Registration of ‘NW13493’ hard white winter wheat


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Abstract
Historically, wheat (Triticum aestivum L.) cultivars developed by the cooperative University of Nebraska–USDA-ARS wheat improvement project were hard red winter wheat. With the expanding hard white wheat market, there is a greater emphasis on developing hard white winter wheat lines adapted to the Great Plains. ‘NW13493’ (tested as NW13493) (Reg. no. CV-1197, PI 699380) was selected for its white kernels, agronomic performance, relevant disease resistances, and end-use quality and is adapted to the central Great Plains. NW13493 was licensed to Bay State Milling Company on the basis of its superior agronomic and end-use quality performance and also the need to ensure hard white wheat growers

Abbreviations: FHB, Fusarium head blight; GEBV, genetic estimated breeding value; NESVT, Nebraska State Variety Trial; SRPN, Southern Regional Performance Nursery.
1 | INTRODUCTION

Historically hard wheat (*Triticum aestivum* L.) cultivars developed in the Great Plains have tended to be hard red winter wheat, though the market for hard white winter wheat is clearly valuable, and more hard white winter cultivars are becoming available (e.g., ‘Sunshine’, Haley et al., 2017; ‘Matterhorn’, Graybosch et al., 2019; and ‘KS Silverado’, Zhang et al., 2021). As described by Zhang et al. (2021), a major limitation to the expansion of hard white wheat is the limited number of grain elevators that accept hard white wheat. Hard red and hard white wheat grains are classified as separate market classes and must be kept segregated in grain elevators to avoid having wheat of mixed classes, which increases elevator costs and potential quality risk. Many elevators choose to handle only one wheat class, the predominant hard red winter wheat class. An additional concern is that hard white winter wheat cultivars often have higher levels of preharvest sprouting, which prevents hard white wheat cultivars from being grown in higher rainfall areas, especially with rainfall at harvest.

A successful hard white winter wheat must be competitive with hard red winter wheat. In Nebraska, it must have the following: (a) survive the winter, (b) be resistant to stem rust (caused by *Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks & E. Henn.), (c) perform well agronomically, and (d) have the capability of producing an acceptable loaf of bread (Baenziger et al., 2001). Hard white winter wheat should also have some level of resistance to preharvest sprouting, though this need can be reduced by targeting the cultivar to the drier wheat production areas. Also, until hard white winter wheat is broadly accepted by grain elevators, a critical need is to ensure the produced grain can be sold. ‘NW13493’ (tested as NW13493) (Reg. no. CV-1197, PI 699380, PVP no. 202100495 pending) was developed by the cooperative University of Nebraska–USDA-ARS wheat improvement project to provide wheat producers in Nebraska and the surrounding states with competitive, elite hard white winter wheat cultivars. NW13493 was licensed to Bay State Milling Company (Quincy, MA) to ensure there would be a market for the produced grain. NW13493 was released primarily for its white kernel color and superior adaptation to rainfed wheat production systems throughout Nebraska and in adjacent wheat producing states as determined by the developing institutions.

2 | METHODS

2.1 | Line development and selection history

The breeding methods that are used in the cooperative University of Nebraska–USDA-ARS wheat improvement project have been described in detail previously (e.g., Baenziger et al., 2020), so they will be described briefly here with attention to modifications in the standard protocol. NW13493 is a hard white winter wheat selected from the cross ‘SD98W175-1’/‘NW03666’. The pedigree of SD98W175-1 is ‘KS84273BB-10’/‘KSSB110-9’/‘KS831374-141B’/‘YE1110’/‘KS82W418’/‘Stephens’ and the pedigree of NW03666 is ‘N94S097KS’/‘NE93459’. The F1 generation was grown in the greenhouse in 2008, and the F2 to F3 generations were advanced as bulks at Mead, NE, in 2009–2010. NW13493 was evaluated in replicated trials beginning in 2014. It has excellent winter survival and agronomic performance, acceptable disease reactions to many of the common diseases in its target area, and good end-use quality for bread making.
was one row of a group of four rows planted 3 m long with 30 cm between rows. Six sib lines were advanced from the preliminary observation nursery to the preliminary yield trial (F_{3.6}), which again would be considered an indication of a superior group of lines. The Nebraska preliminary yield trial was grown at seven locations in four environmental zones (Southeastern Zone: Mead, Lincoln; Southcentral Zone: Clay Center; Southwestern Zone: McCook, North Platte; and Western Zone: Sidney, and Alliance) in an unreplicated nursery with replicated check cultivars. NW13493 was identified in 2013 as the experimental line, NW13493, and selected for further testing. In addition to our phenotypic selection, NW13493 was selected using genomic selection and its genomic estimated breeding value (GEBV) (El-Basyoni et al., 2013; Endelman & Jannink, 2012), where its estimated breeding value was 19th out of 280 elite lines. 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 from rainfed trials were used as a training population. Remarkably, all six lines were advanced to the advanced yield trial in 2014 and evaluated in the same seven locations described above. Of those six lines, three were advanced to the elite yield trial in 2015, where NW13493 continued to be tested until it was released in February 2021. The elite yield trial was evaluated at eight locations (Mead, Lincoln, Clay Center, Grant [Southwestern Zone], McCook, North Platte, Sidney, and Alliance). Also, at Lincoln (2015 and thereafter) and Mead (2015 and 2016), the elite trial had two replications grown without fungicide applications, and two replications grown with fungicide applications. The trials had two replications at McCook, Grant, and North Platte, and three replications at Clay Center, Mead (in 2017 and thereafter), Sidney, and Alliance. The fungicide sprayed plots were sprayed at flag leaf (Feekes growth stage [GS] 9) with Twinline (pyraclostrobin, [2-[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl methoxy-, methyl ester) + metconazole, 5-[4-(chlorophenyl)methyl]-2,2-dimethyl-1-(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol, BASF) at the recommended 657 mL ha^{-1} to control stem rust, leaf rust (caused by P. triticina Eriks), stripe rust (caused by P. striiformis Westendorp f. sp. tritici), and tan spot [caused by Pyrenophora tritici-repentis (Died) Drechs]. At the flowering growth stage (Feekes GS 10.5), the fungicide-treated plots were sprayed with Caramba [metconazole, 5-[4-(chlorophenyl)methyl]-2,2-dimethyl-1-(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol, BASF] at the recommended rate of 1.170 mL ha^{-1} to suppress Fusarium head blight (caused by Fusarium graminearum Schwabe) (Andersen et al., 2014; Wegulo et al., 2015). Lines were advanced based on winter survival (determined at Mead), resistance to stem rust and other foliar diseases (potentially leaf and stripe rust, tan spot, and Fusarium head blight) that could be prevalent in the field, uniformity, agronomic performance, and acceptable end-use quality for making bread. Agronomic performance included plant height measured from the soil surface to the tip of the head, excluding the awns; flowering (syn. anthesis) date measured as the number of days after 1 January when 50% of the emerged spikes had extruded anthers; straw strength measured using a scale of 1 to 10, with 1 being little-to-10% lodging, and 10 being 100% lodged; grain yield; and grain volume weight. Experimental wheat lines were compared to relevant released cultivars and experimental lines for their targeted region for advancement (in this case compared with semi-dwarf wheat lines). Selections were also based on three main ecological zones (eastern and southcentral Nebraska, west central and southwest Nebraska, and the panhandle) (Peterson, 1992). Lines that did well in all three ecological zones were considered broadly adapted, whereas lines that did well in one or two ecological zones were considered more narrowly adapted.

NW13493 was evaluated in the USDA-ARS–coordinated Southern Regional Performance Nursery (SRPN) in 2016 and 2017 and in the University of Nebraska Fall Sown Wheat Performance Trials (NESVT) in 2017–2020 (state-wide). 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 because of hail, freezes, drought, or severe disease incidence.

### Disease and insect resistance evaluation

Over the winter, lines entered in the preliminary observation and preliminary, advanced, and elite yield trials were evaluated in the greenhouse in Lincoln for their resistance to stem rust using race TPMKC or QFSC as previously described Baenziger et al. (2020) using the protocol of Sidiqi et al. (2009). The USDA-ARS Cereal Disease Laboratory evaluated the advanced yield trial and uniform USDA regional performance nurseries using various races in the greenhouse and a composite of races QFSC, QTHJC, RCRSC, RKRQC,
and TPMKC in the field at St. Paul, MN (Rouse et al., 2011). In addition, lines in the preliminary, advanced, and elite yield trials were evaluated in the greenhouse at Lincoln and in the uniform USDA regional performance nurseries at the Cereal Disease Laboratory for various races of leaf rust (Kolmer, 2003; Watkins et al., 2001). Field data were used from states that grew the uniform USDA regional performance nurseries where leaf and stripe rust occurred using naturally occurring isolates. For Soil-borne wheat mosaic virus, the lines were screened in the field at Lincoln and in the uniform USDA regional performance nurseries using naturally occurring strains (Hunger et al., 1989). NW13493 was screened for its reaction to Wheat streak mosaic virus by using a field screen that involved exposure to virus through natural fall infestations of wheat curl mites during 2016–2017.

Lines in the elite yield trial were evaluated in the greenhouse and field for Fusarium head blight (Baenziger et al., 2020) using the protocols of Hernandez Nopsa et al. (2014) and Wegulo et al. (2011). Lines in the elite yield trial were also evaluated for their resistance to Hessian fly (Great Plains biotype) by the USDA-ARS Hard Winter Wheat Genetics Research Unit (Chen et al., 2009).

2.3 End-use quality evaluation

Lines selected from the preliminary observation nursery were evaluated by the Nebraska Wheat Quality Laboratory using a Mixograph (National Manufacturing) to estimate Mixograph peak time and tolerance and for protein concentration by near infrared reflectance using a Perten DA7250 spectrometer (Perten Instruments North America) calibrated to combustion analysis (LECO FP528) (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 (Cereal & Grains Association, 2021). Bake mixing time, water absorption, external and internal grain, and texture were recorded (Cereal & Grains Association, 2021; Baenziger et al., 2001; 2008).

2.4 Statistical analyses

Breeding trials were analyzed using the previously described methods in Baenziger et al. (2020). Briefly, we analyzed our incomplete block design within blocks using the alpha lattice procedure within Agrobase GEN II (Agronomix Software, Inc.) (Stroup et al., 1994). Occasionally in fields with heterogeneity, we used the nearest neighbor analysis procedure of Agrobase GEN II (Stroup et al., 1994). Data were analyzed within a location or an irrigation treatment (irrigated or rainfed), and lines were selected by having excellent performance within a location or irrigation treatment, across locations within a region, and all locations or irrigation treatments within a year. A truncated selection procedure was used as a risk avoidance strategy, where a line was discontinued if it performed poorly in any year of its development because it might perform poorly in a producer’s field. For summary data, however, we used the head-to-head cultivar (syn. variety) comparison of Agrobase GEN II, which allowed us to compare lines from different sets of trials to each other. Analyses of the SRPN data used PROC GLM for randomized complete block experiments (version 9.4, SAS Institute Inc.). Entries tested in the SRPN were statistically analyzed only within years because of many entries being tested for only 1 yr. For the NESVT, the trials were analyzed using SAS Mixed Model for a randomized complete block design with a row and column repeated statement in order to account for possible spatial effects within the block randomization restrictions. The NESVT had different entries in each region, so data were reported by region. No across-region analyses were done.

3 CHARACTERISTICS

3.1 Botanical and agronomic description

The juvenile growth habit of NW13493 is prostrate. NW13493 is an awned, tan-glumed cultivar. After heading, the canopy is moderately closed and heads are erect to inclined. The flag leaf is erect and twisted at the boot stage. The foliage is green with a waxy bloom on the leaf sheath, the spike at anthesis and on the leaves. The leaves are glabrous. The spike is tapering, narrow, and lax. The glume is medium and wide, and the glume shoulder is wanting to narrow. The beak is obtuse. The spike is predominantly inclined at maturity with some recurved spikes. Kernels are white colored, hard textured, and mainly ovate in shape. The kernel has no collar, a brush of short length, rounded cheeks, midsize germ, and a narrow and deep crease.

3.2 Agronomic performance

NW13493 is moderately late in maturity (143.4 d after 1 January, data from 14 observations in eastern Nebraska), which is very similar to ‘Ruth’ (143.8 d after 1 January). 1 d later than ‘Freeman’ (142.6 d after 1 January) (Baenziger et al., 2014) and 2 d later than ‘LCS Valiant’ (141.7 d compared with 143.5 d after 1 January for NW13493, n = 15). NW13493 is a semi-dwarf wheat cultivar and contains the Rht-Bib allele (formerly Rht1) for reduced plant height. The mature plant height of NW13493 is taller than Freeman, LCS Valiant, ‘Settler CL’ (Baenziger et al., 2011), and ‘Wesley’ (Peterson et al., 2001) (Table 1). NW13493 is shorter than Ruth,
‘Robidoux’ (Baenziger et al., 2012), ‘Overland’ (Baenziger et al., 2008), and ‘Scout 66’ (Schmidt et al., 1971). NW13493 has moderate straw strength for a semi-dwarf wheat with little lodging reported in the years it has been tested and lodging occurred. The winter hardness of NW13493 is good (data not shown) and comparable to other winter wheat cultivars grown in Nebraska. The grain yield of NW13493 is similar to LCS Valiant, Ruth, and Robidoux, and higher than Freeman, ‘Siege’ (PI 693222), Overland, Scout 66, and Wesley. The grain volume weight of NW13493 is comparable to high volume weight cultivars of Ruth and Sieged, and superior to Freeman, LCS Valiant, Robidoux, Overland, Scout 66, Settler CL, and Wesley.

NW13493 was evaluated in the USDA-ARS–coordinated Southern Regional Performance Nursery as NW13493 in 2016 and 2017. NW13493 ranked 16th and 11th region-wide of the 38 and 50 entries tested in those years (data available in USDA-ARS [2022]). NW13493 was also evaluated in the University of Nebraska Fall Sown Wheat Performance Trials in 2018–2020.

Using the three-year averages (Table 2, full data available in CropWatch [2022]), NW13493 had a grain yield of 4,575 kg ha⁻¹ compared with 4,518 kg ha⁻¹ for Freeman, 4,650 kg ha⁻¹ for Ruth, 4,727 kg ha⁻¹ for LCS Valiant, 3,516 kg ha⁻¹ for Scout 66, and 3,541 kg ha⁻¹ for ‘Turkey’ (CI 1558). The results for plant height, grain volume weight, and grain protein content from NESVT were very similar to those from the elite trials in Nebraska and confirmed that NW13493 is a short semi-dwarf cultivar with good grain volume weight and protein content. Based upon these data, NW13493 is a moderately late winter wheat that is adapted to all rainfed wheat production zones in Nebraska and has performed well in adjacent states.

### 3.3 Disease and insect resistance

Using data predominantly from the 2016 and 2017 SRPN or from field data in Nebraska, NW13493 is resistant to *Soil-borne wheat mosaic virus*. It was moderately resistant to stem rust in field nursery tests at St. Paul, MN, and is resistant at the seedling stage to stem rust pathotypes QFSC (the main pathotype in the United States), QTHJC, MCCFC, RCRSC, RKRQC, TPMKC, and TTKSK (also known as Ug99) (Table 3). However, it was susceptible to stem rust pathotypes TKTTP, TKTTF, TTTTF (Y. Jin personal communication, 2016), and the Ug99 derivative TTKTT. This phenotypic pattern is consistent with the presence of *SrTmp* in NW13493. The highly resistant reaction to races MCCFC and TPMKC, which are virulent to *SrTmp*, indicates the presence of one or more additional resistance genes. Molecular marker analysis indicates that NW13493 is believed to carry *Sr6* (Mourad et al., 2018) and the *Aegilops ventricosa* 2N⁸ translocation carrying *Lr37/Sr38/Yr17* (Helgouvera et al., 2003). In field plots NW13493 is moderately resistant to leaf rust. NW13493 had very low infection types at the seedling stage to *P. triticina* pathotypes TNBJ, TNRJ, TBBGS, TCRKG, KFBJG, MCTNB, and PBLRG; intermediate infection type to pathotypes MBDS and MFJSB; and susceptible infection type to MBJG. Based on the infection type data, NW13493 was postulated to have *Lr16*, which has been common in Nebraska germplasm in the past. By

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**TABLE 1** Head-to-head comparisons of ‘NW13493’ to popularly grown or new cultivars and the historic cultivar, ‘Scout 66’, from trials in Nebraska from 2015 to 2020

<table>
<thead>
<tr>
<th>Line</th>
<th>Height cm</th>
<th>Grain yield kg ha⁻¹</th>
<th>Grain volume weight kg hl⁻¹</th>
</tr>
</thead>
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<tr>
<td>Freeman</td>
<td>42</td>
<td>87.1</td>
<td>3,949, 4,142**</td>
</tr>
<tr>
<td>LCS Valiant</td>
<td>44</td>
<td>84.5</td>
<td>4,150, 4,183n.s.†</td>
</tr>
<tr>
<td>Ruth</td>
<td>42</td>
<td>90.8</td>
<td>4,054, 4,142n.s.</td>
</tr>
<tr>
<td>Siege</td>
<td>44</td>
<td>86.9</td>
<td>3,923, 4,183**</td>
</tr>
<tr>
<td>Robidoux</td>
<td>44</td>
<td>90.0</td>
<td>4,041, 4,183**</td>
</tr>
<tr>
<td>Overland</td>
<td>37</td>
<td>93.6</td>
<td>3,835, 4,279**</td>
</tr>
<tr>
<td>Scout 66</td>
<td>42</td>
<td>101.7</td>
<td>2,934, 4,142**</td>
</tr>
<tr>
<td>Settler CL</td>
<td>39</td>
<td>92.6</td>
<td>3,441, 4,187**</td>
</tr>
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<td>Wesley</td>
<td>24</td>
<td>89.8</td>
<td>3,424, 4,187**</td>
</tr>
</tbody>
</table>

Note. Data on plant height, lodging, grain yield, and grain volume weight were from trials at up to 10 rainfed trials (Mead [unsprayed or sprayed with fungicides], Lincoln [unsprayed or sprayed with fungicides], 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 in every year.

* Significantly different at the p = .05 probability level.
** Significantly different at the p = .01 probability level.
† n.s., not significantly different at the p = .05 probability level.
molecular markers, NW13493 may also carry adult plant leaf rust resistance genes *Lr34/Yr18, Lr68* (Herrera-Foessel et al., 2012), and *Lr77* (Kolmer et al., 2018). It was moderately resistant to moderately susceptible to stripe rust in field nurseries in Nebraska and the Great Plains. The resistance is likely attributable, at least in part, to *Lr37/Sr38/Yr17* and *Lr34/Yr18* (Lagudah et al., 2009).

Based on field data taken in Nebraska in years when *Fusarium* head blight (FHB) intensity was moderate to high during the period from 2013 to 2019, as well as greenhouse data taken during the same period, NW13493 is moderately resistant to moderately susceptible to FHB (25% field severity; 5.7 on a scale of 1–9 whole plot field rating where 1 = resistant and 9 = susceptible; and 49% greenhouse severity). NW13493 is moderately susceptible to deoxynivalenol (DON) accumulation (8.5 μg ml⁻¹ field DON). NW13493 is less resistant to FHB than Overland, but superior to most other commonly grown wheat cultivars. Based on three evaluations over three seasons, NW13493 is susceptible to Hessian fly (*Mayetiola destructor* Say). It is moderately sus-
Table 4  Comparison of ‘NW13493’ to Overland from 2014 to 2018 for flour yield, bran score, mill type score, flour protein content, flour ash content, Mixograph water absorption, Mixograph mixing peak time (measured in minutes), Mixograph tolerance, loaf volume, external appearance (bread exterior), crumb grain score, crumb texture score, and overall baking score (Overall) as determined by the Wheat Quality Laboratory at the University of Nebraska (Baenziger et al., 2001)

<table>
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<tr>
<th>Year</th>
<th>Milling Flour yield</th>
<th>Bran</th>
<th>Mill type</th>
<th>Flour Protein</th>
<th>Ash</th>
<th>Mixograph Water absorption</th>
<th>Peak time</th>
<th>Tolerance</th>
<th>Baking Loaf volume</th>
<th>Bread exterior</th>
<th>Crumb texture</th>
<th>Overall</th>
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<td>g kg⁻¹</td>
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Overland (check)

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<td>635</td>
<td>3.5</td>
<td>3.4</td>
<td>4.8</td>
<td>3.1</td>
<td>3.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Mean</td>
<td>719a</td>
<td>3.7a</td>
<td>4.3a</td>
<td>118a</td>
<td>4.2a</td>
<td>628a</td>
<td>3.7b</td>
<td>3.6b</td>
<td>4.7a</td>
<td>3.7a</td>
<td>3.6a</td>
<td>4.0a</td>
</tr>
</tbody>
</table>

Note. All reported values were measured at a 140-g water 1,000 g flour basis. Means followed by a common letter are not significantly different at the p = .05 probability level.

aScores use a 1 to 5 scale with 5 being very good and 1 being very poor.
bScores use a 0 to 7 scale with 0 being intolerant and 7 being very tolerant to dough mixing.
cScores use a 1 to 6 scale with 1 being very poor and 6 being excellent.

cceptible to Barley yellow dwarf virus, and susceptible to wheat stem sawfly (Cephus cinctus Norton) and Wheat streak mosaic virus (data obtained from the USDA-ARS Southern Regional Performance Nursery and field observations in Nebraska).

3.4  End-use quality

The milling and baking properties of NW13493 were determined for 5 yr by the Nebraska Wheat Quality Laboratory (Table 4). In these tests, Overland, a very widely grown and acceptable (not superior) milling and baking wheat, was used for comparison. The average flour protein concentration of NW13493 (122 g protein kg flour⁻¹) was similar to Overland (118 g protein kg flour⁻¹) for the corresponding years. The average flour extraction on the Buhler Laboratory Mill for NW13493 (718 g flour kg grain⁻¹) was similar to Overland (719 g flour kg grain⁻¹). The flour ash concentration (4.1 g kg flour⁻¹) was similar to Overland (4.2 g kg flour⁻¹). NW13493 is a high polyphenol oxidase wheat and hence is not suitable for Asian noodles (data from the USDA regional nursery reports). Dough mixing properties of NW13493 were superior (Mixograph peak time was 7.5 min, and Mixograph tolerance was scored as 4.5 on a 0–7 scale where 7 is very tolerant) and stronger than Overland (Mixograph peak time of 3.7 min, and Mixograph tolerance scored as 3.6). Average Mixograph water absorption (634 g H₂O kg flour⁻¹) was similar to Overland (628 g H₂O kg flour⁻¹) for the corresponding years. The average loaf volume of NW13493 (0.938 L) was higher than Overland (0.924 L). The scores for the internal crumb grain and texture were 4.5 and 4.5, which were higher than Overland (3.7 and 3.6, respectively). Molecular marker data indicate that NW13493 has the desirable GluD1d (+5’10’) high molecular weight glutenin allele, while Overland has the inferior GluD1a (‘2+12’) (Liu et al., 2008) allele. The overall end-use quality characteristics for NW13493 (scored as 4.5, where 3 is fair, 4 is good, and 6 is excellent) was higher than Overland (4.0) and similar to many of the superior quality and commonly grown wheat cultivars. For the 3 yr that NW13493 and Wesley (an excellent end-use quality wheat cultivar) were evaluated from the same nursery (data not shown), the two cultivars were comparable. NW13493 should be acceptable to good for the milling and baking industries. In fact, the license of NW13493 to Bay State Milling Company is a testament to its superior end-use quality.
3.5 Seed purification and increase

Seed purification of NW13493 began in 2016 and continued through 2020 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 grown under rainfed conditions at Lincoln and Mead. Up to 1% (10:1.000) variant plants may be encountered in subsequent generations. In addition, in 2017, NW13493 was sent to the Iowa State University Seed Science Center for kernel color sorting to select white kernels and to remove dark and discolored kernels. Previous tests found up to 6 red kernels per 100 kernels of NW13493. In the sorting process, 87% white kernels were retained, and 13% dark or mixed light and dark kernels were discarded. It is customary to err on the side of discarding any ambiguous kernels. The sorted seed was increased in Yuma, AZ, and the harvested seed had less than 0.6% red kernels. Up to 2% red kernels could be encountered in subsequent generations.

4 AVAILABILITY

NW13493 was licensed to Bay State Milling Company, and commercial sales are controlled by them for this cultivar. The Nebraska Foundation Seed Division, University of Nebraska-Lincoln, Lincoln, NE, provides foundation seed to Bay State Milling Company and its authorized growers. The seed classes are breeder, foundation, registered, and certified. NW13493 is protected by U.S. Plant Variety Protection under P. L. 105-77 with the certification option (Certificate number 202100495 pending). Small quantities of seed for research purposes may be obtained from the Small Grains Project in 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 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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AUTHOR CONTRIBUTIONS

P. S. Baenziger: Conceptualization; Funding acquisition; Investigation; Project administration; Writing – original draft; Writing – review & editing. K. A. Freis: Investigation; Supervision; Writing – review & editing. J. Boehm, Jr.: Investigation, Writing – review & editing. V. Belamkar: Data curation; Formal analysis; Investigation; Methodology; Writing – review & editing. D. J. Rose: Investigation; Methodology; Writing – review & editing. L. Xu: Investigation; Writing – review & editing. S. M. Finnie: Funding acquisition; Investigation; Writing – review & editing. S. N. Wegulo: Conceptualization; Funding acquisition; Investigation; Methodology; Writing – review & editing. T. Regassa: Investigation; Writing – review & editing. A. C. Easterly: Investigation; Methodology; Writing – review & editing. C. F. Creech: Investigation; Project administration; Writing – review & editing. D. K. Santra: Investigation; Writing – review & editing. R. N. Klein: Investigation; Writing – review & editing. R. L. Bowden: Investigation; Writing – review & editing. M. J. Guttiieri: Investigation; Writing – review & editing. G. Bai: Investigation; Writing – review & editing. I. El-Basyoni Salah: Conceptualization; Formal analysis; Investigation; Methodology; Writing – review & editing. S. D. Masterson: Formal analysis; Investigation; Writing – review & editing. J. Kolmer: Investigation; Writing – review & editing. M.-S. Chen: Investigation; Writing – review & editing. Y. Jin: Investigation; Methodology; Writing – review & editing. J. Kolmer: Investigation; Writing – review & editing. J. Poland: Data curation; Methodology; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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