

Registration of 'LCS Compass' Wheat

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Abstract

'LCS Compass' (Reg. No. CV-1149, PI 675458), a hard red winter (HRW) wheat (*Triticum aestivum* L.), was developed and tested as VA10HRW-13 and co-released by the Virginia Agricultural Experiment Station and Limagrain Cereal Seeds, LLC, in 2015. LCS Compass was derived from the cross 'Vision 20'/'Stanof' using a modified bulk breeding method. LCS Compass is a widely adapted, high-yielding, awned, semidwarf (*Rht1*) HRW wheat with early to medium maturity and resistance or moderate resistance to diseases prevalent in the mid-Atlantic and Great Plains regions of the United States. In the 2013 Uniform Bread Wheat Trial conducted over 18 locations in eastern states, LCS Compass produced an average grain yield of 4609 kg ha⁻¹ that was similar to 'Vision 30' (4697 kg ha⁻¹). In the northern Great Plains, the average grain yield of LCS Compass (4015 kg ha⁻¹) over 44 locations in 2013 was similar to 'Jerry' (4013 kg ha⁻¹). In the South Dakota crop zone 3 variety test, LCS Compass had a 3-yr (2015–2017) yield average of 5575 kg ha⁻¹ and was one of highest-yielding cultivars among the 19 cultivars tested over the 3-yr period. LCS Compass has good end-use quality in both the eastern and Great Plains regions of the United States.

THE HARD WINTER WHEAT (*Triticum aestivum* L.) breeding program at Virginia Tech, Blacksburg, VA, was initiated in the early 1990s. The primary objective of this program is to develop hard winter wheat cultivars to meet market demands in the eastern United States. Hard wheat is mainly grown in the Great Plains and soft red winter 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 the higher prices paid for hard versus 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 (LCS), LLC.

'LCS Compass' (Reg. No. CV-1149, PI 675458) is well adapted in South Dakota and Nebraska in the northern Great Plains region. It provides growers in those regions with a hard red winter (HRW) wheat cultivar with short stature, early to medium maturity, high grain volume weight, and high grain yields similar to those of 'Wesley' (PI 605742; Peterson et al., 2001) and 'Overland' (PI 647959; Baenziger et al., 2008). In

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

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addition, LCS Compass expresses resistance to many of the diseases endemic in one or both regions, including *Barley yellow dwarf virus*, Fusarium head blight (FHB; caused by *Fusarium graminearum* Schwabe), and stem rust (caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Erikss. & E. Henn.). The milling quality and baking quality of LCS Compass are excellent. For HRW wheat producers in South Dakota and Nebraska, LCS Compass is an improvement over Overland and Wesley as it provides more FHB and stem rust resistance.

Methods

Parentage, Breeding History, and Line Selection

LCS Compass was derived as an F_5 head row from the cross 'Vision 20'/'Stanof'. Vision 20 was a red seed repurification of line KS00F5-58-3 that was segregating for seed color. KS00F5-58-3 was developed by Kansas State University from the cross 'Hickok' (PI 591802)/KS94U213/'Karl 92' (PI 564245). Parental line KS94U213 has the gene *Lr21*; however, its pedigree is unknown as it was derived as a bulk selection. Stanof is a sib of 'KS90WGRC10' (PI 549278), which was derived from the cross 'TAM107' (PI 495594)*3/TA2460. TA2460 is an *Aegilops squarrosa* accession (KU 2084) from Kyoto University with leaf rust resistance gene *Lr41*.

The cross Vision 20/Stanof was made in spring 2004, and the F_1 generation was grown in the field as a single 1.2-m headrow in 2005 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-m² blocks at Blacksburg and/or Warsaw, VA, each fall. Spikes selected from the F_4 bulk were threshed individually and planted in separate 1.2-m headrows at Warsaw. LCS Compass was derived from one of these F_5 headrows selected in 2009. It was evaluated as entry 13 in nonreplicated observation yield tests at Blacksburg and Warsaw in 2010. LCS Compass was evaluated in Virginia Tech's replicated Bread Wheat Preliminary Yield Test at two locations in 2011 (data not presented). LCS Compass was evaluated in the Virginia Bread Wheat Elite Tests over total 12 environments for 4 yr (2012–2016) and in the USDA–ARS Uniform Bread Wheat Trial (UBWT) in 2013. In collaboration with Limagrain Cereal Seeds LLC, LCS Compass was evaluated in the USDA–ARS Northern Regional Performance Nursery (NRPN) in 2012 and 2013 over 98 environments, and it was also evaluated in their program's 2012, 2013, and 2014 replicated yield trials under 41 environments in Kansas, Nebraska, Oklahoma, and Montana (data not presented). LCS Compass was tested in the South Dakota winter wheat variety trial from 2015 to 2017 and was recommended as a winter wheat variety for crop zone 3 of South Dakota in 2017.

Evaluation in Replicated Yield Trials

LCS Compass, previously designated and tested as VA10HRW-13, was evaluated in Virginia Tech's replicated bread wheat variety trials from 2012 to 2016, in replicated regional tests in the UBWT in 2013, and in the NRPN in 2012

and 2013 in Great Plains regions. The UBWT (USDA–ARS, 2018b) and NRPN (2018a) 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 Compass was tested as LCH10-13 in the NRPN. Plant traits assessed visually (e.g., winter kill, straw strength, and disease resistance) were rated using ordinal scales such as 0 (no visible symptoms) to 9 (severe symptoms) on the basis of 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 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 m². At Painter, VA, plots were composed of six rows with 17.8 cm between rows with two replications; at Warsaw and Blacksburg, plots consisted of seven rows with 15.2 cm between rows with three replications. Assessment of reaction to FHB 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 (American Association of Cereal Chemists [AACC] Method 55-31) (AACC, 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 and mixing tolerance were also determined from the mixograph (AACC Method 54-40). Corrected mixograph mix time was adjusted on the basis of protein content of flour. Mixograph mix time for one cultivar growing at different locations increases with reducing protein content if protein content is lower than 12%, so corrected mixograph mix time is necessary for a good comparison. A straight-dough, 100-g pup-loaf bake test method was used to measure bread-making properties, including crumb grain score and loaf volume (AACC Method 10-10B). Crumb grain was graded from poor open grain (0) to outstanding closed grain (6).

Analysis of variance was conducted on data from individual locations and years and across locations and years in Virginia Tech tests using Agrobases 20 (Agronomix Software, 1999), Agrobases 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 NRPN. The analysis of variance and mean for grain, milling, and baking data were obtained with Microsoft Excel 2010 (Microsoft, 2013). There is no replication for quality data each year. The data from 1 yr were treated as one replication for the analysis. The common lines in different year were included analysis, but only the checks are presented here. The mean comparisons of traits between genotypes were based on an unprotected LSD ($P = 0.05$) test (Saville, 1990; Piepho, 2004).

Seed Purification and Increase

Initial breeder seed of LCS Compass was derived in 2012 from a 21-m² F_{5,8} seed increase block grown at the Virginia Tech Eastern Virginia Agricultural Research and Extension Center in Warsaw, in which visible variant plants were removed before harvest. This seed was grown in a 0.09-ha field at Milliken, CO, in 2012–2013 by Limagrain Cereal Seeds and produced 122 kg of an initial seed increase. Yields were approximately one-fourth of normal due to poor stand establishment and winter desiccation. The field was rogued for variants in July 2013, including removal of 18 awnless plants and 18 red-chaffed plants. In fall 2013, 0.4 ha of LCS Compass was planted in Fort Collins, CO; the field was rogued three times and produced 1796 kg of foundation seed. The foundation seed was treated with Dividend Extreme fungicide (Syngenta) and split into two lots for planting in fall 2014. One lot was planted on 12 ha in Onida, SD, and the other on 12 ha in Hemingford, NE. In fall 2015, a total of 108 t of foundation seed was available for sale.

During spring 2013, approximately 300 F_{5,9} heads of LCS Compass were hand harvested at Wichita, KS. These heads were threshed individually, planted in progeny rows, and evaluated for purity and trueness of type at Fort Collins during 2013–2014. Among the 266 breeder seed headrows planted, 6 rows (2%) were taller and 1 row (<0.05%) was taller and darker in chaff color. These variant rows were removed before harvest. The remaining 259 rows that were similar in phenotype and visually homogenous were harvested in bulk, resulting in 54 kg of purified LCS Compass breeder seed. This seed was used in subsequent years to generate foundation seed.

Characteristics

Botanical and Agronomic Characteristics

The juvenile growth of LCS Compass is semi-erect. At the boot stage, plants of LCS Compass are blue-green in color and have flag leaves that are erect, nontwisted, and without wax. Stems are hollow and lack anthocyanin. Auricles and coleoptiles lack anthocyanin. LCS Compass has yellow colored anthers. Spikes of LCS Compass are awned, erect, oblong, mid-dense, and white in color at maturity. Straw lacks anthocyanin at physiological maturity. The white, glabrous glumes are medium in length, are narrow in width, and have short acuminate beaks and oblique shoulders. The hard red kernels of LCS Compass are ovate in shape with rounded cheeks and short brush hairs.

In Virginia, the 3-yr average (Table 1) for spike emergence (days to heading from 1 January) of LCS Compass (127 d) is

Table 1. Three-year (2014–2016) performance of LCS Compass hard red winter wheat in the Virginia Tech Bread Wheat Elite Test.†

Cultivar	Grain yield	Grain volume weight	Heading date	Plant height	Lodging	Disease resistance					
						Leaf rust	Powdery mildew	BYDV‡	FHBS incidence	FHB severity	FHB index¶
	kg ha ⁻¹	kg hL ⁻¹	d after 1 Jan.	cm	0–9#	0–9††		%			
5187J‡‡	5544 a§§	78.5 a	124 de	80 b	1.6 a	0.8 bc	1.2 cd	0.7 c	67.5 abcd	35.7 a	25.6 abc
Shirley ‡‡	5514 a	72.4 d	126 bc	79 b	0.3 c	0.1 c	0.3 e	0.9 bc	78.3 a	34.6 a	28.9 a
Vision 45	5310 a	74.9 c	129 a	94 a	0.6 c	0.6 c	0.6 de	0.9 bc	60.0 bcd	29.6 a	17.0 bc
Tribute ‡‡	4941 b	78.1 ab	124 de	78 b	1.2 bc	0.8 bc	3.1 b	1.9 ab	50.8 d	27.8 a	15.1 c
LCS Wizard	4667 bcd	75.8 c	126 bc	81 b	0.5 c	1.4 bc	0.9 de	0.5 c	73.3 ab	38.4 a	28.5 ab
Vision 30	4610 cd	75.0 c	124 de	82 b	1.5 b	3.2 a	0.4 e	0.6 c	70.0 abc	33.2 a	23.5 abc
LCS Compass	4605 cd	77.0 b	127 b	90 a	2.3 a	0.9 bc	0.7 de	0.9 bc	55.8 cd	34.0 a	18.2 abc
Soissons	4360 d	71.8 d	127 b	77 c	0.1 c	2.9 a	0.6 de	0.6 c	68.3 abc	30.9 a	20.4 abc
Karl 92	4019 e	75.8 c	123 e	81 b	1.1 bc	3.1 a	1.7 c	1.1 bc	70.0 abc	28.7 a	21.3 abc
Jagger	3925 e	75.8 c	120 f	79 b	1.6 a	2.1 ab	4.8 a	2.2 a	56.7 cd	32.9 a	18.4 abc
Mean (N = 27)	4767 bc	74.9 c	125 cd	81.8 b	0.9 bc	1.2 bc	1.1 cd	1.1 bc	65.6 abcd	33.9 a	22.5 abc
LSD (0.05)	329.0	1.1	1.5	4.3	0.8	1.4	0.7	1.0	17.3	12.5	11.8
CV (%)	4.2	0.9	0.7	3.2	53.9	72.1	37.0	58.6	16.1	22.4	32.0
No. of site-years	9	9	6	6	6	5	8	4	3	3	3

† Gran yield and grain volume weight data from Blacksburg (2014–2016), Warsaw (2014–2016), and Painter (2014–2016); leaf rust from Blacksburg (2014, 2016) and Warsaw (2014–2016); powdery mildew data from Blacksburg (2014–2016), Warsaw (2014–2016), and Painter (2014, 2015); heading date, plant height, and lodging from Blacksburg (2014–2016) and Warsaw (2014–2016); *Barley yellow dwarf virus* (BYDV) from Blacksburg (2014, 2015), Warsaw (2016), and Painter (2014); *Fusarium head blight* (FHB) from Blacksburg Scab Nursery (2014–2016).

‡ BYDV = *Barley yellow dwarf virus*.

§ FHB = *Fusarium head blight*.

¶ FHB index = % incidence × % severity ÷ 100.

0 = erect; 9 = completely lodged.

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

‡‡ Soft red winter wheat check cultivar.

§§ Means in a column followed by the same letter are not significantly different at 0.05 probability level based on Fisher's unprotected LSD pairwise comparison.

2 d earlier than 'Vision 45' (PI 667642, Liu et al., 2015) and 3 d later than Vision 30 (PI 661153; Hall et al., 2011a). Average plant height of LCS Compass (90 cm) is similar to Vision 45 (94 cm) and 8 cm taller than Vision 30 (82 cm). Straw strength (0 = erect to 9 = completely lodged) of LCS Compass (2.3) is similar to that (1.6) of 'Jagger' (PI 593688, Sears et al., 1997).

In the 2013 USDA-ARS UBWT (Table 2), average spike emergence of LCS Compass (131 d) was 2 d later than Vision 30 and 2 d earlier than 'Shirley' (PI 656753; Griffey et al., 2010). Average plant height of LCS Compass (97 cm) was 10 cm taller than Vision 30 and 5 cm shorter than Vision 45. Straw strength of LCS Compass (3.7) was most similar to 'NuEast' (PI 657997), and stronger than 'Appalachian White' (PI 657998).

In the northern Great Plains, average spike emergence of LCS Compass (143 d) in the 2013 NRPN (Table 3) was most similar to Wesley, 3 d earlier than Overland, and 4 d earlier than the long-term check cultivar Kharkof (PI 5641).

Field Performance

In the Virginia Tech Bread Wheat Elite Test (2014–2016), LCS Compass had a 3-yr average grain yield (4605 kg ha⁻¹) similar to Vision 30 (4610 kg ha⁻¹). The 3-yr average grain volume weight of LCS Compass (77.0 kg hL⁻¹) was significantly ($P < 0.05$) higher than all six HRW wheat checks (Table 1).

LCS Compass was evaluated with 45 other entries over 18 diverse environments in the 2013 USDA-ARS UBWT (Table

2). The average grain yield of LCS Compass (4609 kg ha⁻¹) over locations was similar to those of HRW wheat cultivars Vision 30 (4697 kg ha⁻¹) and 'Vision 40' (4643 kg ha⁻¹; PI 661154; Hall et al., 2011b) and the overall trial mean (4510 kg ha⁻¹). Average grain volume weight of LCS Compass (73.5 kg hL⁻¹) was similar to HRW wheat check NuEast (73.2 kg hL⁻¹) but significantly ($P < 0.05$) higher than the other soft and hard wheat checks. LCS Compass has good winterhardiness based on winter kill ratings (0 = no injury, 9 = severe injury), with a value of 1.9, which was significantly ($P < 0.05$) lower than those of Vision 30 (3.1), Vision 40 (3.1) and Vision 45 (3.2).

In the northern Great Plains region, LCS Compass had an average grain yield (4015 kg ha⁻¹) that was similar to those of the other checks and the NRPN average over all locations (Table 3). LCS Compass had the highest mean test weight (77.6 kg hL⁻¹) compared with the checks and was 2.3 kg hL⁻¹ higher than the overall nursery average. LCS Compass was also tested in 2012 NRPN, and data are available on the USDA website (USDA-ARS, 2018a).

LCS Compass was evaluated in the South Dakota Winter Wheat Variety Trial over 14, 17, and 17 environments, divided into seven crop zones on the basis of soil and climate information, in 2015, 2016, and 2017, respectively. LCS Compass performed best in crop zone 3, which includes 13 counties in southeastern South Dakota (Table 4). The 3-yr average yield of LCS Compass (5575 kg ha⁻¹) was significantly ($P < 0.05$) higher than the overall trial mean and was one of the highest yielding of

Table 2. Mean performance of LCS Compass hard red winter wheat in the 2012–2013 USDA-ARS Uniform Bread Wheat Trial.

Cultivar	Grain yield	Volume weight	Head date	Plant height	Lodging	Winter kill	Disease resistance						Kernel weight	Kernel diam.	
							Powdery mildew	Leaf rust	Stripe rust	BYDV†	Stag. nod. ‡ leaf blotch	Stag. nod. ‡ glume blotch			SBWMV§
	kg ha ⁻¹	kg hL ⁻¹	d after 1 Jan.	cm	0–9¶	0–9#	0–9††	0–9‡‡	0–9‡‡	0–9‡‡	0–9‡‡	0–9‡‡	0–9‡‡	mg	mm
Shirley§§	5368 a¶¶	70.6 cd	133 abc	85 e	2.0 f	2.5 cde	0.3 d	0.0 c	4.0	0.9 a	3.0 b	0.8 cd	1.0 e	37.7 a	2.7 bc
USG 3120§§	5201 a	71.2 bc	128 f	87 de	2.9 def	5.5 a	2.6 b	0.3 c	0.0	0.4 bc	4.2 ab	1.0 cd	2.5 bcd	37.9 a	2.8 a
Vision 45	4891 ab	72.3 ab	135 a	102 a	2.6 ef	3.2 cd	1.0 cd	2.7 a	0.0	0.8 ab	4.5 ab	0.5 d	1.5 cde	36 ab	2.8 a
Vision 30	4697 bc	69.9 cd	129 ef	87 de	4.1 abc	4.5 ab	0.7 d	1.7 abc	2.0	0.7 abc	5.4 ab	1.0 cd	1.3 de	31.4 f	2.7 bc
Vision 40	4643 bc	70.6 cd	132 bcd	94 bc	2.3 ef	3.1 cd	2.4 b	2.0 ab	0.0	0.7 abc	4.5 ab	1.3 bcd	1.5 cde	32.1 def	2.7 c
LCS Compass	4609 bc	73.5 a	131 cde	97 b	3.7 bcd	1.9 e	2.2 b	1.3 abc	0.0	0.2 c	5.9 a	1.0 cd	1.7 cde	33.5 cdef	2.7 bc
NuEast	4482 c	73.2 a	127 f	94 c	3.7 bcd	3 cde	4.0 a	0.0 c	1.0	0.7 abc	6.3 a	2.8 a	1.8 cde	34.8 bc	2.8 a
TAM 303	4441 cd	69.5 d	128 f	90 d	5.0 a	2.1 de	3.0 ab	0.7 bc	1.0	0.7 abc	5.9 a	2.2 ab	4.5 a	34.1 bcd	2.8 abc
Endurance	4058 de	70.2 cd	132 bc	94 bc	3.8 bcd	4.5 ab	2.8 b	0.3 c	0.0	0.7 abc	6.0 a	1.7 bc	3.8 ab	34.3 bc	2.7 abc
Appalachian White	4025 e	69.2 d	134 ab	93 c	4.5 ab	2.5 cde	1.9 bc	0.0 c	0.0	0.6 abc	3.5 ab	1.0 cd	1.5 cde	31.7 ef	2.7 bc
Mean (N = 46)	4510 bc	70.6 cd	129 def	89 d	3.2 cde	3.4 bc	2.0 bc	0.9 bc	0.5	0.9 a	4.5 ab	1.5 bcd	2.7 bc	33.8 bcde	2.8 ab
LSD (0.05)	390	1.4	2.3	2.8	1	1.2	1.1	1.4	–	0.5	2.9	1	1.3	2.2	0.08
CV (%)	15.7	3.4	2.3	5	42.9	17.8	57.8	108.9	–	46.3	38.9	68.7	47.1	6.1	2.63
No. of locations	18	15	9	14	10	1	6	1	1	3	2	2	3	5	5

† BYDV = Barley yellow dwarf virus.

‡ Stag. nod. = *Stagonospora nodorum*.

§ SBWMV = Soil-borne wheat mosaic virus.

¶ 0 = erect; 9 = completely lodged.

Winter kill (late-winter rating plant damage): 0 = no injury to 9 = complete kill.

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

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

§§ Soft red winter wheat check cultivar.

¶¶ Means in a column followed by the same letter are not significantly different at 0.05 probability level based on Fisher's unprotected LSD pairwise comparison.

Table 3. Performance of LCS Compass hard red winter wheat in the 2013 Northern Regional Performance Nursery.

Cultivar	Grain yield kg ha ⁻¹	Grain volume weight kg hL ⁻¹	Plant height cm	Heading date d after 1 Jan.	Winter survival %	Disease resistance							Hessian fly							
						Powdery mildew 1-5§	BYDV†	Stag. nod. # glume blotch	Bacterial leaf streak 0-10#	Stripe rust‡ infection type	Disease severity	Fusarium head blight incidence %	Severity %	Stem rust‡‡ Field rating	Leaf rust Field	Stem rust‡‡ Field	Leaf rust Field	great plain biotype resistant plants %	Acid soil tolerance	
Overland	4342 a¶¶	76.7	87	146	27.5	3.5	0.3	2.8	1	5	80	31.7	16.7	60S	15MS,MR	20MS	100	0-5¶¶	4.7	
Lyman	4316 a	76.7	85	144	22.5	1	1.7	1.1	3.5	5	90	48.3	13.3	40MR	15MS,MR	10R	96		4	
LCS Compass	4015 ab	77.6	82	143	27.5	2	0.3	3.3	2.5	5	50	18.3	10	40MR	15MR,MS	40S+	0		3	
Jerry	4013 ab	74.7	95	147	47.5	2.5	1.3	2.1	3.5	6	80	26.7	10	50S	20MS	20MR	0		3.3	
Wesley	3923 b	75.0	76	143	15	3	1	3.5	1.5	5	40	28.3	46.7	20MR/70S	30MS	40MS	0		2.3	
LCS Wizard	3864 b	74.8	76	145	15	1	0	2.8	1.5	3	5	23.3	23.3	90S	DEAD	40S	96		3.3	
Kharkof	3353 c	76.9	111	147	40	1.5	1	1.6	5.5	2	3	40	13.3	70S	30MSS	30MS	0		5	
Mean (n = 37)	3953 b	75.3	84.6	145.1	22.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CV (%)	11.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No. of sites	44	11	9	6	Willisto, ND	Castroville, TX	Wichita, KS	Casselton, ND	Lincoln, NE	Rossville, KS	Rossville, KS	Crookston, MN	Crookston, MN	St. Paul, MN	Njoro, Kenya	Castroville, TX	1	Enid, OK		
LSD (0.05)	363	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

† BYDV = *Barley yellow dwarf virus*.

‡ *Stag. nod.* = *Stagonospora nodorum*.

§ 1 = highly resistant; 5 = highly susceptible.

¶ 0 = highly resistant; 5 = highly susceptible.

0 = highly resistant; 10 = highly susceptible.

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

‡‡‡ Stem rust was rated at St. Paul, MN, in a nursery inoculated with a bulk of races QFCSC, QTHJC, RCRSC, RKQQC and TPMKC. Stem rust and leaf 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.

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

¶¶ Means in a column followed by the same letter are not significantly different at 0.05 probability level based on Fisher's unprotected LSD pair-wise comparison.

the 19 cultivars in crop zone 3 (iGrow, 2017). The 3-yr average grain volume weight of LCS Compass (77.3 kg hL⁻¹) was relatively higher than all other checks.

Disease and Insect Resistance

Reaction of LCS Compass to diseases (0 = immunity to 9 = very susceptible) has been evaluated over diverse environments in the eastern and northern Great Plains regions of the United States (Tables 1-4). LCS Compass was resistant (0.7) to powdery mildew [caused by *Blumeria graminis* (DC) E.O. Speer] in the Virginia Tech Bread Wheat Elite Test (Table 1) and moderately resistant (2.0- 2.2) in the UBWT (Table 2) and NRPN (Table 3). LCS Compass has been consistently resistant (0.2-0.9) to *Barley yellow dwarf virus* in the eastern United States (Tables 1 and 2) and Great Plains regions (Tables 3). LCS Compass expressed resistance (0.9-1.3) to leaf rust (caused by *Puccinia triticina* Eriks.) in the eastern United States (Tables 1 and 2), moderate susceptibility at Castroville, TX (Table 3), and variable resistance in South Dakota (Table 4). Based on infection type (IT = 0- 9) and severity (%) ratings (Line and Qayoum, 1992) for stripe rust (caused by *Puccinia striiformis* Westend.), LCS Compass was resistant (0) in the UBWT (Table 2). However, it was rated as moderately susceptible (IT = 5 and 50%) in Kansas in the 2013 NRPN (Table 3), and moderately susceptible to susceptible in South Dakota (Table 4). In NRPN tests evaluated by the USDA Cereal Disease Laboratory, LCS Compass expressed moderate resistance to the prevalent US stem rust races in seedlings (infection type = 2 to QFCSC, data not presented), and in field tests (40MR, Table 3). LCS Compass also expressed moderate resistance (15MR-MS) to race TTKSK (Ug99) of stem rust in field tests conducted in Njoro, Kenya (Table 3), and was rated as resistant in South Dakota in both 2015 and 2016 (Table 4). In the 2013 UBWT (Table 2), LCS Compass was rated as moderately resistance (1.7) to *Soil-borne wheat mosaic virus* and also was moderately resistant (1) in the 2012 NRPN at Stillwater, OK (data not presented). LCS Compass was moderately resistant to FHB in tests conducted in both regions. In tests conducted at Virginia Tech (Table 1), the 3-yr mean values for FHB incidence (55.8%), severity (34.0%), and index (18.2%) were similar to those of the moderately resistant soft red winter wheat cultivar Tribute (50.8, 27.8, and 15.1%) (PI 654422; Griffey et al., 2005). In tests conducted at

Table 4. Performance of LCS Compass hard red winter wheat in 2015–2017 South Dakota winter wheat variety trial.†

Cultivar	Grain yield# 2015–2017 kg ha ⁻¹	Volume weight 2015–2017 kg hL ⁻¹	Grain protein content 2015–2017 g 100 g ⁻¹	Baking quality			Winter hardiness			Disease resistance							
				2015–2017		2015–2017		2015–2017		2015–2016		2015–2016		2015–2016		2015–2016	
				quality	rating#	lodging	hardness	2015	2016	2015–2016	2017	2015–2016	2017	2015–2016	2017	2015–2016	2017
Lyman	4506 e§§	74.6	12.8	A	F–G	G–E	MR	S	R	MR	MR	MR	S	MR	MR	MR	MR
Redfield	5178 cd	74.6	12.5	G	G	G	MR	S	MR	MS–MR	MS	MS	MS–S	MR	S	MR	MR
Overland	4855 d	75.4	12.1	A	F–G	G–E	MR	S	MR	MR	MR	MS	S	MR	MS	MR	MR
SY Wolf	5555 ab	74.3	12.7	A	G	G	MR–MS	S	MR	MR	R	MR	MS	MR	MR	S	S
LCS Compass	5575 a	77.3	12.2	E	F	G	MR–MS	S	R	MS–MR	MR–R	S	S	S	S	R	MR
Trial mean##	5225 bc	74.9	12.3	na	na	na	na	na	na	na	na	na	na	na	na	na	na
LSD (0.05)	330	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
CV (%)	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na

† Crop zone 3 test located in Beresford, SD; crop zones for small grains are based on soil and climate information.

Data adjusted to 13% moisture basis.

§ WSMV = *Wheat streak mosaic virus*.

¶ FHB = *Fusarium head blight*.

Ratings = excellent (E), good (G), acceptable (A), and fair (F).

†† Disease reaction type rating = resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S).

Trial means for yield were based on 19 cultivars; volume weight and grain protein content were based on 83 cultivars for 3 yr.

§§ Means in a column followed by the same letter are not significantly different at 0.05 probability level based on Fisher's unprotected LSD pairwise comparison.

Crookston, MN (Table 3), LCS Compass expressed resistance to FHB with mean values for FHB incidence (18.3%) and severity (10.0%) lower than those of the FHB-resistant check cultivar Overland (31.7 and 16.7%). LCS Compass expressed moderate resistance to resistance to FHB in South Dakota (Table 4). LCS Compass expressed moderate resistance (2.5) to bacterial leaf streak caused by *Xanthomonas campestris* pv. *translucens* (Jones, Johnson, & Reddy) Dye in the NRPN trial conducted at Lincoln, NE (Table 3). In the UBWT (Table 2) and NRPN (Table 3), LCS Compass expressed resistance (1.0) and moderate resistance (3.3) to glume blotch caused by *Stagonospora nodorum* (Berk.) Castellani & E.G. Germano, while it was moderately susceptible (5.9) to leaf blotch caused by *S. nodorum* in the eastern region (Table 2). LCS Compass was also moderately susceptible to tan spot (caused by *Pyrenophora tritici-repentis*) and susceptible to *Septoria tritici* leaf blotch (caused by *Mycosphaerella graminicola*) in South Dakota (Table 4). LCS Compass was susceptible to *Wheat streak mosaic virus* in South Dakota (Table 4). Reaction of LCS Compass to *Wheat spindle streak mosaic virus* is not known.

LCS Compass is susceptible to the Hessian fly [*Mayetiola destructor* (Say)] Great Plains biotype (Table 3). LCS Compass expressed resistance (1.5) to stem sawfly (*Cephus cinctus*) at Fort Benton, MT, in the Limagrain Cereal Seeds Y3 trial in 2014 (data not shown). It was susceptible to greenbug (*Schizaphis graminum*) biotype E in the 2012 NRPN (USDA–ARS, 2018a). LCS Compass expressed moderate tolerance to acid soil conditions in the NRPN test (Table 3).

End-Use Quality

Grain characteristics, milling quality, and baking quality of LCS Compass in Virginia Tech tests have been evaluated by the USDA–ARS Hard Wheat Quality Laboratory in Manhattan, KS, since 2012. Mean data over 3 yr (2013–2015) are presented in Table 5. Grain hardness score from near-infrared analyzers for LCS Compass (71.3) was higher, but not statistically different, than that (63.4) of the HRW wheat quality check Jagger. Flour yield of LCS Compass (67.2 g 100 g⁻¹) was most similar to that of Karl 92 (67.6 g 100 g⁻¹). Grain and flour protein concentrations of LCS Compass (11.7 and 10.2 g 100 g⁻¹) were most similar to those of Jagger (11.7 and 10.4 g 100 g⁻¹). Flour water absorption of LCS Compass (59.6 g 100 g⁻¹) was most similar to that of Vision 45 (59.8 g 100 g⁻¹) but not significantly lower than that of Jagger (60.5 g 100 g⁻¹). Farinogram dough peak time and tolerance (0 = poorest to 6 = best) of LCS Compass (3.6 min and 3.3) were most similar to those of Jagger (3.7 min and 3.0). Bread pup loaf volume and bread crumb grain scores (0 = poorest to 6 = best) of LCS Compass (828 cm³ and 4.0) were most similar to those of Vision 45 (828 cm³ and 3.9).

Grain characteristics and milling and baking quality of LCS Compass in the northern Great Plains NRPN evaluated by the USDA–ARS Hard Wheat Quality Laboratory in Manhattan, KS are presented in Table 6. The 2-yr mean kernel hardness index (0–100) value for LCS Compass (61.0) was higher than that of Jerry (58.0) (PI 632433; Peel et al., 2004) but lower than those of Wesley (64.0), Overland (67.5), and 'Lyman' (69.0) (PI 658067). Average protein concentrations of wheat and flour of LCS Compass (13.4 and 11.9 g 100 g⁻¹) were most similar to those of 'LCS Wizard' (13.1 and 11.8

g 100 g⁻¹) (PI 669574; Liu et al., 2016). Mean flour yields and water absorption of LCS Compass (69.7 and 62.4 g 100 g⁻¹) were similar to those of LCS Wizard (69.0 and 62.7 g 100 g⁻¹). Average adjusted dough mixing time and dough mixing tolerance (0 = poorest to 6 = best) for LCS Compass (3.7 min and 3.0) were most similar to those of Jerry (3.7 min and 3.5). Mean bread loaf volume and crumb score (0 = poorest to 6 = best) for LCS Compass (940 cm³ and 5.0) were the highest among all cultivars in Table 6.

Baking quality in the South Dakota test for LCS Compass was rated as excellent and better than that of the other checks in Table 4.

Availability

Foundation seed was sent to seed producers by Limagrain Cereal Seeds LLC in fall 2015. Limagrain Cereal Seeds, LLC will be responsible for distribution of foundation seed of LCS Compass west of the Mississippi River in the Great Plains

Table 5. Milling and baking quality of LCS Compass and other hard red winter wheat cultivars in 2013–2015 Virginia Tech tests conducted by the USDA–ARS Hard Winter Wheat Quality Laboratory, Manhattan, KS.

Cultivar	Kernel weight	Near infrared hardness	Grain protein†	Flour yield	Flour protein†	Flour ash†	Flour water absorption	Adjust dough mixing time	Dough mixing tolerance	Pup-loaf volume	Crumb grain score
	mg	1–100‡	g 100 g ⁻¹					min	0–6§	cm ³	0–6¶
Jagger	35.9 a#	67.4 a	11.7 ab	68.7 bc	10.4 ab	0.43 a	60.5 ab	3.7 ab	3.0 b	802 a	3.5 ab
Karl 92	36.6 a	63.7 ab	12.8 a	67.6 bc	11.3 a	0.41 a	62.0 a	4.4 a	4.0 a	860 a	3.8 ab
LCS-Wizard	31.6 b	66.4 a	11.4 b	69.8 bc	9.8 b	0.41 a	59.0 bc	2.0 c	2.0 c	802 a	3.2 ab
Soissons	33.6 ab	55.7 c	11.1 b	74.2 a	9.7 b	0.42 a	58.1 c	3.6 ab	4.0 a	810 a	4.2 a
LCS Compass	34.1 ab	71.3 a	11.7 b	67.2 c	10.2 ab	0.41 a	59.6 bc	3.6 ab	3.3 ab	828 a	4.0 ab
Vision 30	34.4 ab	58.0 bc	12.0 ab	69.8 bc	10.7 ab	0.39 a	60.0 b	4.1 a	3.3 ab	853 a	3.6 ab
Vision 45	34.8 ab	63.8 ab	11.9 ab	71.0 bc	10.5 ab	0.39 a	59.8 b	3.5 ab	2.6 bc	828 a	3.9 ab
Mean (n = 21)	35.7 ab	63.8 ab	11.5 b	69.4 bc	10.0 b	0.41 a	58.9 bc	2.8 bc	2.4 bc	777 a	3.0 b
CV (%)	8.5	23.5	5.2	2.5	6.8	7.77	3.2	31.2	39.1	7	28.1
LSD (0.05)	4.1	7.8	1.09	4.0	1.19	0.035	1.7	1.2	0.9	94	1.1
P value	<0.001	<0.001	0.040	ns	0.02	<0.001	<0.001	<0.001	<0.001	0.01	<0.001

† Data adjusted to 14% moisture basis.

‡ 1 = 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.

Means in a column followed by the same letter are not significantly different at 0.05 probability level based on Fisher's unprotected LSD pairwise comparison.

Table 6. Grain, milling, and baking quality of LCS Compass in the 2012 and 2013 Northern Regional Performance Nursery evaluated by the USDA–ARS Hard Winter Wheat Quality Laboratory, Manhattan, KS using grain sourced from the North Central Plains: Lincoln, NE, St. Paul, MN, Crookston, MN, Brookings, SD, Dakota Lakes, SD, and Winner, SD.

Cultivar	SKCS† kernel hardness			Wheat protein‡			Flour yield			Flour ash‡			Flour protein‡		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
	0–100§			g 100 g ⁻¹											
Overland	73	62	67.5	12.4	13.7	13.1	71.7	71.1	71.4	0.43	0.49	0.46	10.8	12.2	11.5
Wesley	68	60	64.0	13.5	14.3	13.9	72.4	71.7	72.1	0.37	0.48	0.43	12.2	13.3	12.8
Jerry	64	52	58.0	13.3	14.0	13.7	71.0	70.4	70.7	0.40	0.48	0.44	12.0	12.9	12.5
Lyman	72	66	69.0	13.9	14.6	14.3	71.5	69.7	70.6	0.41	0.50	0.46	12.2	13.2	12.7
LCS Wizard	74	64	69.0	12.4	13.7	13.1	69.8	68.1	69.0	0.39	0.49	0.44	11.1	12.5	11.8
LCS Compass	68	54	61.0	12.9	13.9	13.4	70.2	69.2	69.7	0.35	0.44	0.40	11.2	12.5	11.9
Cultivar	Flour water absorption			Adjusted mixing time			Dough mixing tolerance			Loaf volume			Crumb score		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
	g 100 g ⁻¹			min			0–6¶			cm ³			0–6#		
Overland	60.9	61.8	61.4	2.1	2.4	2.3	1.0	1.0	1.0	795	800	797.5	3.0	2.0	2.5
Wesley	63.3	63.5	63.4	4.0	4.4	4.2	5.0	4.0	4.5	925	930	927.5	4.0	4.0	4.0
Jerry	63.0	64.4	63.7	3.5	3.9	3.7	4.0	3.0	3.5	785	910	847.5	3.0	3.5	3.3
Lyman	62.2	64.0	63.1	3.9	3.6	3.8	2.0	2.0	2.0	875	930	902.5	3.0	3.5	3.3
LCS Wizard	61.5	63.8	62.7	1.9	2.6	2.3	2.0	2.0	2.0	740	930	835.0	1.0	3.0	2.0
LCS Compass	61.1	63.7	62.4	3.4	4.0	3.7	2.0	4.0	3.0	885	995	940.0	5.5	4.5	5.0

† SKCS, single kernel characterization system, AACC method 55–31.

‡ 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.

region. In the eastern United States, LCS Compass 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, in West Point, VA. A Plant Variety Protection certificate was awarded to LCS Compass on 6 July 2016. A seed sample of LCS Compass has been deposited in the USDA–ARS National Center for Genetic Resources Preservation and will be available for distribution after expiration of its US Plant Variety Protection. Small amounts of seed for research purposes may be obtained from the corresponding author for at least 5 years after the date of this publication.

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