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Registration of 'LCS Wizard' Wheat

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Abstract

The objective of this research was to develop widely adapted hard winter wheat (*Triticum aestivum* L.) varieties to meet the needs of mills, bakeries, and consumers in the eastern and Great Plains regions of the United States. 'LCS Wizard' (Reg. No. CV-1111, PI 669574), a hard red winter (HRW) wheat, was developed and tested as VA08HRW-80 and co-released by the Virginia Agricultural Experiment Station and Limagrain Cereal Seeds, LLC in 2013. LCS Wizard was derived from the three-way cross S.6742/92PAN1#33//92PIN#107 using a modified bulk breeding method. LCS Wizard is a widely adapted, high-yielding, awned, semidwarf (*Rht1*) HRW wheat with midseason spike emergence and resistance or moderate resistance to diseases prevalent in the mid-Atlantic and Great Plains regions. In the 2014 Uniform Bread Wheat Trial conducted over 17 locations in eastern states, LCS Wizard produced an average grain yield of 4717 kg ha^{-1}, similar to 'Vision 45' (4650 kg ha^{-1}). In the northern Great Plains, the average grain yield over 54 locations in 2012 of LCS Wizard (4419 kg ha^{-1}) was slightly lower than that of 'Overland' (4659 kg ha^{-1}). In the southern Great Plains, its average grain yield (3844 kg ha^{-1}) over 85 locations was slightly higher than that of Fuller (3757 kg ha^{-1}). LCS Wizard has acceptable end-use quality in both the eastern and Great Plains regions of the United States.

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The hard winter wheat (*Triticum aestivum* L.) breeding program at Virginia Tech was initiated in the early 1990s. The primary objective of this program is to develop varieties of hard winter wheat to meet market demands in eastern United States. Hard wheat is mainly grown in the Great Plains and soft red winter (SRW) wheat in eastern states, thus requiring mills in eastern states to transport hard wheat from the Great Plains. Hard wheat production in eastern states will benefit mills by reducing these transportation expenses and provide economic benefit to growers via higher prices paid for hard wheat compared with soft wheat (Hall et al., 2011a;). Hard winter wheat lines developed at Virginia Tech are tested in the eastern and Great Plains regions in collaboration with Limagrain Cereal Seeds, LLC (LCS).

'LCS Wizard' (Reg. No. CV-1111, PI 669574) is widely adapted and provides producers in the mid-Atlantic and Great Plains regions with a hard red winter (HRW) wheat cultivar that is short in stature, early to mid-season maturity, and high in grain volume weight, and that produces grain yields similar to those of the top-yielding commercial cultivars. LCS Wizard is well adapted to the central and eastern wheat-growing regions of Oklahoma and Kansas and the southwestern irrigated regions of Nebraska, providing growers in those regions with a high-yielding, stiff straw cultivar that is tolerant to acid soils and resistant to *Wheat soil borne mosaic virus* and *Barley yellow dwarf virus*. In addition, LCS Wizard expresses moderate resistance

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Abbreviations: AACC, American Association of Cereal Chemists; FHB, Fusarium head blight; HRW, hard red winter; KSU, Kansas State University; LCS, Limagrain Cereal Seeds; NRPN, Northern Regional Performance Nursery; SRPN, Southern Regional Performance Nursery; SRW, soft red winter; UBWT, Uniform Bread Wheat Trial.

to many of the diseases endemic in one or both regions including powdery mildew [caused by *Blumeria graminis* (DC) E.O. Speer)], leaf rust (caused by *Puccinia triticina* Eriks.), stripe rust (caused by *Puccinia striiformis* Westend.), glume blotch [caused by *Stagonospora nodorum* (Berk.) Castellani & E.G. Germano], Fusarium head blight (caused by *Fusarium graminearum* Schwabe), and Hessian fly [*Mayetiola destructor* (Say)].

Methods

Parentage, Breeding History, and Line Selection

LCS Wizard was derived as an F_5 headrow from the cross S.6742/92PAN1#33//92PIN#107. The French bread wheat line S.6742 was developed by the Serasem Company in Premesques, France, and was provided to the Virginia Tech Small Grains breeding program for evaluation in research trials. Parentage of this line was not provided by Serasem. The pedigree of 92PAN1#33 is W2424/'Siouxland' (PI 483469; Schmidt et al., 1985)//Pioneer Brand '2163' (PI 601722). Parentage of the Pioneer experimental line W2424 is 'Stepova' (PI 372146)/'TAM W-101' (CItr 15324; Porter, 1974). Parentage of 92PIN#107 is Pioneer Brand '2157' (PI 601070)/'Parker 76' (CItr 17685; Heyne, 1977)//'Rocky' (CItr 17879)/Pioneer Brand '2165' (PI 601069). Lines 92PAN1#33 and 92PIN#107 (Selection numbers HBF0174-122 and HBB036J) were developed, evaluated, and advanced within Pioneer Hi-Bred's former HRW wheat breeding program. Pioneer closed its wheat breeding station at Hutchinson, KS, in 1990 and donated its HRW wheat breeding lines and germplasm to Kansas State University (KSU). Lines 92PAN1#33 and 92PIN#107 were evaluated in advanced yield trials at KSU in 1992 and subsequently were distributed by Dr. R.G. Sears to cooperating breeding programs for testing and use in crossing.

The final cross from which LCS Wizard originated was made in spring 2002, and the F_1 generation was grown in the field as a single 1.2-m headrow in 2003 to produce F_2 seed. The population was advanced from the F_2 to F_4 generation using a modified bulk breeding method. Wheat spikes were selected from the population in each segregating generation (F_2–F_3) on the basis of absence of obvious disease, early maturity, short straw, and desirable head shape and size. Selected spikes were threshed in bulk, and the seed was planted in 20.9-m^2 blocks at Blacksburg and/or Warsaw, VA, in the fall of each year. Spikes selected from the F_4 bulk were threshed individually and planted in separate 1.2-m headrows. LCS Wizard was derived as a bulk of one of the F_5 headrows selected in 2007. The line was tested as entry 80 in nonreplicated observation yield tests at Blacksburg and Warsaw in 2008 and was designated VA08HRW-80. In 2009, it was tested in the program's bread wheat preliminary test at Blacksburg and Warsaw (data not presented). It was subsequently tested in Virginia Tech's bread wheat elite test from 2010 to 2014 and in the USDA-ARS Uniform Bread Wheat Trial (UBWT) in 2011 and 2014. In collaboration with LCS, LCS Wizard was evaluated in its program's 2011 to 2014 replicated yield trials in multiple environments in Kansas, Nebraska, and Oklahoma (data not presented). LCS Wizard was also evaluated throughout the Great Plains in the Northern Regional Performance Nursery (NRPN) and Southern Regional Performance Nursery (SRPN) in 2012 and 2013 (only data for 2012 are presented herein as overall performance of LCS Wizard was similar in both years).

Evaluation in Replicated Yield Trials

LCS Wizard, previously designated and tested as VA08HRW-80, was evaluated in Virginia Tech's replicated bread wheat variety trials from 2009 to 2014, in replicated regional tests in the UBWT in 2011 and 2014, and in the NRPN and SRPN in 2012 and 2013 in Great Plains regions. The UBWT (http://www.ars.usda.gov/Main/docs.htm?docid=8419&page=2), NRPN and SRPN (http://www.ars.usda.gov/Main/docs.htm?docid=11932) were conducted using randomized complete block designs with two to four replications, standard variety testing protocols, and recommended management practices that vary slightly from state to state. LCS Wizard was tested as LCH08-80 in the NRPN and SRPN. Plant traits assessed visually (e.g., winter kill, straw strength, and disease resistance) were rated using a scale from 0 (no visible symptoms) to 9 (severe symptoms) based on intensity and severity of the affected plant area.

All replicated yield tests in Virginia were conducted according to small grain production and management protocols recommended by Brann et al. (2000) with late season nitrogen applied to tests at Warsaw, VA, according to Thomason et al. (2007). Conventional till yield plots were planted at 22 seeds per 0.304 m of row with a harvest area of 4.2 m^2. At Painter, VA, plots were composed of six rows with 17.8 cm between rows, while at Warsaw and Blacksburg, VA, plots consisted of seven 15.2-cm rows. Assessment of reaction to Fusarium head blight (FHB; caused by *Fusarium graminearum* Schwabe) was conducted in replicated inoculated and mist-irrigated nurseries according to the procedures described by Chen et al. (2006).

Grain subsamples (1000 g) were supplied to the USDA Hard Winter Wheat Quality Laboratory, in Manhattan, KS, for grain, flour, and milling and baking quality analysis. Grain samples from Virginia Tech tests came from a bulk of three replicated plots at Warsaw; samples from the 2012–2013 Northern Regional Performance Nursery were a bulk composite of grain from Lincoln, NE, Crookston, MN, Brookings, SD, Dakota Lakes, SD, and Winner, SD. Single kernel wheat characteristics were determined by the Single Kernel Characterization System (SKCS) (American Association of Cereal Chemists [AACC] Method 55-31) (American Association of Cereal Chemists, 2000). Wheat and flour protein (%N × 5.7) were determined by a Nitrogen Determinator (Leco Corp.) (AACC Method 46-30). Moisture and ash contents were determined by AACC Methods 08-01 and 44-15A, respectively. Wheat samples, tempered to constant moisture (16%), were milled on a Quadrumat Senior experimental mill (C.W. Brabender Co.) according to AACC Methods 26-10A and 26-50. Flour yield was determined as percentage of straight grade flour. A mixogram for each flour sample (10 g, on a 14% moisture basis) was obtained using a 10-g mixograph (National Mfg. Co.) with optimum water adsorption (Finney and Shogren, 1972). Mix time was visually determined from the mixogram. Mix time to peak dough development and mixing tolerance were also determined from the mixograph (AACC Method 54-40). Corrected mixograph mix time was corrected on the basis of protein content of

flour. A straight-dough, 100-g pup-loaf bake test method was used to measure bread-making properties, crumb grain score, and loaf volume (AACC Method 10-10B). Crumb grain of representative bread slices were graded from poor open grain (0) to outstanding closed grain (6).

The end-use quality of LCS Wizard also was evaluated in the grain quality laboratory at LCS, Fort Collins, CO. Grain samples from the 2012 Limagrain Cereal Seed Y3 trial were composed of a bulk of three replicated plots from Wichita, KS. Quality testing was performed identical to that conducted at the USDA Hard Wheat Quality Laboratory with the following exceptions. Wheat moisture, flour moisture, wheat protein, flour protein, and flour ash were determined by near-infrared spectrophotometry using a FOSS DS2500 (Foss North America). Flour SDS sedimentation was determined by Sedimentation Micro Method (Seabourn et al., 2012); SDS was run on whole meal samples ground on an Udy cyclone mill (Udy Corp.). Wheat was tempered to 14.5% moisture and milled on a modified Quadrumat Senior mill (C.W. Brabender Co.). Moisture loss from milling averaged 0.5% from grain to flour.

Analysis of variance was conducted on data from individual locations and years and across locations and years in Virginia Tech tests using Agrobase 20 (Agronomix Software, 1999), Agrobase Generation II SQL version 36.5.1 (Agronomix Software, 2004) for data of UBWT, and SAS version 9.2 (SAS Institute, 2009) for data of NPRN and SPRN. The mean comparisons of traits between genotypes were based on a protected LSD ($P = 0.05$) test. The mean and standard deviation for grain, milling, and baking data were obtained with Microsoft Excel 2010 (2013).

Seed Purification and Increase

During fall 2010, 400 $F_{8:9}$ headrows of LCS Wizard were planted at Warsaw, VA, in an isolation block and evaluated for purity and trueness of type. Among these 400 breeder seed headrows, 117 rows were removed and discarded on the basis of variability and lack of trueness to cultivar type. The remaining 283 centermost rows that were similar in phenotype and visually homogenous were harvested in bulk to form the LCS Wizard breeder seed.

From this initial breeder seed, 36.3 kg were delivered to LCS and split into two lots. One lot of 10.4 kg seed was planted on 0.2 ha in Milliken, CO, in September 2011, and the other lot of 25.9 kg seed was planted on 2.0 ha at Casa Grande, AZ, in November 2011. Both fields were inspected by LCS at the hard dough stage and found to be very uniform. An occasional tall plant, on the order of 1 per 100,000, was removed from both fields. The 0.2-ha field in Milliken was harvested in July 2012 and produced 34 units (22.7 kg unit^{-1}) of cleaned breeder seed. This seed is in storage at LCS in Fort Collins, CO. The 2.0-ha field in Casa Grande was inspected by Arizona Crop Improvement Association on 31 May 2012 and passed field inspection for the foundation class of seed. However, this seed was labeled again as breeder seed since the cultivar had not yet been released or brought into the AOSCA certification scheme. Approximately 11,975 kg (12 t) of breeder seed was transported to an LCS distributor in north-central Kansas and professionally conditioned to produce two lots of breeder seed for fall planting in 2012. Approximately 5443 kg (5.4 t) of breeder seed was planted under pivot irrigation in Kansas in September 2012, and approximately 5443 kg of breeder seed was transported to Oklahoma and planted under irrigation in September 2012. Approximately 544,320 kg (544 t) of foundation seed was produced in 2013 and made available to seed producers of LCS in fall 2013.

Characteristics

Botanical and Agronomic Characteristics

The juvenile growth of LCS Wizard is semi-erect. At the boot stage, plants of LCS Wizard are green in color and have flag leaves that are erect, twisted, and waxy. Stems are hollow and waxy, lack anthocyanin, and have five nodes, semi-erect peduncles, hairy terminal rachis internodes, and auricles lacking hairs and anthocyanin. LCS Wizard has yellow-colored anthers. Spikes of LCS Wizard are awned, inclined to recurved, mid-dense, blocky to slightly tapering in shape, and creamy white in color at maturity. Straw is yellow and lacks anthocyanin at physiological maturity. The white, pubescent glumes are long and narrow and have obtuse beaks and oblique shoulders of narrow width. The hard red kernels of LCS Wizard are oval with rounded cheeks, medium wide and mid-deep creases, and large germ and brush sizes. The seed phenol reaction color is brown.

In Virginia, 4-yr average spike emergence (days to heading from 1 January) of LCS Wizard (123 d) is 3 d earlier than 'Vision 45' (PI 667642, Liu et al., 2015) (126 d) and 3 d later than 'Vision 30' (PI 661153; Hall et al., 2011a) (120 d). Average plant height of LCS Wizard (88 cm) is similar to Vision 30 (87 cm) and 14 cm shorter than Vision 45 (102 cm). Straw strength (0 = erect to 9 = completely lodged) of LCS Wizard (1.0) is very good, being most similar to that (1.2) of 'Vision 40' (PI 661154; Hall et al., 2011b) and better than that (2.4) of Vision 30 (Table 1).

In the 2014 USDA-ARS UBWT, average spike emergence of LCS Wizard (130 d) was 1 d later than Vision 30 and 3 d earlier than Vision 45. Average plant height of LCS Wizard (83 cm) was 2 cm taller than 'Shirley' (PI 656753; Griffey et al., 2010) and 15 cm shorter than Vision 45. Straw strength of LCS Wizard (2.1) was good and significantly better than that of Vision 30, 'TAM 303', and 'Appalachian White' (PI 657998) (Table 2).

In the northern Great Plains, average spike emergence of LCS Wizard (147 d) in the 2012 NRPN was 2 d earlier than 'Overland' and the nursery mean and 6 d earlier than the long-term check cultivar Kharkof (PI 5641). In the southern Great Plains, spike emergence of LCS Wizard (124 d) in the 2012 SRPN was 1 d later than the nursery average, 3 d later than Fuller (PI 653521), and 9 d earlier than Kharkof. Average plant height of LCS Wizard (74 cm) in the NRPN was similar to that of 'Wesley' (PI 605742; Peterson et al., 2001) and 7 cm less than the nursery average. In the SRPN, average plant height of LCS Wizard (72 cm) was most similar to that (73 cm) of 'TAM 107' (PI 495594; Porter et al., 1987) and 2 cm shorter than the nursery average (Table 3).

Field Performance

In the Virginia Tech Bread Wheat Elite Test (2011– 2014), LCS Wizard had a 4-yr average grain yield (5159 kg ha^{-1}) that was similar to SRW wheat cultivar Tribute (PI 654422; Griffey

Table 1. Four-year (2011–2014) mean performance of LCS Wizard and other hard red winter cultivars in the Virginia Tech Bread Wheat Elite Test in Virginia.†

Cultivar	Grain yield	Grain volume weight	Heading date	Plant height	Lodging	Disease resistance					
						Leaf rust	Powdery mildew	BYDV‡	FHB§ inc	FHB§ sev	FHB§ index
	kg ha^{-1}	kg hL^{-1}	d after 1 Jan.	cm	0–9¶	0–9#			%		
Vision 45	5499	76.1	126	102	1.4	1.0	0.4	1.3	45.0	12.2	5.4
Vision 30	5260	75.0	120	87	2.4	3.4	0.1	0.8	43.1	13.1	7.1
Tribute††	5181	78.0	121	83	2.6	2.7	4.3	2.4	43.8	15.3	5.4
LCS Wizard	5159	76.8	123	88	1.0	1.0	1.9	0.6	51.3	13.6	7.5
Vision 40	5007	74.6	123	92	1.2	1.7	2.0	1.7	54.4	12.4	9.3
Soissons	4847	72.9	125	81	0.1	4.0	0.6	0.8	51.9	13.9	6.2
Vision 20	4803	76.6	121	88	1.7	0.6	1.5	1.2	47.5	16.2	11.2
Jagger	4240	74.1	116	86	2.6	2.1	5.6	2.3	35.0	14.4	6.1
Karl 92	4203	75.6	119	87	2.1	4.3	1.3	1.8	42.5	13.9	8.1
Mean (*N* = 15)	5066	75.1	122	89	1.7	1.8	1.6	1.6	45.0	13.5	7.6
CV (%)	6.3	1.4	1.0	1.7	38.9	50.0	44.8	48.2	28.4	36.5	53.4
LSD (0.05)	378.4	1.3	1.5	1.8	0.8	1.0	0.9	0.9	15.2	5.9	4.8
No. of site-years	11	11	8	8	8	8	10	4	4	4	4

† Grain yield and grain volume weight data from Blacksburg (2011–2014), Warsaw (2011–2014), and Painter (2011, 2013, 2014); leaf rust from Blacksburg (2011–2014), Warsaw (2011, 2012, 2014), and Painter (2013); powdery mildew data from Blacksburg (2012–2014), Warsaw (2011–2014), and Painter (2011, 2013, 2014); heading date, plant height, and lodging from Blacksburg (2011–2014) and Warsaw (2011–2014); *Barley yellow dwarf virus* from Blacksburg (2011, 2012), Warsaw (2013), and Painter (2014); Fusarium head blight from Blacksburg Scab Nursery (2011–2014).

‡ BYDV = *Barley yellow dwarf virus*.

§ FHB = Fusarium head blight; inc = incidence%; sev = severity%; index = % incidence × % severity ÷ 100.

¶ 0 = erect; 9 = completely lodged.

0 = highly resistant; 9 = highly susceptible.

†† Soft red winter wheat check cultivar.

et al., 2005), which was 5181 kg ha^{-1}. The 4-yr average grain volume weight of LCS Wizard (76.8 kg hL^{-1}) was higher than all other HRW wheat checks (Table 1).

LCS Wizard was evaluated with 40 other entries in 18 diverse environments in the USDA-ARS UBWT in 2014 (Table 2). The average grain yield over locations of LCS Wizard (4717 kg ha^{-1}) was similar to that of HRW wheat Vision 45 (4650 kg ha^{-1}) and SRW wheat check cultivar USG 3120 (4811 kg ha^{-1}). Average grain volume weight of LCS Wizard (73.4 kg hL^{-1}) was similar to the nursery average. Winter stress rating (0 = no injury, 9 = severe injury) for LCS Wizard (6.0) was lower than that of Vision 30 (7.0) and Vision 45 (7.0). LCS Wizard test data for the 2012 USDA-ARS UBWT are presented on USDA website (http://www.ars.usda.gov/Main/docs.htm?docid=8419&page=2).

In the Great Plains region, LCS Wizard had an average grain yield (4419 kg ha^{-1}) that was 216 kg above the nursery average over all locations in the NRPN. In the SRPN, LCS Wizard had an average grain yield (3844 kg ha^{-1}) that was 149 kg higher than the overall nursery average. In both nurseries, LCS Wizard was in the highest test weight groups among released cultivars and had mean volume weights (77.2 and 76.6 kg hL^{-1}) that were 0.9 and 1.4 kg hL^{-1} higher than the overall nursery averages, respectively (Table 2). LSC Wizard was also tested in 2013 SRPN and NRPN; data are available on USDA website (http://www.ars.usda.gov/Main/docs.htm?docid=11932).

Disease and Insect Resistance

Reaction of LCS Wizard to diseases (0 = immunity to 9 = very susceptible) has been evaluated in diverse environments in the mid-Atlantic and Great Plains regions of the United States (Tables 1–3). In the mid-Atlantic region, LCS Wizard has been moderately resistant (1.9– 2.1) to powdery mildew. In both regions, LCS Wizard on average has expressed moderate resistance (1.0– 3.0) to leaf rust. Moderate infection type (0–9) and severity (%) ratings (Line and Qayoum, 1992) to stripe rust were noted for LCS Wizard in the NRPN (4 and 5%), SRPN (5 and 10%), and UBWT (6). In tests conducted in both regions, LCS Wizard is susceptible to stem rust, with field severities of 90%, and adult plants evaluated in a field test in Kenya also had a rating of 70 MS-S (moderate susceptible to susceptible) to race TTKSK (Ug99) (Tables 2–3). In both regions, LCS Wizard is moderately resistant to *Barley yellow dwarf virus* (0.6–3.3). In the 2012 UBWT at Kinston, NC, LCS Wizard was rated as moderately susceptible (6) to *Wheat soilborne mosaic virus* (http://www.ars.usda.gov/Main/docs.htm?docid=8419&page=2), while it was rated as moderately resistant (1) in the NRPN and SRPN at Stillwater, OK (Table 2). In the mid-Atlantic region, LCS Wizard has expressed moderate resistance (1.0) to glume blotch (Table 2), while it is susceptible to leaf blotches caused by *Stagonospora nodorum* (Berk.) Castellani & E.G. Germano (5.1–7.0) and *Septoria tritici* Roberge in Desmaz (8.0) in UBWT tests (http://www.ars.usda.gov/Main/docs.htm?docid=8419&page=2). In tests conducted at Virginia Tech (Table 1), LCS Wizard expressed moderate resistance to FHB, with 4-yr average values for FHB incidence (51.3%), severity (13.6%), and index (7.5%) similar to those of the moderately resistant SRW wheat cultivar Tribute (43.8, 15.3, and 5.4%). Seedlings of LCS Wizard were resistant to Hessian fly biotypes B and O in the 2011 UBWT, moderately resistant (3.2) under natural field conditions (Table 2), and resistant to the Great Plains biotype. It is susceptible to greenbug (*Schizaphis graminum*) biotype E (Table 3). Reaction

Table 2. Mean performance of LCS Wizard and other hard red winter wheat cultivars in the 2013–2014 USDA-ARS Uniform Bread Wheat Trial.

Line	Grain yield	Volume weight	Heading date	Plant height	Lodging	Growth habit	Winter stress	Disease resistance									Hessian fly	Kernel diam.
											Stag. nod. †				Stem rust			
								Powdery mildew	Leaf rust	Stripe rust	Leaf blotch	Glume blotch	FHB†‡	Bacterial leaf streak	St. Paul, MN	Njoro, Kenya		
	kg ha^{-1}	kg hL^{-1}	d after 1 Jan.	cm	0–9§	0–9¶	0–9#	0–9††					– 1–9‡‡ –		– rating§§ –		0–9¶¶	mm
Shirley##	5348	70.8	130	81	1.5	5.2	5.0	0.2	0.6	7.5	3.9	0.5	8.0	4.8	0	0	3.5	2.76
USG 3120##	4811	73.4	124	86	2.5	2.5	7.0	1.4	1.2	4.5	5.6	1.5	7.8	2.2	10MR	60MS	3.5	2.85
LCS Wizard	4717	73.4	130	83	2.1	4.8	6.0	2.1	1.0	6.0	5.1	1.0	8.2	3.3	90S	70MSS	3.2	2.72
Vision 45	4650	73.1	133	98	2.7	5.5	7.0	0.3	0.9	0.0	3.5	0.0	7.2	4.1	60S	60S	5.7	2.76
NuEast	4623	76.3	128	93	2.4	5.5	5.0	2.8	0.8	8.0	5.8	6.0	5.9	3.8	70MSS	40MRMS	3.7	2.89
Everest	4589	76.2	124	82	2.1	4.8	5.0	1.8	0.7	7.0	6.8	2.0	4.4	4.1	70MS	70S	4.0	2.85
Appalachian White	4555	74.2	130	90	3.6	6.0	4.0	0.5	0.8	0.5	3.6	0.0	5.9	3.1	TMS	40S	3.5	2.72
Vision 30	4515	72.5	129	85	3.4	3.2	7.0	0.4	1.8	7.0	3.9	0.5	6.1	4.7	20MS	60S5R	3.8	2.73
TAM 303	4347	72.2	126	89	3.5	5.5	4.0	2.4	1.0	6.0	7.4	7.5	6.8	4.5	10MR70S	30MRMS	3.3	2.77
Mean (N = 41)	4546	73.4	129	86	2.4	5.1	4.9	1.1	0.9	3.9	5.0	2.5	6.7	3.4	–	–	4.3	2.80
CV (%)	13.9	3.3	1.7	4.8	46.2	15.5	17.5	142.7	76.6	18.1	28.4	39.1	11.3	23.2	–	–	21.1	1.9
LSD (0.05)	348.0	1.4	1.8	2.6	0.9	1.3	1.4	1.7	0.8	1.2	1.7	1.6	1.2	1.3	–	–	1.2	0.1
No. of locations	18	17	8	13	9	3	1	5	4	1	4	1	1	1	–	–	3	7

† Stag. nod. = *Stagonospora nodorum.*

‡ FHB = Fusarium head blight.

§ 0 = erect; 9 = completely lodged.

¶ Growth habit (midwinter rating): 0 = very upright; 9 = very prostrate.

Winter stress (midwinter rating leaf damage): 0 = no injury; 9 = complete kill.

†† 0 = highly resistant; 9 = highly susceptible.

‡‡ 1 = highly resistant; 9 = highly susceptible.

§§ Stem rust field reaction; St. Paul, MN used a composite races of QFCSC, QTHJC, RCRSC, RKQQC, and TPMKC; Kenya race was TTKSK (Ug99); ratings included severity as percent area affected from 0 to 100, and infection response types of resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S); Tr = trace.

¶¶ 0 = no plant damage; 9 = yellow/dead lower leaves, poor tillering, stunted.

Soft red winter wheat check cultivar.

Table 3. Performance of LCS Wizard and other HRW wheat cultivars in the 2012 Northern and Southern Regional Performance Nurseries.

Cultivar	Grain yield	Grain volume weight	Heading date	Plant height	Disease resistance						Greenbug biotype E	Hessian fly Great Plains biotype resistant plants
					Leaf rust‡	Stripe rust†		Stem rust§	BYDV¶	WSBMV#		
						Infection type	Disease severity					
	kg ha^{-1}	kg hL^{-1}	d after 1 Jan.	cm	—— 0–9†† ——		%	rating	0–9††	1–4‡‡	rating	%
2012 Northern Regional Performance Nursery												
Overland	4659	77.9	149	84	5	5	40	70MS-S	1	2	susceptible	86.4
LCS Wizard	4419	77.2	147	74	3	4	5	90S	1	1	susceptible	100.0
Wesley	4214	76.0	147	74	6	5	5	30MR-MS	3	2	susceptible	0.0
Lyman	4134	77.5	148	83	2	3	5	30MR	4	2	susceptible	70.0
Jerry	3725	75.3	153	89	4	6	5	50MS-S	5	1	susceptible	44.4
Kharkof	2775	77.0	153	98	4	2	1	–	6	2	susceptible	15.4
Mean (*N* = 34)	4203	76.3	149	81								
LSD (0.05)	354.8											
CV (%)	9.8											
No. of sites	54	9	11	10	1	1	1	1	2	1	1	1
2012 Southern Regional Performance Nursery												
LCS Wizard	3844	76.6	124	72	3	5	10	90S	3.3	1	susceptible	100
Fuller	3757	74.7	121	73	5	5	1	–	5.3	1	susceptible	0
TAM 107	3324	73.3	120	73	7	7	50	80S	5.4	2	susceptible	0
Scout 66	2714	74.2	126	89	5	4	10	90S	6.8	4	susceptible	0
Kharkof	1809	68.0	133	94	3	2	1	100S	5.9	2	susceptible	0
Mean (*N* = 44)	3695	75.2	123	74								
LSD (0.05)	234											
CV (%)	11											
No. of sites	85	16	12	13	1	1	1	1	3	1	1	1

† Stripe rust was rated at Rossville, KS, in nursery inoculated with PST100.

‡ Leaf rust was rated at Castroville, TX.

§ Stem rust was rated at Buckthorn, MN, in nursery inoculated with bulk of races QFCSC, QTHJC, RCRSC, RKQQC, and TPMKC. Stem rust ratings included severity as percentage area affected from 0 to 100, and infection response types of resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S); Tr = trace.

¶ BYDV = *Barley yellow dwarf virus*.

WSBMV = *Wheat soil-borne mosaic virus*, rated at Stillwater, OK.

†† 0 = highly resistant; 9 = highly susceptible.

‡‡ 1 = highly resistant; 4 = highly susceptible.

of LCS Wizard to *Wheat spindle streak mosaic virus* and *Wheat streak mosaic virus* is not known.

End-Use Quality

Grain characteristics and milling and baking quality of LCS Wizard in Virginia Tech tests have been evaluated by the USDA-ARS Hard Wheat Quality Laboratory in Manhattan, KS, since 2009; the last 3 yr of data are presented in Table 4. The 3-yr average grain hardness score from Single Kernel Characterization System for LCS Wizard (71.4) was higher than that (63.4) of the HRW wheat quality check cultivar Jagger (PI 593688, Sears et al., 1997). The 3-yr average flour yield of LCS Wizard (70.2 g 100 g^{-1}) was similar to that of Jagger (70.3 g 100 g^{-1}). The 3-yr average grain and flour protein concentrations of LCS Wizard (11.6 g 100 g^{-1} and 10.2 g 100 g^{-1}) were similar to those of Jagger (12.1 g 100 g^{-1} and 10.6 g 100 g^{-1}). The 3-yr average flour water absorption of LCS Wizard (60.0 g 100 g^{-1}) was the same as that of Vision 40, while it was lower than that of Jagger (61.3 g 100 g^{-1}). Farinogram dough mixing characteristics of LCS Wizard for peak mixing time (1.8 min) and mixing tolerance (0 = poorest to 6 = best) scores (2.0) were lower than those of Jagger (3.4 min and 2.7). Average bread pup-loaf volume and bread crumb grain scores (0 = poorest to 6 = best) of LCS Wizard (760 cm^3 and 2.5) were similar to those of Jagger (773 cm^3 and 2.8).

Grain characteristics and milling and baking quality of LCS Wizard in Great Plain tests were evaluated by the USDA-ARS Hard Wheat Quality Laboratory in Manhattan, KS, in 2012 and 2013 (http://www.ars.usda.gov/Research/docs.htm?docid=14298&page=3), but only results from the 2013 NRPN are presented in Table 5. Kernel hardness index (0–100) value for LCS Wizard (64) was higher than those of 'Jerry' (52) (PI 632433; Peel et al., 2004), Wesley (60), and Overland (62) but lower than that of 'Lyman' (66) (PI 658067). Protein concentrations of wheat and flour of LCS Wizard (13.7 g 100 g^{-1} and 12.5 g 100 g^{-1}) are most similar to those of Overland (13.7 g 100 g^{-1} and 12.2 g 100 g^{-1}). Flour yields and water absorption of LCS Wizard (68.1 g 100 g^{-1} and 63.8 g 100 g^{-1}) were similar to those of Lyman (69.7 g 100 g^{-1} and 64.0 g 100 g^{-1}). Adjusted dough mixing time and adjusted bake mixing time for LCS Wizard (2.63 and 3.0 min) were lower than those of Lyman (3.63 and 5 min), while mixing tolerance (0 = poorest to 6 = best) and bread loaf volume for LCS Wizard (2 and 930 cm^3) were the same as those of Lyman (2 and 930 cm^3). Crumb

Table 4. Milling and baking quality of LCS Wizard and other hard red winter wheat cultivars in 2012–2014 Virginia Tech tests conducted by the USDA-ARS Hard Winter Wheat Quality Laboratory, Manhattan, KS.

Cultivar	Single-kernel hardness				Flour yield				Grain protein†				Flour protein†				Flour ash†			
	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean
	0–100‡				g 100 g^{-1}															
Vision 20	63.6	64.3	59.5	62.5	67.7	70.6	64.7	67.7	13.4	11.6	11.6	12.2	11.8	10.1	9.8	10.5	0.40	0.43	0.40	0.41
Vision 30	57.8	55.6	54.0	55.8	66.9	72.9	67.4	69.0	11.7	11.5	11.8	11.7	10.7	10.2	10.2	10.4	0.39	0.41	0.38	0.39
Vision 40	56.0	52.7	53.8	54.2	70.9	72.5	67.9	70.4	12.3	11.6	10.2	11.4	10.9	10.1	9.0	10.0	0.39	0.41	0.42	0.41
Vision 45	55.4	56.0	56.6	56.0	70.5	72.2	69.4	70.7	12.8	12.3	10.8	11.9	11.4	10.8	9.4	10.5	0.38	0.40	0.42	0.40
Jagger	64.7	64.7	60.9	63.4	71.9	72.5	66.6	70.3	13.4	11.5	11.3	12.1	11.9	10.1	9.8	10.6	0.43	0.44	0.41	0.43
Karl 92	58.1	55.7	51.6	55.2	69.0	70.5	66.3	68.6	13.8	12.2	12.0	12.6	12.3	10.9	10.1	11.1	0.40	0.43	0.38	0.40
LCS Wizard	73.8	73.5	67.0	71.4	71.3	72.4	66.9	70.2	12.3	11.5	11.0	11.6	11.3	10.0	9.2	10.2	0.42	0.43	0.42	0.42
Soissons	55.3	50.7	52.5	52.8	74.6	75.9	71.4	74.0	11.2	10.7	10.5	10.8	10.0	9.4	9.0	9.5	0.41	0.42	0.41	0.41
Mean§	60.4	56.7	56.0	57.7	70.5	72.0	66.8	69.8	12.2	11.3	11.0	11.5	10.9	9.8	9.4	10.0	0.41	0.43	0.41	0.42
SD§ (0.05)	8.0	16.1	15.9	13.3	2.4	1.6	2.8	2.3	0.9	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.0	0.0	0.0	0.0

Cultivar	Flour water absorption				Dough mixing time				Dough mixing tolerance				Pup-loaf volume				Crumb grain score			
	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean
	g 100 g^{-1}				min				0–6¶				cm^3				0–6#			
Vision 20	63.5	59.7	60.2	61.2	3.28	4.43	3.22	3.6	0	4	4	2.7	800	810	785	798.3	2.5	2.5	3.5	2.8
Vision 30	61.7	58.5	60.3	60.2	3.47	3.94	3.45	3.6	4	3	3	3.3	700	820	795	771.7	2.0	4.2	3.0	3.1
Vision 40	62.1	59.7	58.3	60.0	2.29	2.88	2.38	2.5	0	3	3	2.0	705	855	755	771.7	1.5	4.5	3.5	3.2
Vision 45	62.0	61.0	59.3	60.7	3.38	4.07	2.57	3.3	2	4	2	2.7	795	825	775	798.3	2.2	4.2	3.5	3.3
Jagger	63.7	59.8	60.4	61.3	3.45	3.88	2.74	3.4	3	3	2	2.7	765	785	770	773.3	2.0	2.5	4.0	2.8
Karl 92	64.4	61.0	61.4	62.3	3.63	4.74	3.09	3.8	1	4	4	3.0	895	855	805	851.7	2.8	3.0	4.5	3.4
LCS Wizard	62.2	59.6	58.2	60.0	1.72	2.18	1.43	1.8	2	2	2	2.0	690	810	780	760.0	1.0	3.0	3.5	2.5
Soissons	60.1	58.6	58.2	59.0	2.86	3.25	3.05	3.1	2	4	4	3.3	780	785	745	770.0	3.2	4.0	4.5	3.9
Mean§	61.5	58.7	58.6	59.6	2.7	2.8	2.3	2.6	1.7	2.4	2.5	2.2	729.3	746.3	740.6	738.7	2.1	2.8	3.0	2.6
SD§ (0.05)	1.4	1.9	2.1	1.8	0.5	1.0	0.9	0.8	1.2	1.1	1.2	1.2	61.0	64.6	52.4	59.3	0.9	0.9	1.2	1.0

† Data adjusted to 14% moisture basis.

‡ 0 = very soft; 100 = very hard.

§ Mean value of all entries evaluated in trial in 2012 (*N* = 30), 2013 (*N* = 31), and 2014 (*N* = 34).

¶ 0 = weak dough with poor mixing tolerance; 6 = strong dough with good mixing tolerance.

0 = poor open grain; 6 = outstanding closed grain.

grain score (0 = poorest to 6 = best) for LCS Wizard (3) was slightly lower than that of Lyman (3.5) (Table 5).

In grain and flour quality tests conducted by LCS (Table 6), the kernel hardness index (0–100) value for LCS Wizard (59.3) was higher than that of 'Everest' (53.4). Protein concentrations of grain and flour of LCS Wizard (13.3 g 100 g^{-1} and 12.9 g 100 g^{-1}) were similar to those of Everest (13.7 g 100 g^{-1} and 12.8 g 100 g^{-1}). Flour yields and water absorption of LCS Wizard (69.3 g 100 g^{-1} and 62.8 g 100 g^{-1}) also were similar to those of Everest (69.6 g 100 g^{-1} and 62.7 g 100 g^{-1}). Mixing tolerance (0 = poorest to 6 = best) and SDS sedimentation values for LCS Wizard (2 and 70 mm) were slightly higher than those of Everest (1 and 65 mm). Bread loaf volume of LCS Wizard (860 cm^3) was higher than that of Everest (820 cm^3), while crumb grain scores (0 = poorest to 6 = best) were similar (4) for both cultivars.

Availability

Foundation seed was sent to seed producers by Limagrain Cereal Seeds, LLC in fall 2013. Limagrain Cereal Seeds, LLC

Table 5. Grain, milling, and baking quality of LCS Wizard and other hard red winter wheat cultivars in the 2012–2013 Northern Regional Performance Nursery evaluated by the USDA-ARS Hard Wheat Quality Laboratory, Manhattan, KS, using grain sourced from the North Central Plains: Lincoln, NE, Crookston, MN, Brookings, SD, Dakota Lakes, SD, Winner, SD.

Cultivar	Single-kernel hardness	Wheat protein†	Flour yield	Flour ash†	Flour protein†	Flour water absorption	Adjusted dough mixing time	Dough mixing tolerance	Adjusted bake mixing time	Loaf volume	Crumb grain score
	0–100‡	g 100 g^{-1}					min	0–6§	min	cm^3	0–6¶
Wesley	60	14.3	71.7	0.48	13.3	63.5	4.38	4	8	930	4.0
Lyman	66	14.6	69.7	0.5	13.2	64.0	3.63	2	5	930	3.5
LCS Wizard	64	13.7	68.1	0.49	12.5	63.8	2.63	2	3	930	3.0
Jerry	52	14.0	70.4	0.48	12.9	64.4	3.88	3	5	910	3.5
Overland	62	13.7	71.1	0.49	12.2	61.8	2.38	1	3	800	2.0

† Data adjusted to 14% moisture basis.

‡ 0 = very soft; 100 = very hard.

§ 0 = weak dough with poor mixing tolerance; 6 = strong dough with good mixing tolerance.

¶ 0 = poor open grain; 6 = outstanding closed grain.

Table 6. Grain, milling and baking quality of LCS Wizard and other hard red winter wheat cultivars in the 2012 Limagrain Cereal Seed Y3 Trial, Wichita, KS.†

Cultivar	SKCS‡ hardness	SKCS‡ 1000-kernel weight	SKCS‡ kernel diameter	Flour yield	NIR§ whole grain protein	NIR§ flour protein	NIR§ flour ash	SDS sedimentation	Flour water absorption	Mixing tolerance	Loaf volume	Crumb grain
	0–100¶	g	cm	——— g 100 g^{-1} ———				mm	g 100 g^{-1}	0–6#	cm^3	0–6††
Karl 92	52.7	28.5	2.6	68.5	14.0	12.8	0.56	85.0	62.7	4.0	910	5
LCS Wizard	59.3	26.2	2.6	69.3	13.3	12.9	0.57	70.0	62.8	2.0	860	4
Vision 10	59.5	27.6	2.5	68.7	13.6	13.0	0.56	70.0	63.0	1.0	850	4
Vision 45	47.0	37.6	2.9	70.2	15.1	13.3	0.55	80.0	63.4	1.0	845	4
Duster	65.2	27.0	2.5	68.0	13.7	11.9	0.56	70.0	61.4	5.0	830	4
Everest	53.4	30.3	2.7	69.6	13.7	12.8	0.50	65.0	62.7	1.0	820	4
Denali	57.3	28.9	2.5	66.1	13.6	12.7	0.52	70.0	62.5	2.0	725	3

† 2012 was an extremely hot and early season. Grain sample was bulk of three replicated plots from Wichita, KS.

‡ Single Kernel Characterization System (SKCS), AACC Method 55-31.01 (American Association of Cereal Chemists, 2000).

§ Near-infrared (NIR) method. For whole grain protein AACC Method 39-25.01; flour protein AACC Method 39-11.01; flour ash AACC Method 08-21.01 (American Association of Cereal Chemists, 2000).

¶ 0 = very soft; 100 = very hard.

0 = weak dough with poor mixing tolerance; 6 = strong dough with good mixing tolerance.

†† 0 = poor open grain; 6 = outstanding closed grain.

will be responsible for distribution of foundation seed of LCS Wizard west of the Mississippi River in the Great Plains region. In the eastern United States, LCS Wizard will be marketed by the Mennel Milling Company based in Fostoria, OH, and seed will be produced and distributed by Virginia Identity Preserved Grains, LLC, West Point, VA. An application for Plant Variety Protection of LCS Wizard is currently under review by the USDA-AMS-S&TP-Plant Variety Protection Office. A seed sample of LCS Wizard has been deposited in the USDA-ARS National Center for Genetic Resources Preservation and will be available for distribution after expiration of its U.S. Plant Variety Protection. Small amounts of seed for research purposes may be obtained from the corresponding author for at least five years after the date of this publication.

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References

Agronomix Software. 1999. Agrobase user's guide and reference manual. Agronomix Software, Winnipeg, MB, Canada.

Agronomix Software. 2004. Agrobase Generation II user's manual. Agronomix Software, Winnipeg, MB, Canada.

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

Brann, D.E., D.L. Holshouser, and G.L. Mullins. 2000. Agronomy handbook. Pub. 424-100, Virginia Coop. Ext., Blacksburg, VA.

Chen, J., C.A. Griffey, M.A. Saghai Maroof, E.L. Stromberg, R.M. Biyashev, W. Zhao, M.R. Chappell, T.H. Pridgen, Y. Dong, and Z. Zeng. 2006. Validation of two major quantitative trait loci for fusarium head blight resistance in Chinese wheat line W14. Plant Breed. 125:99–101. doi:10.1111/j.1439-0523.2006.01182.x

Finney, K.F., and M.D. Shogren. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flours. Bakers Digest 42:32–35, 38–42, 77.

Griffey, C.A., W.L. Rohrer, T.H. Pridgen, W.S. Brooks, J. Chen, J.A. Wilson, D. Nabati, D.E. Brann, E.G. Rucher, H.D. Behl, M.E. Vaughn, W.L. Sisson, T.R. Randall, R.A. Corbin, J.C. Kenner, D.W. Dunaway, R.M. Pitman, A.E. Smid, H.E. Bockelman, C. Gaines, D.L. McVey, S.E. Cambron, and L. Whitcher. 2005. Registration of 'Tribute' wheat. Crop Sci. 45:419–420. doi:10.2135/cropsci2005.0419

Griffey, C.A., W.E. Thomason, R.M. Pitman, B.R. Beahm, J.J. Paling, J. Chen, et al. 2010. Registration of 'Shirley' wheat. J. Plant Reg. 4:38–43. doi:10.3198/jpr2009.05.0260crc

Hall, M.D., C.A. Griffey, A. Green, S. Liu, P. Gundrum, G. Berger, et al. 2011a. Registration of 'Vision 30' wheat. J. Plant Reg. 5:353–359. doi:10.3198/jpr2011.03.0183crc

Hall, M.D., C.A. Griffey, A. Green, S. Liu, P. Gundrum, G. Berger, et al. 2011b. Registration of 'Vision 40' wheat. J. Plant Reg. 5:360–366. doi:10.3198/jpr2011.03.0184crc

Heyne, E.G. 1977. Registration of Parker 76 wheat. Crop Sci. 17:825. doi:10.2135/cropsci1977.0011183X001700050046x

Line, R.F., and A. Qayoum. 1992. Virulence, aggressiveness, evolution, and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America, 1968-87. US Department of Agriculture Technical Bull. 1788. USDA-ARS, Washington, DC.

Liu, L., M.D. Barnett, C.A. Griffey, S. Malla, W.S. Brooks, J.E. Seago, et al. 2015. Registration of 'Vision 45' wheat. J. Plant Reg. 9:338–344. doi:10.3198/jpr2015.03.0019crc

Microsoft Excel 2010. 2013. Description of the office 2010 update: September 10 2013. Version 14.0.7106.5001 (64 bit). Microsoft Co., Redmond, WA.

Peel, M.D., J.A. Anderson, J.B. Rasmussen, J.D. Miller, T.C. Olsen, and G.W. Johnson. 2004. Registration of 'Jerry' wheat. Crop Sci. 44(3):1026. doi:10.2135/cropsci2004.1026

Peterson, C.J., D.R. Shelton, P.S. Baenziger, D.D. Baltensperger, R.A. Graybosch, W.D. Worrall, L.A. Nelson, D.V. McVey, J.E. Watkins, and J. Krall. 2001. Registration of Wesley wheat. Crop Sci. 41:260. doi:10.2135/cropsci2001.411260-ax

Porter, K.B. 1974. Registration of TAM W-101 wheat. Crop Sci. 14:608. doi:10.2135/cropsci1974.0011183X001400040050x

Porter, K.B., W.D. Worrall, J.H. Gardenhire, E.C. Gilmore, M.E. McDaniel, and N.A. Tuleen. 1987. Registration of TAM 107 wheat. Crop Sci. 27:818. doi:10.2135/cropsci1987.0011183X002700040050x

SAS Institute. 2009. What's new in SAS® 9.2. SAS Inst., Cary, NC.

Seabourn, B.W., Z.S. Xiao, M. Tilley, T.J. Herald, and S. Park. 2012. A rapid, small-scale sedimentation method to predict breadmaking quality of hard winter wheat. Crop Sci. 52:1306–1315. doi:10.2135/cropsci2011.04.0210

Sears, R.G., J.M. Moffatt, T.J. Martin, T.S. Cox, R.K. Bequette, S.P. Curran, O.K. Chung, and W.F. Heer. 1997. Registration of 'Jagger' wheat. Crop Sci. 37:1010. doi:10.2135/cropsci1997.0011183X003700030062x

Schmidt, J.W., V.A. Johnson, P.J. Mattern, A.F. Dreier, D.V. McVey, and J.H. Hatchett. 1985. Registration of Siouxland wheat. Crop Sci. 25:1130. doi:10.2135/cropsci1985.0011183X002500060070x

Thomason, W.E., S.B. Phillips, T.H. Pridgen, J.C. Kenner, C.A. Griffey, B.R. Beahm, and B.W. Seabourn. 2007. Managing nitrogen and sulfur fertilization for improved bread wheat quality in humid environments. Cereal Chem. 84:450–462. doi:10.1094/CCHEM-84-5-0450