-1}	g kg^{-1}	g kg^{-1}	min.	g kg^{-1}	mL
Bolles	34.8	158.6	148.1	5.3	602.2	218
Glenn§	33.8	151.9	140.3	5.4	601.7	209
RB07	30.8	141.8	131.5	4.5	584.8	204
SY Ingmar	31.5	147.5	136.8	4.8	581.8	203
Linkert	36.5	148.0	136.8	5.5	590.7	201
SY Soren	31.9	147.0	134.5	3.6	590.2	200
Elgin-ND	32.7	146.5	135.4	4.1	592.8	198
WB-Mayville	36.2	148.9	136.3	4.2	590.0	198
Forefront	34.0	144.4	130.9	4.3	578.3	197
SY Rowyn	31.3	137.2	128.6	5.7	574.5	194
Knudson§	34.1	135.8	125.3	6.1	581.1	193
Faller	37.2	136.6	126.1	4.1	571.7	193
Norden	33.1	143.1	129.9	4.1	591.4	192
Prevail	34.5	139.7	126.8	3.8	574.3	191
LCS Albany	30.9	129.8	118.4	4.1	567.2	188
Shelly	35.1	136.2	126.0	5.2	571.8	183
Rollag	35.3	149.9	137.4	2.9	594.2	179
Mean	33.8	143.7	132.3	4.6	584.6	196
LSD (0.05)	1.5	4.8	4.5	0.5	9.7	8.5
No. of environments	6	6	6	6	6	6

† Cultivars are sorted by loaf volume.

‡ 12% moisture basis.

§ Long-term check.

St. Paul, MN 55108. United States Plant Variety Protection (PVP protection no. 201700119) for Shelly with the seed certification option has been applied for. 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 5 years from the date of this publication.

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