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CULTIVAR

Registration of 'Linkert' Spring Wheat with Good Straw Strength and Adult Plant Resistance to the Ug99 Family of Stem Rust Races

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Abstract

Straw strength is one of the most important criteria for spring wheat (*Triticum aestivum* L.) cultivar selection in the north central United States. 'Linkert' (Reg. No. CV-1137, PI 672164) hard red spring wheat was released by the University of Minnesota Agricultural Experiment Station in 2013 and has very good straw strength, high grain protein concentration, strong gluten, and good bread baking characteristics along with competitive grain yields. Linkert is moderately susceptible to Fusarium head blight, is moderately resistant to the prevalent races of leaf rust, and has field resistance to the Ug99 family of stem rust races, a rarity among spring wheat cultivars adapted to the region.

Growers of hard red spring wheat (*Triticum aestivum* L.) in the northern plains of the United States select cultivars predominantly based on their grain yield, protein concentration, straw strength, and disease resistance. In recent years, growers have had few choices among cultivars that have all of these attributes, especially straw strength. 'Linkert' (Reg. No. CV-1137, PI 672164) hard red spring wheat was developed by the University of Minnesota Agricultural Experiment Station and released in 2013. Linkert was released on the basis of its very good straw strength, high grain protein concentration, strong gluten, and good bread baking characteristics, along with competitive grain yields.

Linkert, tested as MN06028, is an F_6–derived selection from the cross MN97695-4/'Ada' sel. MN97695-4 has the pedigree MN92387/SBE0303-23. The unreleased line MN92387 has the pedigree MN88064 ('TAM 105' [Porter et al., 1980]/2*'Len' [CI 17790])/'Prospect' (Cholick et al., 1990); SBE0303-23 is from the former Pioneer Hi-Bred hard red spring wheat breeding program and has the pedigree SGZ352 ('Ranjaja 12' [PI 372147]/'Sonora 64' [CI 13930]//'Ciguena')/3/'Sapsucker 3' (PI 428429)/'Guard' (Cholick et al., 1984). Ada sel. is a selection from the cultivar Ada, released by the Minnesota Agricultural Experiment Station in 2006 (Anderson et al., 2007). The cultivar name was given to recognize the contributions of Mr. Gary Linkert, a scientist who served as the lead technician on the University of Minnesota wheat breeding program for more than 20 yr.

Methods

Early Generation Development

The cross of MN97695-4/Ada sel. was made in 2002 and designated 02X054. Approximately 700 F_2 seed were grown in a St. Paul, MN, field in 2003. This field included inoculated spreader rows of wheat lines highly susceptible to leaf rust (caused by *Puccinia triticina* Eriks.) and stem rust (caused by *Puccinia graminis*

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Abbreviations: FHB, Fusarium head blight; PYT, preliminary yield trial; QTL, quantitative trait locus; VSK, visually scabby kernels.

Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn.). A single spike from 46 plants with appropriate maturity, plant height, and leaf and stem rust resistance was harvested. A total of 120 F_3 seeds (2–3 per selected F_2 spike) were sown for modified single seed descent generation advance in a New Zealand winter nursery, and a single spike from 95 resulting plants was harvested.

Line Selection and Evaluation

In 2004, 95 $F_{3:4}$ headrows were grown in St. Paul, and 22 were selected on the basis of their appropriate plant height, maturity, and leaf and stem rust resistances. Four F_5 seeds from a single spike of each of the 22 selections were grown in University of Minnesota greenhouses in St. Paul to increase seed. Seed from each $F_{4:5}$ line was bulked and used to sow 1-m observation rows at Crookston and St. Paul, MN, and in a Fusarium head blight (FHB; caused primarily by *Fusarium graminearum* Schwabe) nursery in St. Paul in 2005. Fourteen of the 22 lines were selected for advancement on the basis of agronomic characteristics and acceptable FHB resistance, and a single spike from each selected line was sown in a winter nursery in New Zealand. Eleven of the 14 lines were harvested in New Zealand, on the basis of acceptable plant height. One of the 11 rows was designated MN06028 and grown in an F_7 preliminary yield trial (PYT) at Crookston, Morris, and St. Paul, MN, in 2006. 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. MN06028 was entered in a three-replication advanced yield trial grown in Crookston, Morris, and St. Paul in 2008 and at 6 to 12 Minnesota locations from 2009 to 2012. MN06028 was tested in the 2009 and 2010 Uniform Regional Hard Red Spring Wheat Nursery with 18 sites in Minnesota, Montana, North Dakota, South Dakota, Washington, Wyoming, and the Canadian provinces of Manitoba and Saskatchewan.

A sample of the harvested grain from two to three locations each year, beginning in 2006, 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 (Approved Method 10-10.03).

Preharvest sprouting resistance was evaluated by harvesting 10 intact spikes at physiological maturity from each of two replicates grown at Crookston and St. Paul. Spikes were air dried for 5 d and stored at −20°C for 4 to 16 wk. Spikes were then 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).

MN06028 was grown in inoculated, mist-irrigated FHB nurseries at Crookston and St. Paul annually starting in 2006. The Crookston FHB nursery used *Fusarium graminearum*–colonized corn (*Zea mays* L.) kernel inoculum, and the St. Paul nursery was inoculated with a macroconidial suspension of *F. graminearum* following the methods of Fuentes et al. (2005). The FHB data collected included heading date, disease incidence and severity recorded 18 to 21 d after anthesis, spike 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 concentration of mature seed (Fuentes et al., 2005).

MN06028 and all other experimental lines at the PYT stage or later were grown annually as single 1-m-long rows, 0.3 m apart, in an inoculated rust nursery in St. Paul, beginning in 2006. This nursery contained a mixture of leaf rust- 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 races following the methods of Roelfs et al. (1992). MN06028 was tested for seedling reaction to leaf rust races FHPTQ, KFBJ, MBBJ, MBDS, MFPS, MHDS, MJBJ, MLDS, TDBG, TDBJ, THBJ, TJBGH, and TLGF following the methods of Oelke and Kolmer (2004) and stem rust races MCCFC, QFCSC, QTHJC, RCRSC, RKQQC, TPMKC, TTKSK, TTTTF following the methods of Jin and Singh (2006). MN06028 was evaluated for reaction to stem rust races TTKSK (syn. Ug99) and TTKST (Ug99 with additional virulence to *Sr24*) in the Kenya stem rust nursery in 2009, 2011, and 2012 (Newcomb et al., 2016) according to methods described in Jin et al. (2007).

Seed Purification and Increase

A purification process was initiated in 2006 when eight random spikes of MN06028 were harvested from the PYT in St. Paul. Seed from the eight spikes were grown in St. Paul in 2007 but no phenotypic differences were observed among them. MN06028 seed harvested from the 2007 yield trial at Crookston was used to sow all 2008 trials, including a seed increase in St. Paul. Two hundred random spikes were harvested from the seed increase, and 160 of the spikes were sown as headrows in St. Paul in 2009. Thirty of the 160 rows were discarded because they had one or more taller tillers or were earlier heading. One or two heads were harvested from the remaining 130 selections, and a total of 160 spikes were grown as headrows in 2010. Of the 160 headrows, 33 rows were discarded because they had one or more taller tillers or were earlier heading. The remaining 127 selections were combine harvested in bulk and used to sow a seed increase in St. Paul in 2011. Approximately 0.2% of plants in the 2011 increase produced one spike at least 10 cm above the canopy and were removed. Approximately 89 kg of seed was produced from the seed increase, and 35 kg of this seed was sown near Brawley, CA, for further seed increase. A total of 2409 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 as 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

Linkert has erect juvenile plant growth, an erect 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. Linkert is an early to mid-maturity cultivar, averaging 62.9 d from planting to heading in Minnesota locations from 2010 to 2012 (Table 1), similar to 'Knudson'. Linkert is much shorter than average at 73.7 cm, measured from soil level to the tip of the spike, excluding awns (Table 1). Its height is significantly shorter than all but 2 of the 21 comparison cultivars. As many as 0.5% of Linkert plants have a tiller that is up to 10 cm taller than the canopy height, including 0.2% up to 20 cm taller than the canopy height. Although hard red spring wheat cultivars routinely contain 0.03 to 0.3% plants with a single tiller up to 10 cm taller than the canopy height, Linkert's incidence of taller tillers is higher and more consistent across environments compared with other cultivars. This high incidence of tall tillers has been maintained for eight generations of headrow purification (80–160 headrows per year) despite annual roguing of all headrows containing any tall plants. Seed grown from taller tillers segregates in a non-Mendelian, unpredictable fashion for plant height. The cause of the tall plants is not known.

Linkert has very good straw strength with a score of 0.76 on a 0-to-9 scale across 16 environments where differential lodging occurred from 2010 to 2012 (Table 1). This level of straw strength places Linkert among the strongest cultivars available in the region and significantly ($P < 0.05$) stronger than 17 of the other 21 comparison cultivars (Table 1).

Field Performance

In 34 Minnesota yield trials from 2010 to 2012, Linkert's average grain yield was 4599 kg ha^{-1}, significantly higher than 'Glenn' (4135 kg ha^{-1}), a cultivar that also has high grain protein concentration and excellent bread baking quality (Table 1). Linkert's grain yield is higher, but not significantly, than the cultivars with comparable grain protein concentration, including 'Barlow', 'Vantage', and 'Rollag'. When evaluated in 26 environments (excluding Montana, Washington, and Wyoming sites) of the 2009 and 2010 regional nurseries, Linkert's grain yield (4001 kg ha^{-1}) was significantly lower than 'Prosper' (4510 kg ha^{-1}), a cultivar with 9.1 g kg^{-1} lower grain protein concentration, but not significantly different than the check 'Verde' (3904 kg ha^{-1}) (Table 2).

Table 1. Performance of Linkert and other hard red spring wheat cultivars in Minnesota, 2010–2012. Cultivars are sorted in descending order based on grain yield.

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 planting	cm	0–9‡	0–9§
LCS Albany	PI 658002	5433	76.6	138.3	65.8	78.0	2.12	2.35
Samson	PI 652923	4975	75.9	145.6	62.4	74.5	1.42	2.37
Jenna	PI 658039	4918	76.4	147.5	65.7	78.5	2.55	3.16
Prosper	Mergoum et al., 2013	4900	76.5	145.7	64.3	83.9	2.84	0.90
Faller	Mergoum et al., 2008	4872	76.2	145.1	64.0	82.9	2.46	0.98
Knudson¶	PI 619609	4726	77.1	143.3	63.2	78.8	2.64	1.27
LCS Breakaway	PI 667103	4675	78.8	151.0	61.2	75.5	1.99	1.67
Norden	Anderson et al., 2018	4639	78.4	146.1	63.6	79.5	1.19	0.53
Sabin	Anderson et al., 2012a	4614	76.2	148.5	63.8	76.6	2.79	2.03
Linkert	–	4599	76.8	155.3	62.9	73.7	0.76	1.03
Barlow	Mergoum et al., 2011	4569	78.0	152.8	61.3	84.8	3.18	1.82
Select	Glover et al., 2011	4555	78.4	147.6	58.9	83.6	2.94	1.52
RB07	Anderson et al., 2009	4522	76.6	149.1	61.8	79.0	2.88	1.60
Brennan	PI 658041	4503	77.0	150.1	61.0	73.3	2.23	0.50
Briggs	Devkota et al., 2007	4485	77.7	149.5	60.1	83.1	3.73	1.73
Vantage	PI 653518	4484	78.4	157.0	67.5	78.8	0.62	1.85
Cromwell	PI 653527	4477	78.0	148.8	64.3	81.0	2.70	1.58
Rollag	Anderson et al., 2015	4425	77.6	152.6	61.9	76.5	1.31	0.80
Velva	Mergoum et al., 2014	4365	74.3	146.2	65.3	81.1	1.91	1.40
Brick	Glover et al., 2010	4306	78.6	149.0	58.4	84.3	2.96	2.23
Glenn	Mergoum et al., 2006	4135	79.3	154.6	60.4	84.7	1.71	0.68
Marshall¶	Busch et al., 1983	3961	74.0	140.7	66.4	78.5	1.99	0.98
Mean		4365	74.3	146.2	65.3	81.1	1.91	1.40
LSD (0.05)		176	0.6	2.1	0.7	1.7	0.71	0.96
Location-years		34	30	27	15	21	16	6

† Cultivars are sorted by grain yield.

‡ 0 = no lodging; 9 = flat.

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

¶ Long-term check.

Linkert is rated as resistant to preharvest sprouting. In six tests conducted from 2012 to 2014, Linkert had a preharvest sprouting rating of 1.03, below the average of 1.40 for all cultivars evaluated in the same trials (Table 1).

Disease Resistance

Linkert has been evaluated in FHB nurseries since 2006 and is moderately susceptible to this disease; it has been assigned a rating of 5 on a 1-to-9 scale (1 = resistant to 9 = susceptible) for commercially available cultivars. In inoculated nurseries, Linkert's reaction is similar to other popular cultivars such as 'Faller' and Prosper but is significantly more susceptible than moderately resistant cultivars such as 'Select' and Rollag (Table 3). Linkert does not possess the major FHB resistance QTL *Fhb1* (Liu et al., 2008b).

Linkert is moderately resistant to prevalent leaf rust races under field conditions and produces resistant infection types (;, 0, 1, or 2) when inoculated as seedlings to races FHPTQ, KFBJ, MBBJ, MBDS, MFPS, MHDS, MJBJ, MLDS, TDBG, THBJ, TJBGH, and TLGF and a susceptible infection type (3) to TDBJ (Table 4). In naturally infected sites, Linkert has shown good resistance to stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Eriks.). The results of DNA marker testing indicate that Linkert contains the adult plant leaf rust resistance gene *Lr34* (Lagudah et al., 2009) and the resistant *tsn1* allele for tan spot [caused by *Pyrenophora tritici-repentis* (Died.) Drechs] resistance according to DNA marker fcp394 (Zhang et al., 2009).

Linkert is highly resistant to the prevalent race QFCSC and other stem rust races that are important in North America (QTHJC, RCRSC, RKQQC, TPMKC, and MCCFC) at the seedling stage (Table 5). Since the beginning of field evaluations of MN06028 in 2006, natural infection by stem rust on Linkert has not been observed. Linkert has shown susceptible reactions to TTKSK (syn. Ug99) when evaluated in seedling tests in the greenhouse but exhibited moderate resistance in field stem rust nurseries in Kenya in 2009, 2011, and 2012. Linkert displayed moderate resistance similar to the Ug99-resistant cultivar Tom (Table 5).

End-Use Quality

Linkert has very good end-use quality and performs better than the average of all comparison cultivars for all key metrics of end-use quality (Table 6). Linkert's grain and flour protein concentrations (Tables 1 and 6) are among the highest of the comparison cultivars. Among the comparison cultivars, only RB07 had a significantly higher loaf volume than Linkert. The farinograph stability of Linkert was 25.8 min, averaged over grain samples from four environments. This is above the mean of 18.8 min and not significantly lower than any of the comparison cultivars. Linkert contains the 1 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 Linkert. Foundation seed will be produced and maintained by the Minnesota Crop Improvement Association, 1900 Hendon Ave., St. Paul, MN, 55108. Linkert has been approved for US Plant Variety Protection (PVP no. 201400242) with the seed certification option. A seed sample has been deposited in the USDA–ARS National Laboratory 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 yr from the date of this publication.

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Table 2. Performance of Linkert and other hard red spring wheat cultivars in the Uniform Regional Hard Red Spring Wheat Nursery, 2009–2010. Cultivars are sorted in descending order by grain yield.

Cultivar	Reference	Yield	Test wt.	Protein	Heading	Height	Lodging
		kg ha^{-1}	kg hL^{-1}	g kg^{-1}	d from 1 June	cm	0–9†
Prosper	Mergoum et al., 2013	4510	76.9	143.7	29.0	86.7	1.2
Forefront	Glover et al., 2013	4043	77.6	150.4	25.1	93.2	1.4
Linkert	–	4001	77.5	152.1	26.9	75.4	0.2
Verde‡	Busch et al., 1996	3904	76.7	148.0	27.8	79.7	0.7
Rollag	Anderson et al., 2015	3879	78.3	149.8	27.2	79.0	0.9
2375‡	PI 601477	3865	77.0	141.5	26.6	85.2	2.4
Keene‡	PI 598224	3726	77.4	145.1	27.5	98.5	1.6
Chris‡	Heiner and Johnston, 1967	2871	75.1	151.5	29.4	102.0	5.1
Marquis‡	PI 90834	2845	75.7	145.5	30.1	104.5	3.8
Mean		3717	76.8	146.0	28.0	91.4	2.2
LSD (0.05)		236	0.6	3.0	0.7	2.1	0.9
No. of environments		26	26	20	23	26	11

† 0 = no lodging; 9 = flat.

‡ Long-term check.

Table 3. Performance of Linkert and other hard red spring wheat cultivars and checks in inoculated Fusarium head blight (FHB) nurseries, 2009–2011. Cultivars are sorted in ascending order by the deoxynivalenol (DON) concentration of harvested grain.

Line	Heading	FHB incidence	FHB severity	FHB index	Spike seed wt.	Test wt.	Visually scabby kernels	DON
	d after 1 June	———	%	———	g	kg hL^{-1}	%	µg g^{-1}
Select	27.2	84.0	25.9	23.4	0.69	67.6	12.0	6.2
Alsen†	30.6	95.0	21.7	21.0	0.42	69.5	8.6	6.6
Rollag	30.7	95.0	23.1	22.3	0.62	70.3	8.3	6.7
Brick	26.5	89.8	23.2	21.6	0.65	68.6	8.9	6.7
Briggs	28.2	93.7	37.2	36.5	0.60	65.9	15.7	6.8
BacUp†	27.3	79.2	23.5	18.5	0.60	68.5	10.2	7.0
RB07	29.8	90.0	25.3	24.0	0.59	67.6	12.2	7.1
LCS Albany	33.3	98.0	34.8	34.4	0.53	69.5	10.0	7.4
Sabin	31.3	98.3	24.1	23.8	0.61	67.2	9.3	7.7
Barlow	28.5	95.5	28.7	27.8	0.57	68.3	9.6	7.8
Glenn	28.5	80.3	19.9	17.5	0.58	72.0	9.3	7.9
Cromwell	31.5	95.0	40.6	39.3	0.52	67.1	11.1	7.9
Breaker‡	30.8	91.7	24.9	21.8	0.52	70.4	12.3	8.3
Faller	31.4	92.7	23.9	22.2	0.70	69.0	10.0	9.3
Norden	30.3	91.0	43.5	40.6	0.55	69.1	10.5	9.7
Vantage	34.2	94.7	32.2	31.2	0.58	70.8	11.0	10.0
Linkert	30.4	94.3	37.2	36.3	0.50	66.2	14.0	10.2
LCS Breakaway	28.8	100.0	32.9	32.9	0.52	67.4	14.3	11.0
Prosper	31.8	90.0	31.0	28.1	0.62	67.2	11.4	11.3
Knudson§	30.6	93.3	31.2	30.2	0.59	66.5	22.1	11.3
Roblin¶	27.0	100.0	80.4	80.4	0.34	60.2	56.3	12.6
Jenna	33.0	100.0	55.9	55.9	0.47	63.9	30.3	13.7
Brennan	30.7	100.0	59.9	59.9	0.48	63.1	25.9	13.8
MN00269¶	34.8	100.0	79.1	79.1	0.20	52.9	35.6	14.9
Marshall§	33.6	99.7	48.9	48.8	0.36	64.3	18.3	15.2
Samson	30.2	100.0	56.5	56.5	0.49	63.2	39.6	17.8
Wheaton‡¶	31.8	100.0	84.7	84.7	0.22	54.6	62.5	18.3
Mean	30.5	94.1	38.9	37.7	0.52	66.3	18.5	10.1
LSD (0.05)	1.1	11.5	15.0	15.3	0.12	3.2	9.5	3.5
No. of environments	7	5	5	5	6	7	7	7

† Moderately resistant check.

‡ Breaker, PI 654521; Wheaton, Busch et al. (1984).

§ Long-term check.

¶ Susceptible check.

Table 4. Leaf rust reaction of Linkert and hard red spring wheat cultivars in seedling greenhouse tests and one field evaluation in the Uniform Regional Hard Red Spring Wheat Nursery, 2009–2010.†

Line	FHPTQ	KFBJ		MBBJ	MBDS	MFPS		MHDS		MJBJ	MLDS		TDBG		TDBJ	THBJ		TJBGH	TLGF	Field
	2009	2009	2010	2009	2010	2009	2010	2009	2010	2010	2009	2010	2009	2010	2010	2009	2010	2009	2010	2010
2375‡	3§	0;	;	;2–	3+	2+3	3+2+	3+	3+	3+	3+	3+	2+3	3+	3+	;22+	32+;	;23	;1	30MS¶
Chris‡	33+	3+	3+	2+3	3+	3+	3+	3+	3+	3+	3+	3+	3	3+	3+	3	3+	3+	;22+	30M
Forefront	;	;	;	;	;1	;2	;	23	;1–	;	;1	;2–	;1–	;	;12–	;	;1–	;	;	20MR
Keene‡	;	;	;	;	0;	;1–	;1–	0	0;	0;	;1–	;	1+	1+2	1+2	;/33+	;/3	1+2	;1	50MS
Linkert	;	;	;	;	;	;	;	;	0;	;1–	;	;	;	;	2+3	;/;2	;	;	;	10MR
Marquis‡	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	3+	;23	;12-	3+	3+	3+	;12	2+	70S
Prosper	;	;	;	0;	0;	;	;	0;	0;	0;	0;	;	;	;	;2–	;2	;1	;	;	5R
Rollag	;	;	;	;	;1–	;	;	;	0;	;	3	;2–	0;	0;	2+3	;	;1	;	;	60MS
SY-Soren	;	;	–	;	–	;	–	;	–	–	2	–	;	–	–	;	–	;	–	–
Verde‡	;	;	;	;	;1	;2	;'1-	;12	12+	12	;1–	;1–	;	;1–	1	;	;1	;	;	30MRMS

† Reaction of individual leaf rust races is based on seedling evaluations.

‡ Long-term check.

§ 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).

¶ R = resistant; MR = moderately resistant; M = moderate; MS = moderately susceptible; S = susceptible.

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

Line	QFCSC†	QTHJC	MCCFC	RCRSC	RKQQC	TPMKC	TTTTF	TTKSK (Ug99)	Kenya field‡			
									Oct. 2009	Oct. 2011	Apr. 2012	Oct. 2012
Linkert	0;§	12–	;1–	0;	22–	22+	0;	3	20MS	10MRMS	5S	2.5MRMS
Tom¶	0	;2–	0;	0	;1–	1–;	0;	3–1;	5MS	20MS	10S	5MRMS
RB07	0;	1–1	0;	0	31	;1-	0;	3+	40MSS	–	–	25MS
Sabin	0;	1-	0;	0	;	0;	0;	3	20MS	–	–	50MSS
LMPG-6¶	4	4	4	4	4	4	4	3	60S	25MSS	40S	60S
Red Bobs¶	–	–	–	–	–	–	–	–	60S	40S	35S	50S

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

‡ Stem rust severity and infection response recorded as described in Jin et al. (2007). MR = moderately resistant; M = moderate; MS = moderately susceptible; S = susceptible.

§ 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).

¶ Red Bobs, CItr 6255; Tom, Anderson et al. (2012b).

Table 6. Grain end-use quality of Linkert and other hard red spring wheat cultivars grown in Minnesota in 2010, 2011, and 2012.

Cultivar†	1000 kernel weight	Grain protein‡	Flour protein‡	Bake mix time	Bake absorption	Loaf volume	Farinograph stability
	mg kernel^{-1}	g kg^{-1}	g kg^{-1}	min	g kg^{-1}	mL	min
RB07	26.5	144.9	134.1	2.5	551.3	205	15.9
Vantage	29.0	154.4	146.8	2.3	555.9	201	14.8
Jenna	35.0	144.9	133.1	2.3	560.8	201	15.7
Glenn	29.5	151.9	140.8	3.0	573.9	197	29.4
Barlow	31.2	147.4	137.6	2.2	570.4	196	16.2
Linkert	32.4	150.8	141.1	2.9	560.9	196	25.8
Sabin	27.2	148.5	138.3	2.8	574.5	196	24.6
Samson	29.6	141.0	130.1	2.6	546.9	194	21.4
Prosper	34.2	138.5	128.6	2.3	548.5	192	15.8
Velva	30.3	143.9	134.5	2.8	550.6	192	19.0
Briggs	32.1	149.9	137.6	1.9	555.1	190	14.9
Brick	29.7	147.0	135.3	3.3	562.4	190	30.4
Faller	34.0	139.5	129.4	2.2	548.5	188	20.0
LCS Breakaway	30.6	146.3	138.6	2.0	553.0	188	12.1
Marshall§	26.0	132.9	120.3	1.9	524.4	187	12.1
Brennan	28.2	148.0	136.0	2.3	560.3	185	17.8
Knudson§	31.3	139.0	127.6	3.3	556.8	185	30.4
Norden	29.0	140.3	131.6	2.3	560.8	184	14.0
Cromwell	31.6	143.1	133.1	3.1	556.1	184	20.8
LCS Albany	25.9	132.3	122.5	2.2	541.9	183	9.0
Select	30.6	142.0	131.1	2.9	557.1	181	25.3
Rollag	30.9	148.0	137.0	1.9	566.3	180	9.0
Mean	30.2	144.3	133.9	2.5	556.2	191	18.8
LSD (0.05)	1.4	3.8	4.0	0.3	10.8	9.2	9.0
No. of environments	6	8	8	8	8	8	4

† Cultivars are sorted by loaf volume.

‡ 12% moisture basis.

§ Long-term check.

& 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.

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