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Registration of ‘NE10589’ (Husker Genetics Brand Ruth) hard red winter wheat

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REGISTRATION

Cultivar

Registration of 'NE10589' (Husker Genetics Brand Ruth) hard red winter wheat

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Abstract

With climate variation common in the U.S. Great Plains and particularly in Nebraska, wheat growers prefer broadly adapted cultivars. 'NE10589' (Reg. no. CV-1165, PI 675998) hard red winter wheat (*Triticum aestivum* L.) was developed cooperatively by the Nebraska Agricultural Experiment Station and the USDA–ARS and released in January 2015 by the developing institutions. NE10589 was released primarily as a broadly adapted semi-dwarf cultivar for its superior performance under rainfed conditions throughout Nebraska and adjacent areas of the Great Plains. Its broad adaptation ensures that it will perform well under the typical environmental fluctuations that occur in Nebraska. NE10589 was selected from the cross 'OK98697'/'Jagalene'//'Camelot', where the pedigree of OK98697 is 'TAM 200'/'HBB313E'//'2158'. The F_2 to F_3 generations were advanced using the bulk breeding method at the Eastern Nebraska Research and Extension Center near Mead, NE, in 2006–2007. In 2007–2008, single $F_{3:4}$ head rows were grown for selection. There was no further selection within the line thereafter. The $F_{3:5}$ was evaluated as a single four-row plot at Lincoln, NE, and a single row at Mead, NE, in 2009. In 2010, it was assigned the experimental line number NE10589. NE10589 was evaluated in replicated trials thereafter. It has excellent winter

Abbreviations: GEBV, genomic estimated breeding value; NESVT, Nebraska State Variety Trial; NRPN, Northern Regional Performance Nursery; SRPN, Southern Regional Performance Nursery.

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survival, acceptable disease reactions to many of the common diseases in its target area, and acceptable end-use quality for bread making.

1 | INTRODUCTION

Nebraska is climatically and geographically diverse (Peterson, 1992), with an annual moisture gradient from higher moisture in eastern Nebraska to lower moisture in western Nebraska. Similarly, there are temperature and elevation gradients across the state. Due to temporal and spatial rainfall and temperature variations, wheat (*Triticum aestivum* L.) cultivars with broad adaptation are preferred by wheat producers who understand environmental fluctuations and want cultivars that can be grown in wet or dry, hot or cool years, which are unknown and unpredictable at the time of selecting a cultivar and planting. Popular previous wheat cultivars with broad adaptation included 'Arapahoe' (Baenziger et al., 1989), 'Millennium' (Baenziger et al., 2001), 'NE01643' (Husker Genetics Brand Overland; Baenziger et al., 2008), 'NI04421' (Husker Genetics Brand Robidoux; Baenziger et al., 2012a), and 'NE06545' (Husker Genetics Brand Freeman; Baenziger et al., 2014). All five cultivars are semi-dwarf lines. Providing higher yielding, semi-dwarf wheat cultivars remains a goal of the Nebraska Agricultural Experiment Station and the USDA–ARS cooperative wheat improvement team. Other major goals of the Nebraska wheat improvement team include the ability to survive the Nebraska winter, resistance to stem rust (caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks & E. Henn.), and the capability of producing an acceptable loaf of bread (Baenziger, Shelton, Shipman, & Graybosch, 2001).

'NE10589' (Reg. no. CV-1165, PI 675998) hard red winter wheat was tested under experimental line designation NE10589 and was developed and released in January 2015 cooperatively by the Nebraska Agricultural Experiment Station and the USDA–ARS. It was released primarily for its superior adaptation to rainfed wheat production systems throughout Nebraska and in adjacent wheat-producing states. In addition, it has consistently survived the Nebraska winter, shown good stem rust resistance, and good end-use quality. NE10589 will be marketed as Husker Genetics Brand Ruth hard red winter wheat. It was named in honor of our greenhouse manager, who was a huge aid to the breeding program and who died far too young.

2 | METHODS

2.1 | Selection history

NE10589 was selected from the cross OK98697/'Jagalene'//'Camelot' (Baenziger et al., 2009), where the pedigree of

OK98697 is 'TAM 200' (PI 579255)/'HBB313E'//'2158' (PI 601723). The final cross was made in 2004. The F_1 generation was grown in Yuma, AZ, in 2004–2005. The F_2 to F_3 generations were advanced using the bulk breeding method in the field at the University of Nebraska Eastern Nebraska Research and Extension Center (formerly the Agricultural Research Development Center) near Mead, NE (hereafter referred to as Mead) in 2005–2006 to 2006–2007. Each F_2 bulk was planted in a 2.4-m-long four-row plot with 30 cm between rows at a seeding rate of 66 kg ha^{-1}. After a mild selection among crosses of <15% to remove very poor bulks, based upon poor winter survival, disease susceptibility, extreme lateness, or lodging, F_3 bulks were planted in September 2006 in an unreplicated F_3 bulk nursery, each as a 5-m-long four-row plot with 30 cm between rows. Approximately 40% of the F_3 populations was visually selected on an estimate of winter survival, disease resistance, and general agronomic appearance based mainly on plant height, flowering date, straw strength, and visually estimated yield potential. Each selected population was advanced by randomly sampling approximately 100 spikes (synonym *heads*) in July 2007, although especially meritorious bulks had a sample of 200 to 300 spikes selected. For the F_3 population from which NE10589 was selected, 100 spikes were selected. Selected spikes were threshed individually and planted in a head-row nursery in September 2007 at Lincoln, NE. Each head-row selection was planted as a single 0.9-m row with 30 cm between rows using a four-row drill in a four-row set. Four different head rows were planted in the set. A total of seven head rows were selected from the population from which NE10589 was derived. Seed from the selected head rows was harvested. In fall 2008, NE10589 was planted in a rainfed nursery at Mead as a single row 3 m long to measure winter survival and at Lincoln, NE, in a single 2.4-m-long four-row plot with 30 cm between rows. An unreplicated nursery with replicated check cultivars design was used. Selection in July 2009 was based upon the line surviving the winter, being resistant to stem rust, having agronomic merit (standability, grain yield, grain volume weight, maturity), and having acceptable end-use quality (Baenziger et al., 2001). Two lines from this population were selected for advancement. In fall 2009, NE10589 was planted as the entry 589 (where entries ranged from 401 to 700 and were stratified by flowering date) of the Nebraska preliminary yield trial at 10 environments (Mead [conventional and organic], Lincoln, Clay Center, McCook, North Platte, Sidney [conventional and organic], Alliance, and one in south-central Kansas) in an unreplicated nursery with replicated check cultivars. The experimental name was chosen as the last two digits of the year it was entered and the entry number for the preliminary yield trial. Based upon its performance in the preliminary yield trial, it was entered in the advanced yield trial using an incomplete block design with incomplete blocks of five entries nested in three blocks of 60 entries grown at Mead (conventional and organic), Lincoln, Clay Center, McCook, North Platte, Sidney (conventional and organic), and Alliance in 2011. In 2012, it was advanced to the elite yield trial using an incomplete block design with incomplete blocks of five entries nested in blocks of 60 entries and grown at 11 environments in Nebraska and Kansas (Mead [unsprayed and sprayed with fungicide], Lincoln [unsprayed and sprayed with fungicide], Clay Center, North Platte, McCook, Sidney, Alliance, and one in south-central Kansas), where it continued to be tested until its release.

The fungicide-sprayed plots were sprayed at flag leaf (GS 39) with Twinline ([2-[[[1-(4-chlorophenyl)-1*H*-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester), metconazole, 5-[(4-chlorophenyl)methyl]-2,2-dimethyl-1-(1*H*-1,2,4-triazol-1-ylmethyl) cyclopentanol, BASF Corporation) at the recommended 657 ml ha^{-1}. At the flowering growth stage (GS 61) the fungicide-sprayed plots were sprayed with Caramba (5-[(4-chlorophenyl)methyl]-2,2-dimethyl-1-(1*H*-1,2,4-triazol-1-ylmethyl) cyclopentanol, BASF Corporation) at the recommended rate of 1170 ml ha^{-1} to suppress Fusarium head blight (caused by *Fusarium graminearum* Schwabe; Andersen, Morris, Derksen, Madden, & Paul, 2014). At Lincoln and Mead, the trials had two blocks sprayed with fungicide (as described above) and two blocks that were not treated with fungicides. The trials had two blocks at McCook and three blocks at the remaining locations. Once NE10589 was identified in 2010, the only selection thereafter was rogueing to remove obvious off-types (usually plants that were taller than the majority of plants, awnless, or had bronze chaff). This line seems to be very broadly adapted and was selected using phenotypic, diversity, and the genomic estimated breeding value (GEBV) (El-Basyoni et al., 2013; Endelman & Jannink, 2012). The GEBV was estimated using a ridge regression best linear unbiased prediction model implemented using the R package *rrBLUP* (Endelman & Jannink, 2012) in which the previous season's phenotypic data were used as a training population.

NE10589 was entered into the USDA–ARS coordinated Northern Regional Performance Nursery (NRPN) in 2013 and 2014, the Southern Regional Performance Nursery (SRPN) in 2014 (data at http://www.ars.usda.gov/Research/docs.htm?docid=11932) and in the Nebraska State Variety Trial (NESVT) from 2014–2015 (data available at http://cropwatch.unl.edu/web/varietytest/wheat). The NESVT was planted at 13 to 15 rainfed and one to three irrigated locations with three to six replications in Nebraska or combined with nearby locations

in Wyoming. Normally one to three locations were lost each year due to hail, freeze, drought, or severe disease incidence.

Lines were advanced based upon winter survival (determined at Mead, NE), resistance to stem rust and other foliar diseases prevalent in the field, uniformity, and general agronomic appearance. General agronomic appearance included plant height measured from the soil surface to the tip of the spikes, excluding the awns; flowering date measured as the number of days after 1 January to when 50% of the emerged spikes had extruded anthers, straw strength measured using a scale of 1–10, with 1 being little to 10% lodging and 10 being 100% lodged; grain yield; and grain volume weight. Experimental wheat lines were compared with relevant released cultivars and experimental lines for their targeted region for advancement (e.g., semi-dwarf wheat lines were compared with other semi-dwarf cultivars [historically the highest grain yielding types in Nebraska], tall wheat lines were compared with other tall cultivars, herbicide-tolerant wheat lines were compared with other herbicide-tolerant cultivars, and white- or red-seeded wheat lines were compared with other white- or red-seeded cultivars, respectively). Selections were also based on three main ecological zones (eastern and south-central Nebraska, west-central and southwestern Nebraska, and the Panhandle; Peterson, 1992). Lines that did well in all three ecological zones were considered broadly adapted, while lines that did well in one or two ecological zone are considered more narrowly adapted. In addition to our phenotypic selection, lines with superior GEBVs (Endelman & Jannink, 2012) were selected with a priority given to lines selected by both phenotype and GEBV.

2.2 | Disease and insect evaluation

During the winter, lines in the preliminary observation, preliminary, advanced, and elite yield trails were evaluated in the greenhouse in Lincoln, NE, for their resistance to stem rust using race TPMKC or QFCSC (Sidiqi, Wegulo, Read, & Baenziger, 2009) and at the USDA–ARS Cereal Disease Laboratory using races QFCSC, QTHJC, MCCFC, RCRSC, RKQQC, TPMKC, and TTTTF in the greenhouse and a composite of races QFCSC, QTHJC, RCRSC, RKQQC, and TPMKC in the field at St. Paul, MN, for the advanced yield trial and regional performance nurseries (Rouse, Wanyera, Njau, & Jin, 2011). In addition, lines in the preliminary, advanced, and elite yield trails were evaluated in the greenhouse at Lincoln and in the regional trials at the Cereal Disease Laboratory for leaf rust (caused by *P. triticina* Eriks; Watkins, Schimelfenig, Baenziger, & Eskrdige, 2001; Kolmer, 2003), and in the field (data from the regional performance nurseries using naturally occurring isolates) for leaf rust and stripe rust (caused by *P. striiformis* Westendorp f. sp. *tritici*). For *Wheat soilborne mosaic virus*, the lines were screened in the field at Lincoln and in the regional performance nurseries using naturally occurring strains (Hunger, Armitage, & Sherwood, 1989). NE10589 was screened for its reaction to *Wheat streak mosaic virus* (and possibly *Triticum mosaic virus* and *High Plains wheat mosaic virus*) by using a field screen that involved exposure to virus through natural fall infestations of wheat curl mites during 2015–2016 and 2016–2017.

Lines in the elite yield trial were evaluated in the greenhouse for Fusarium head blight. Each spike was artificially inoculated with a spore suspension of an isolate of *F. graminearum* at 1×10^5 spores ml^{-1} at mid-anthesis using a handheld bottle sprayer. To obtain the spore suspension, an isolate of *F. graminearum* obtained from a Nebraska wheat field was grown on potato dextrose agar plates on a laboratory bench for 3 wk. Sterile distilled water (5 ml) was added to each plate, and a rubber policeman was used to dislodge spores. The spore suspension was filtered through two layers of cheesecloth into a beaker, and the concentration was adjusted to 1×10^5 spores ml^{-1} with distilled water. Approximately 2 ml of the spore suspension was applied to each spike with a handheld bottle sprayer, and the spike was then covered with a transparent plastic bag for 3 d following inoculation. The FHB severity (%) was visually estimated 14 d after inoculation. In the field, natural infection, inoculated without irrigation, and inoculated with mist irrigation nurseries were used to evaluate the lines (Wegulo et al., 2011). Lines in the elite yield trial were also evaluated for their resistance to Hessian fly (*Mayetiola destructor* Say; Great Plains biotype) by the USDA–ARS Hard Winter Wheat Genetics Research Unit (Chen et al., 2009).

2.3 | End-use quality evaluation

For end-use quality, the preliminary lines were evaluated using a Mixograph (National Manufacturing) and for protein concentration (Baenziger et al., 2001). The advanced lines were evaluated using composited grain samples from western Nebraska (locations other than Lincoln or Mead that were harvested for seed). Bread baking properties were evaluated by approved methods of the American Association of Cereal Chemists (2000). Bake mixing time, water absorption, external and internal grain and texture were recorded (American Association of Cereal Chemists, 2000; Baenziger et al., 2001, 2008).

2.4 | Statistical analyses

The elite and advanced breeding trials were analyzed annually using an incomplete block design within blocks (using Agrobase GEN II, Agronomix Software; Stroup, Baenziger, & Mulitze, 1994). Occasionally, advanced and elite trials with three or more blocks were analyzed using the nearest neighbor analysis procedure of Agrobase GEN II (Stroup et al., 1994). Because Nebraska has three major wheat-producing regions (Peterson, 1992) and our irrigated trials are considered environmentally different from the rainfed trials, data were analyzed within a location or an irrigation treatment (irrigated or rainfed). Location means and ranks were examined, and lines were selected by having excellent performance within a location or irrigation treatment, across locations within a region, and at all locations or irrigation treatments within a year based on the arithmetic mean of the adjusted means, or across locations, irrigation treatments, and years based on the arithmetic mean of the adjusted means. A truncated selection procedure was used as a risk avoidance strategy. Basically, if a line did well in 1 or 2 yr and then poorly in the next year, the line was discontinued because it might perform poorly in a producer's field. For summary data, however, we used the head-to-head cultivar (synonym *variety*) comparison of Agrobase GEN II, which allowed us to compare lines from different sets of trials with each other. Analyses of the NRPN and SRPN data used SAS (SAS Institute) for a randomized complete block design within locations and across locations within a year. Entries tested in the NRPN were statistically analyzed only within years due to many entries being tested for only 1 yr. For the NESVT, the trials were analyzed using the SAS Mixed Model for a randomized complete block design with a row and column repeated statement with SP[POWA] in order to account for possible spatial effects within the block randomization restrictions. For NE10589, the data from the rainfed trials (2014 and 2015) were used for advancement and release. The NESVT had different entries in each region, so all of the entries were analyzed using randomized complete block designs unless a spatial correction was needed as a group and data were reported by region. No across-region analyses were done.

3 | CHARACTERISTICS

3.1 | Agronomic and botanical description

The coleoptile color of NE10589 is white and the juvenile growth habit is prostrate. NE10589 is an awned, tan-glumed cultivar. Its field appearance is most similar to 'Wesley' but can be easily separated from Wesley because Wesley has bronze chaff. After heading, the canopy is moderately closed and erect to inclined. The flag leaf is recurved and twisted at the boot stage. The foliage is green with a waxy bloom on the leaf sheath, with little waxy bloom on the spike at anthesis and on the leaves. The leaves are glaborous. The spike is tapering, narrow, and lax. The glume is short and wide, and the glume shoulder is square to elevated. The beak has an acuminate tip. The spike is predominantly inclined at maturity with some recurved spikes. Kernels are red colored, hard textured, and mainly ovate in shape. The kernel has no collar, a medium brush of short length, rounded cheeks, midsize germ, and a narrow and shallow crease.

While considerable data are available from the breeding nurseries during line development, the majority of the data presented here are from the head-to-head cultivar comparison for grain yield from the Nebraska elite trial (Table 1), the NRPN, and NESVT (Table 2) as the latter two have their complete reports readily available (http://www.ars.usda.gov/Research/docs.htm?docid=11932 and http://varietytest.unl.edu/winterwheat.html, respectively). For grain yield in Nebraska (Table 1), NE10589 was significantly higher yielding than Camelot, 'Goodstreak' (Baenziger et al., 2004), 'NE01481' (Husker Genetics Brand McGill, Baenziger et al., 2012b), 'NE05548' (Husker Genetics Brand Panhandle; Baenziger et al., 2016), Freeman, Robidoux, Overland, 'NH03614 CL' (Husker Genetics Brand Settler CL, Baenziger et al., 2011), and Wesley (Peterson et al., 2001). Of these lines, only Goodstreak was a taller wheat and the rest were popular semi-dwarf cultivars at the time of release, hence the logical cultivars for comparison. Freeman and Robidoux would be considered as broadly adapted, hence so was NE10589. These data are supported by the 2013 and 2014 USDA–ARS NRPN and 2014 USDA–ARS SRPN, where NE10589 ranked ninth, second, and 19th, respectively, of the 37, 40, and 40 entries tested regionwide in those years (data available at http://www.ars.usda.gov/Research/docs.htm?docid=11932). In the 2 yr that it was tested in the NESVT across 25 environments (Table 2), NE10589 (3436 kg ha^{-1}) was higher yielding than Freeman (3214 kg ha^{-1}), 'Mattern' (PI 665947; 2988 kg ha^{-1}; Graybosch et al., 2014), Overland (3275 kg ha^{-1}) and Wesley (2947 kg ha^{-1}) as well as the long-term check cultivars 'Scout 66′ (Schmidt, Johnson, Mattern, & Drier, 1971; 2520 kg ha^{-1}) and 'Turkey' (2512 kg ha^{-1}). NE10589 is adapted to rainfed wheat production in all ecological zones of Nebraska and a very competitive semi-dwarf wheat. Using data from the NESVT, NE10589 would be considered a taller semi-dwarf wheat cultivar similar to Overland. Molecular marker data indicate that NE10589 carries the *RhtB1b* (*Rht1*) allele for reduced plant height. NE10589 has a grain volume weight and

TABLE 1 Head-to-head comparisons of NE10589 with nine popularly grown or new cultivars from trials in Nebraska beginning in 2012 until 2015. Data on grain yield, grain volume weight, and plant height were from trials at up to eight rainfed locations (Mead, Lincoln, Clay Center, North Platte, McCook, Grant, Sidney, and Alliance) in Nebraska in each year (total environments in the comparison is *N*) and not every cultivar was grown in the same trial across the state

	Grain yield			Grain volume weight			Height		
Line	***N***	**Line**	**NE10589**	***N***	**Line**	**NE10589**	***N***	**Line**	**NE10589**
		kg ha^{-1}			kg hl^{-1}			cm	
Camelot	22	3,951	4,399**	12	72.9	73.6 ns	17	94.1	88.9**
Goodstreak	31	3,374	3,950**	14	73.0	73.2 ns	24	104.0	90.7**
McGill	17	4,074	4,431**	8	76.0	77.4 ns	13	92.8	88.7**
Panhandle	26	3,263	3,885**	10	74.2	76.1**	20	101.4	90.9**
Freeman	26	3,674	3,885**	10	74.1	76.1 ns	20	87.5	90.9**
Robidoux	26	3,639	3,885**	10	76.6	76.1 ns	20	90.9	90.9**
Overland	31	3,706	3,950**	14	73.8	73.2 ns	24	93.0	90.7**
Settler CL	26	3,339	3,885**	10	76.9	76.1 ns	20	85.7	90.9**
Wesley	31	3,325	3,950**	14	71.6	73.2**	24	85.2	90.7**

**Significantly different at the $p = .01$ probability level; ns, not significantly different at the $p = .01$ probability level.

TABLE 2 Grain yield by region and averaged across the state, and state average for grain volume weight, grain protein content, and plant height for Nebraska from 2014 to 2015 representing 25 location-years of data from rainfed environments in the Nebraska State Variety Trial

		Two-year averages							
		Grain yield				State average			
Brand	**Cultivar**	**Southeast**	**South central**	**West central**	**West**	**Grain yield**	**Bushel weight**	**Grain protein**	**Plant height**
		kg ha^{-1}					kg hl^{-1}	%	cm
Husker Genetics	Freeman	3,709	2,721	3,695	2,567	3,214	72.4	13.5	78.5
	Mattern	3,104	3,024	3,480	2,466	2,988	71.0	14.9	84.2
	NE10589	3,816	3,494	3,924	2,735	3,436	74.0	13.6	82.6
Husker Genetics	Overland	3,648	3,292	3,635	2,701	3,275	74.5	13.8	84.0
	Scout 66	3,104	1,982	2,876	1,935	2,520	72.8	14.5	97.5
	Turkey	3,071	1,982	2,829	1,975	2,512	72.6	15.1	96.1
	Wesley	3,192	2,553	3,662	2,237	2,947	71.3	14.5	75.2
Avg. of all entries[a]		3,410	2,672	3,568	2,374	3,028	72.2	14.2	82.3
L.S.D.at 5%[b]		739	739	739	336				

[a] This value is the average of all the values for the traits for the entries that were in the trial and includes values for many experimental lines not shown here.
[b] The LSD (least significant difference $p < .05$) was calculated from the analysis of variance using all of the values of the entries that were in the trial including many experimental lines not shown here.

grain protein concentration that is considered good and comparable to most higher grain volume weight wheat cultivars grown in Nebraska (Table 2).

3.2 | Disease and insect resistance

Using data predominantly from the 2014 SRPN and 2013 and 2014 NRPN, NE10589 is resistant to *Wheat soilborne mosaic virus*. It is resistant to highly resistant to stem rust in field nursery tests inoculated with a composite of stem rust races (QFCSC, QTHJC, RCRSC, RKQQC, and TPMKC) at St. Paul, MN (Table 3). It was susceptible to stem rust in Njoro, Kenya (where race TTKST predominates). In greenhouse seedling tests, it is resistant or heterogeneous to races QFCSC, QTHJC, MCCFC, RCRSC, RKQQC, TMPKC, GRMNC, and QCCSM but susceptible to race TTKSK (data provided by Y. Jin at the USDA Cereal

TABLE 3 Seedling stem rust reaction scores of NE05548 hard red winter wheat and other check cultivars evaluated in the 2008 and 2009 Northern Regional Performance Nursery at the USDA–ARS Cereal Disease Laboratory, St. Paul, MN, or Kenya

Line or selection	QFCSC 06ND76C	QTHJC 75ND717C	MCCFC 59KS19	RCRSC 77ND82A	RKQQC 99KS76A-1	TPMKC 74MN1407	TTTTF 01MN89A-1-2	Adult plant field response[a]	
								St. Paul	Kenya
2013 Northern Regional Performance Nursery									
Kharkof	;1/1;/4	2/3+	4	3C	4/3/;1	2-Apr	4	70S	30MSS
Overland	1C	1C	4/;	3C	23-	4	4	60S	15MS,MR
Wesley	;	2/4	;	;1–/0;	2/4	;	31;	20MR/70S	30MSS
Jerry	;	3C	;	;1–	4	;	4	50S	20MS
NE10589	2–,2	2–	2–	;2–	2–/4	2	2–	20MR	25MSS
2014 Northern Regional Performance Nursery									
Kharkof	4	3+	4	4/2+3	2+3/4	4	4	70S	30S
Overland	2	2	4	2+	2+3	4	4	70S	50S
Wesley	;	2/4	;	0;/;1–	2/4	;	4	70S	60S
Jerry	;	4/0;	;	;1–	4/2	;	4	50S	30S
NE10589	;	0;	0;	;	;1	0;	–	0/60S	70S

Note. Complete data set can be found at http://www.ars.usda.gov/Research/docs.htm?docid=11932. Seedling infection type: 0, immune response, no sign of infection, 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; semicolon (;), hypersensitive chlorotic or necrotic flecks; S, seedlings with scores of 3 or higher.

[a] Adult plant infection response evaluation from a field stem rust nursery at St. Paul, MN, inoculated with a composite of races QFCSC, QTHJC, RCRSC, RKQQC, MCCFC, and TPMKC, and from Njoro, Kenya, with race TTKST being predominant: R, resistant; MR, moderately resistant; MS, moderately susceptible; and S, susceptible.

Disease Laboratory). NE10589 has the molecular marker indicative of *Lr37/Sr38/Yr17*. It was moderately susceptible to susceptible (20–40 moderately susceptible [MS] in 2013 and 60 susceptible [S] in 2014 at Castroville, TX) to leaf rust races of the Great Plains. Based on molecular marker information, NE10589 did not inherit the *Sr24/Lr24* resistance present in Jagalene. NE10589 is expected to be resistant to *Wheat soilborne mosaic virus* based on an associated single nucleotide polymorphism assay. NE10589 also is positive for the marker associated with the 'Pavon' (PI 520003) allele of *Lr46/Yr29/Pm39/Sr58*. The field reaction to stripe rust is generally moderately resistant. It is moderately susceptible to Fusarium head blight (data from greenhouse and field observations in Nebraska and Kansas and moderately susceptible to deoxynivalenol accumulation). NE10589 is moderately resistant to moderately susceptible to Hessian fly (Great Plains biotype, data provided by M.-S. Chen, USDA and Kansas State University). In different tests it was classified as a resistant line (13 resistant plants and two susceptible plants, NRPN 2014) and as a moderately susceptible line with two resistant plants out of 24 plants tested for Hessian fly resistance. It is susceptible to *Wheat streak mosaic virus* (data obtained from field screens in Nebraska) and the wheat stem sawfly (*Cephus cinctus* Norton; data from western Nebraska).

3.3 | End-use quality

The milling and baking properties of NE10589 were determined for 4 yr by the Nebraska Wheat Quality Laboratory (Table 4). In these tests, Wesley, an excellent milling and baking wheat, and Overland, a lower quality milling and baking wheat, were used for comparison. The average flour protein concentration of NE10589 (116 g protein kg^{-1} flour) was similar to Overland (114 g protein kg^{-1} flour) but lower than Wesley (131 g protein kg^{-1} flour) for the corresponding years (similar to results from the NESVT, Table 2). The average flour extraction on a Buhler Laboratory Mill for NE10589 (723 g flour kg^{-1} grain) was lower than Wesley (734% g flour kg^{-1} grain) and higher than Overland (701 g flour kg^{-1} grain). The flour ash content (4.26 g kg^{-1} flour) was higher than Wesley (4.09 g kg^{-1} flour), and similar to Overland (4.30 g kg^{-1} flour). Dough mixing properties of NE10589 were good (mixtime peak was 4.72 min and mixtime tolerance was scored as 4.3 on a 1–7 scale, where 7 is very tolerant) and similar to Wesley (mixtime peak of 4.88 min and mixtime tolerance scored as 5.0). Both lines were superior to Overland (mixtime peak of 3.53 min and mixtime tolerance scored as 3.40). Average Mixograph absorption (635 g H_2O kg^{-1} flour) was similar to Overland (636 g H_2O kg^{-1} flour) and less than Wesley (650 g H_2O kg^{-1} flour) for the corresponding years. The average

TABLE 4 Comparison of NE10589 with Wesley and Overland from 2011 to 2014 for flour yield, bran score, mill type scores, flour protein content, ash content, Mixograph water absorption (water abs.), Mixograph mixing time (MTime), Mixograph tolerance (MTol), loaf volume, and external appearance (Ext. score), crumb grain score, crumb texture score, and overall baking score as determined by the Wheat Quality Laboratory at the University of Nebraska (Baenziger et al., 2001). All reported values were measured at a 140 g H_2O kg^{-1} flour basis

	Milling					Mixograph			Baking				
Year	Flour yield	Bran score	Mill type score	Protein in flour	Flour ash	Water abs.	MTime	MTol	Loaf vol.	Ext. score	Crumb grain score	Crumb texture score	Overall baking 2score
	g kg^{-1}	1–5[a]			g kg^{-1}		min	0–7[b]	L	0–6[c]			
NE10589													
2011	744	4.0	3.5	112	4.60	630	4.22	4.1	0.793	3.8	3.5	3.8	3.7
2012	717	3.5	0.5	114	4.26	635	5.16	4.4	0.785	3.5	3.0	3.0	3.2
2013	709	3.5	1.5	114	4.22	625	4.30	4.7	0.916	5.0	4.4	4.5	4.6
2014	724	3.5	2.5	125	3.96	650	5.22	4.1	0.968	5.0	4.3	4.0	4.4
Mean	723a	3.6a	2.0b	11.6b	4.26a	635a	4.72a	4.30a	0.865a	4.3a	3.8a	3.8b	4.0b
Wesley													
2011	751	3.5	4.5	116	4.64	635	4.01	4.6	0.835	4.3	3.4	3.6	3.8
2012	734	4.0	4.5	123	3.86	640	5.85	5.4	0.775	3.8	3.8	3.8	3.8
2013	708	3.5	3.5	146	3.90	645	4.35	4.9	0.950	5.4	4.5	5.1	5.0
2014	743	3.5	4.5	139	3.95	680	5.31	4.9	0.968	5.0	4.8	5.0	4.9
Mean	734a	3.6a	4.3a	13.1a	4.09a	650a	4.88a	5.0a	0.882a	4.6a	4.1a	4.4a	4.4a
Overland													
2011	745	3.5	4.5	103	4.46	63.5	3.52	2.8	0.788	3.3	2.3	2.3	2.6
2012	718	3.5	4.5	116	4.48	63.0	3.18	3.9	0.790	4.0	2.8	2.5	3.1
2013	615			122	4.43	64.5	2.91	2.8	0.889	4.9	3.5	3.5	4.0
2014	726	3.5	4.5	116	3.82	63.5	4.51	4.1	0.934	4.8	3.4	3.1	3.8
Mean	701a	3.5a	4.5a	11.4b	4.30a	636a	3.53b	3.40b	0.850a	4.2a	3.0b	2.8c	3.3c

Note. Means followed by the same letter are not significantly different at the $p = .05$ level.

[a]Scores use a 1–5 scale, with 5 being very good and 1 being very poor. [b]Scores use a 0–7 scale, with 7 being very tolerant. [c]Scores use a 0–6 scale, with 6 being excellent.

loaf volume of NE10589 (0.865 L) was less than that of Wesley (0.882 L) and better than that of Overland (0.850 L). The scores for the internal crumb grain and texture were both 3.8, which were lower than Wesley (4.1 and 4.3, respectively) and better than Overland (3.0 and 2.8, respectively). The overall end-use quality characteristic for NE10589 (scored as 4.0, where 3 is fair, 4.0 is good, and 6.0 is excellent) was less than that of Wesley (4.4) and better than that of Overland (3.3) and similar to many commonly grown wheat cultivars. NE10589 should be acceptable to good to the milling and baking industries.

3.4 | Seed purification and increase

Seed purification of NE10589 began in 2013 and continued through 2015 using visual identification and manual removal of variants (plants that were taller in height [5–15 cm], were awnless, or had bronze chaff) in bulk seed increases grown under rainfed conditions at Lincoln and Mead, NE. NE10589 has been uniform and stable since 2013. Less than 0.5% of the plants were rogued from the breeder's seed increase in 2010–2013. Up to 1% (10:1000) variant plants may be encountered in subsequent generations.

4 | AVAILABILITY

The Nebraska Foundation Seed Division, University of Nebraska, Lincoln, NE, has had foundation seed available under the marketing name Husker Genetics Brand Ruth to qualified certified seed enterprises since 2015. The seed classes are breeder, foundation, registered, and certified. Registered seed will be a nonsalable class. NE10589 is protected by U.S. Plant Variety Protection under P. L. 10577 with the certification option (Certificate no. 201700273). A research and development fee will be assessed on all certified seed sales. Small quantities of seed for research purposes may be obtained from Dr. P. S. Baenziger and

the Department of Agronomy and Horticulture, University of Nebraska-Lincoln, for at least five years from the date of this release. A seed sample has been deposited in the USDA–ARS National Center for Genetic Resources Preservation and in the USDA–ARS National Small Grains Collection, Aberdeen, ID, and seed is freely available to interested researchers.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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