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Registration of 'NI04421' Hard Red Winter Wheat

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CULTIVAR

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ABSTRACT

Water for irrigation is a major constraint in the Great Plains, and it is expected that the proportion of irrigated crop land to grow irrigated wheat (*Triticum aestivum* L.), which requires less water than other crops, will increase to conserve irrigation water. 'NI04421' (Reg. No. CV-1064, PI 659690) hard red winter wheat (*Triticum aestivum* L.) was developed cooperatively by the Nebraska Agricultural Experiment Station and the USDA-ARS and released in 2010 by the developing institutions and the Wyoming Agricultural Experiment Station. NI04421 was released primarily for its superior performance under irrigation and rainfed conditions in western Nebraska and eastern Wyoming. NI04421 was selected from the cross NE96644/Wahoo (sib) where the pedigree of NE96644 is 'Odesskaya P'/'Cody'//'Pavon 76'/*3 'Scout 66'. The cross was made in the spring of 1998. NI04421 was selected using a modified bulk-breeding method as an $F_{3:4}$ line (F_3-derived line in the F_4 generation) in 2002, and in 2004 was assigned experimental line number NI04421. After extensive testing, it was released in July 2010.

In 1996, the University of Nebraska wheat (*Triticum aestivum* L.) breeding program began a dedicated project to develop wheat cultivars adapted to irrigated production. The underlying concept was that the acreage devoted to irrigated wheat production was expected to increase to conserve water since wheat requires less water than alternative crops such as corn (*Zea mays* L.; see, e.g., Musick et al., 1990 and Norwood, 1995). In 2007, Nebraska had the most irrigated crop land of any state in the USA (National Agricultural Statistics Service, 2008). Previous research had shown that breeding under rainfed conditions did not adequately select for adaptation under irrigation (Ud-Din et al., 1992). Cultivars that are developed from this irrigated-wheat breeding program are designated NI, where N stands for "Nebraska" and I for "irrigated breeding program."

'NI04421' (Reg. No. CV-1064, PI 659690) hard red winter wheat was tested under the experimental line designation NI04421 and was developed cooperatively by the Nebraska Agricultural Experiment Station and the USDA-ARS. NI04421 is the first line released from this irrigated wheat breeding effort. It was released in July 2010 by the developing institutions and the Wyoming Agricultural Experiment Station as part of the hard red winter wheat improvement effort. NI04421 will be marketed and sold as Husker Genetics brand Robidoux. The name Robidoux was chosen in honor of Robidoux Pass, which was a popular pioneer pathway on the Oregon Trail between Nebraska and Wyoming before 1852. The pass was named after the Robidoux family, who built a fur-trading post at the pass. NI04421 was released primarily for its superior performance under irrigation and rainfed conditions in western Nebraska and eastern Wyoming.

Methods

NI04421 was selected from the cross NE96644/Wahoo (sib), where the pedigree of NE96644 is 'Odesskaya P'/'Cody' (PI 486212, Schmidt et al., 1989)//'Pavon 76'/*3 'Scout 66' (CItr 13996, Schmidt et al., 1971). The cross was made in spring 1998. The F_1 generation was grown in the greenhouse over the winter of 1998–1999, and the F_2 and F_3 generations

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Abbreviations: NESVT, Nebraska State Variety Trial; SRPN, Southern Regional Performance Nursery.

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were advanced using a modified bulk-breeding method in fields at Ithaca, NE in 2000–2001. Each F_2 bulk was planted at a seeding rate of 66 kg ha^{-1} in a 2.4-m long, four-row plot with 30 cm between rows. After a mild culling selection of less than 15% to remove very poor bulks (usually based on poor winter survival, although also on poor disease resistance, extreme lateness, or lodging), the F_3 bulks were planted in September 2001 in an unreplicated F_3 bulk nursery, each as a 5-m long, four-row plot with 30 cm between rows. Approximately 50% of the F_3 populations were visually selected based on an estimate of winter survival, disease resistance, and general agronomic appearance—mainly plant height, flowering date, straw strength, and visually estimated yield potential. Each selected population was advanced by random sampling of approximately 100 spikes in July 2001, although especially meritorious bulks had a sample of 200–300 spikes selected. Selected spikes were threshed individually and planted in a headrow nursery in September 2002. Headrow selections were planted as single 0.9-m rows with 30 cm between rows. Headrows were selected visually on the basis of uniformity and agronomic appearance. Headrows with shorter plants and stronger straw were selected for advancement in rainfed nurseries in a single 2.4-m long, four-row plot with 30 cm between rows at Lincoln, NE and for planting in 3-m long, two-row plots with 30 cm between rows under irrigation near Gurley, NE, which were harvested in 2003. Based on its performance in 2003 under irrigation, the line was advanced in 2004 to the Irrigated-Rainfed Nursery, which has one irrigated testing site in western Nebraska (Gurley in 2004, but the irrigated location varies over years) and three rainfed sites (Hemmingford, North Platte, and Lincoln, NE) with the idea that some irrigated wheat lines selected in western Nebraska may perform well in eastern Nebraska, which gets more rain. NI04421 was the 21st new entry in 2004, hence the experimental line designation of NI04421. Based on its performance in 2004 under both irrigated and rainfed production, NI04421 was continued in the Irrigated-Rainfed Nursery and in the intermediate rainfed nursery (grown in six environments in Nebraska in 2005). From 2006, NI04421 was grown in both the Irrigated-Rainfed Nursery and the elite rainfed nursery (six locations per year). Once the line was identified in 2004, the only selection thereafter was roguing to remove obvious off-types. NI04421 was evaluated in the USDA-ARS coordinated Southern Regional Performance Nursery (SRPN) in 2006 and 2007 and in the Nebraska State Variety Trial (NESVT) from 2006–2010. The NESVT is planted annually at 13–15 rainfed and 2 or 3 irrigated locations in Nebraska or combined with nearby locations in Wyoming. Normally 1–3 locations are lost yearly due to hail, freezes, drought, or severe disease incidence.

Lines were advanced based on winter survival (determined at Ithaca, NE), resistance to stem rust (caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks & E. Henn.) and other foliar diseases prevalent in the field, uniformity, and general agronomic appearance. Traits for the latter 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 to 10, where 1 = little to 10% lodging and 10 = 100% lodged), grain yield, and grain volume weight.

Over the winter, all of the lines were evaluated in the greenhouse in Lincoln, NE for their resistance to stem rust with race TPMK (methods described in Sidiqi et al., 2009) and at the USDA-ARS Cereal Disease Laboratory with races TPMK, QCRS, RCRS, TTTT, and RKQQ in the greenhouse and a composite of races (RCRS, QFCS, QTHJ, RKQQ, and TPMK) in the field for the advanced nursery (methods described in Rouse et al., 2011). In addition, the lines were evaluated in the greenhouse at Lincoln and at the Cereal Disease Laboratory for leaf rust (caused by *P. triticina* Eriks) (methods described in Watkins et al. 2001 and Kolmer et al. 2009), 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 with naturally occurring strains (methods described in Hunger et al., 1989).

The lines were evaluated in the greenhouse for Fusarium head blight (caused by *Fusarium graminearum* Schwabe). 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 7 d following inoculation. The severity of FHB (%) was visually estimated 14 d after inoculation. In the field, nurseries for natural infection, inoculation without irrigation, and inoculation with mist irrigation nurseries were used to evaluate the lines (methods described in Wegulo et al., 2011). The lines were also evaluated for their resistance to Hessian fly [*Mayetiola destructor* (Say)] by the USDA-ARS Center for Grain and Animal Health Research (using methods described in Chen et al., 2009). For end-use quality, the preliminary lines were evaluated with a Mixograph (National Manufacturing Co., Lincoln, NE) and for protein content (Baenziger, 2001b). The advanced lines were evaluated with composited grain samples from western Nebraska (locations other than Lincoln or Ithaca that were harvested for seed). Bread-baking properties were evaluated by approved methods (AACC, 2000). Bake mix time, water absorption, and external and internal grain and texture were recorded (AACC, 2000; Baenziger et al., 2001b; Baenziger et al., 2008).

Statistical Analyses

The elite and advanced breeding trials were analyzed with an incomplete block design (incomplete block size =

5) within blocks (block size = 60) with Agrobase GEN II (Agronomix Software, Inc. Winnipeg, Canada; Stroup et al., 1994). The Irrigated-Rainfed Nurseries were analyzed with an incomplete block design (incomplete block size = 5) within blocks (block size = 40) with Agrobase GEN II. Occasionally, advanced and elite trials with three or more replications were analyzed with the nearest neighbor procedure of Agrobase GEN II (Stroup et al., 1994). Because Nebraska has three major wheat-producing regions (Peterson, 1992) and the irrigated trials are considered environmentally different from the rainfed trials, the data were analyzed within a location within region or irrigation treatment (irrigated or rainfed) and rarely across locations and irrigation treatments for the advanced, elite, and irrigated trials. Location means and ranks were studied and lines were selected by having excellent performance within a location and irrigation treatment, across locations within a region, and all locations and 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 not continued because it might perform poorly in a producer's field. Analyses of the SRPN data used SAS (SAS Institute Inc., Cary, NC) for a randomized complete block design within locations and across locations within a year. Entries tested in the SRPN were statistically analyzed only within years due to many entries being tested for only 1 yr. For the NESVT, the trials were analyzed with SAS using a row and column correction (PROC MIXED) for each location and analyzed across years within a region. Entries varied greatly across regions, hence analysis across regions and locations was not done with SAS, but the arithmetic means of lines in common were considered. Only entries common to the trials across years within a region in the NESVT (2006 to 2009) were analyzed with randomized complete block designs.

Characteristics

Agronomic and Botanical Description

The coleoptile of NI04421 is white and the juvenile growth habit is prostrate. The foliage is green with a light waxy bloom on the leaf sheath and spike at anthesis but not on the leaves. The flag leaf is recurved and twisted at the boot stage. The leaves are generally glabrous. After heading, the canopy is moderately closed and the heads are nodding. The spike is tapering, narrow, midlong, and middense. The glume is long and narrow, and the glume shoulder is absent. The beak is moderately long in length with an acuminate tip. NI04421 is an awned, tan-glumed, semidwarf cultivar that contains the *RhtB1b* allele (formerly *Rht1*). The spike is predominantly nodding at maturity with some spikes inclined. Kernels are red, hard textured, and mainly ovate in shape. The kernel has either a very small collar or none, a midsized brush of medium length, rounded cheeks, large germ, and a narrow, shallow crease.

The coleoptile length of NI04421 (80 ± 1 mm) is similar to that of Husker Genetics brand Overland (79 ± 1 mm; 'NE01643', Baenziger et al., 2008), 'Infinity CL' (82 ± 2 mm; Baenziger et al., 2006), and Wesley (75 ± 1 mm) but shorter than that of Husker Genetics brand Settler CL (96 ± 2 mm; 'NH03614 CL', Baenziger et al., 2011), and conventional-height cultivars such as 'Goodstreak' (109 ± 1 mm; Baenziger et al., 2004) and 'Scout 66' (114 ± 1 mm; Schmidt et al., 1971).

Although considerable data is available from the breeding nurseries during line development, the majority of data presented here will be from the SRPN and NESVT (Table 1) because their complete reports are readily available (http://www.ars.usda.gov/Research/docs.htm?docid=11932 and http://varietytest.unl.edu/winterwheat.html, respectively; verified 15 Aug. 2011). In the SRPN, NI04421 (3590 kg ha^{-1} in 2006 and 3768 kg ha^{-1} in 2007) compared favorably with 'TAM 107' (Porter et al., 1987), the highest-yielding check cultivar (3315 kg ha^{-1} in 2006 and 3574 kg ha^{-1} in 2007). In other measures of performance, NI04421 (74.7 kg hL^{-1}) had a higher grain volume weight than Tam 107 (73.8 kg hL^{-1}). NI04421 matured (131 d after 1 January) later than TAM 107 (127 d after 1 January). NI04421 is a semidwarf wheat (78 cm) and is taller than TAM 107 (74 cm).

In the NESVT (Table 1), NI04421 was identified as a line with specific and local adaptation because its performance for grain yield in many regions (Peterson, 1992) was lower than more broadly adapted cultivars, such as 'Camelot' (Baenziger et al., 2009), Infinity CL, 'Millennium' (Baenziger et al., 2001a), Overland, Settler CL, and 'Wesley' (Peterson et al., 2001). Nebraska is known for having diverse ecogeographic zones, and cultivar performance is best understood by looking at regional performance within Nebraska (Peterson, 1992). NI04421 is adapted to rainfed production in western Nebraska, where its grain yield was competitive with that of the best wheat cultivars in the west central and western or panhandle regions, where Settler CL is currently the highest-yielding cultivar (Table 1). However, NI04421 differs from Settler CL in that NI04421 is not a herbicide-tolerant wheat cultivar and hence does not have the stewardship requirements of such cultivars. In comparing NI04421 with Settler CL, both lines have similar grain volume weight, grain protein content, and lodging. NI04421 is slightly taller than Settler CL (Table 1).

NI04421 is also adapted to irrigated production in western Nebraska and eastern Wyoming (Table 1). Over all irrigated locations, NI04421 (6652 kg ha^{-1}) and Bond CL (6558 kg ha^{-1}; Haley et al., 2006), a herbicide-tolerant wheat, had similar grain yields and both were superior to Wesley (6403 kg ha^{-1}), a popular irrigated cultivar in this region. NI04421 has a higher grain volume weight (77.2 kg hL^{-1}) than Bond CL and Wesley (Table 2). Compared with these cultivars, NI044221 has a similar or lower grain protein content and is similar in height or taller. NI04421and Bond CL have similar ratings for lodging and both are inferior to Wesley.

Disease and Insect Resistance

Using data predominantly from the SRPN, NI04421 is moderately resistant to stripe rust. It is moderately resistant to

Table 1. Three-year averages for characteristics for rainfed trials from 2007 to 2009 in four regions and 4-yr average for irrigated trials from 2006 to 2009 in the west region in the Nebraska State Variety Trial for the lines that were in common all years.

Cultivar	Yield	Grain volume weight	Grain protein content	Lodging	Plant height	Yield	Grain volume weight	Grain protein content	Lodging	Plant height
	kg ha^{-1}	kg hL^{-1}	g kg^{-1}	%	cm	kg ha^{-1}	kg hL^{-1}	g kg^{-1}	%	cm
	Southeast (n = 7)					South Central (n = 3)				
Camelot	3944	72.3	123	0	84.8	3091	68.7	128	4	99.1
Infinity CL	4179	74.0	121	0	84.3	3111	71.3	122	13	96.5
Millennium	4166	74.0	124	0	88.1	3628	71.7	127	5	101.6
NI04421	3467	68.3	122	0	81.0	3111	68.7	125	8	94.0
Overland	4475	74.0	125	0	81.3	3783	70.7	126	4	100.3
Scout 66	2795	73.6	125	0	94.5	2217	45.2	126	29	101.6
Settler CL	3628	73.9	118	0	77.0	3608	71.2	120	9	92.7
Wesley	3669	69.8	122	0	78.5	3716	68.0	127	5	92.7
Average all entries†	3715	72	123	0	80.9	3325	67	126	9	95.4
LSD (0.05)‡	457	3	5	NS	6	565	NS	6	NS	6
	West Central (n = 12)					West rainfed (n = 14)				
Camelot	4717	75.2	115	11	93.5	3689	77.0	113		75.9
Infinity CL	4435	77.1	112	12	92.5	3628	77.0	114		75.2
Millennium	4535	77.4	115	7	97.0	3460	77.1	113		77.5
NI04421	4461	73.9	111	12	90.2	3796	77.2	106		72.9
Overland	4656	76.7	113	8	94.2	3588	77.0	112		75.7
Scout 66	3581	77.6	116	44	106.4	3144	77.2	114		86.9
Settler CL	4650	76.1	112	9	85.9	3830	76.7	109		70.6
Wesley	4656	74.5	113	8	83.6	3447	75.9	116		67.1
Average all entries†	4453	75.7	113	12	90.1	3512	76.9	112		73.9
LSD (0.05)‡	393	0.5	4	7	3	222	1	5		3
	West irrigated (n = 8)									
Bond CL	6558	75.8	110	5	75.9					
Camelot	6161	77.5	116	4	77.7					
NI04421	6652	77.2	108	5	75.7					
NuDakota(W)	6444	76.6	115	1	68.1					
Overland	6309	77.1	113	2	78.5					
Wesley	6403	76.7	117	0	70.1					
Average all entries†	6282	77.2	114	2	73.9					
LSD (0.05)‡	396	0.6	5	NS	2					

†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 in the table.

‡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 in the table.

moderately susceptible to stem rust in field nursery tests inoculated with a composite of stem rust races (RCRS, QFCS, QTHJ, RKQQ, and TPMK). In greenhouse tests, it displayed heterogeneous reactions (e.g., some plants are resistant and others are susceptible) to races QFCS, RCRS, and RKQQ of stem rust. NI04421 is resistant to *Wheat soilborne mosaic virus* (rated as 2 in Lincoln in 2008 on a 1 [resistant] to 9 [susceptible] scale). In this test, Wesley (resistant) was rated as 1 and Millennium (susceptible) was rated as 7. In the 2007 SRPN, NI04421 was rated as 1.5 (on a scale of 1 to 4, where 1 = resistant, and 4 = susceptible), which was similar to many other resistant experimental lines in the trial and superior to the resistant cultivar 'Trego' (2.5), which had a higher score than expected. NI04421 is moderately susceptible to leaf rust (data from the 2006 and 2007 SRPN) and is susceptible to Fusarium head blight (data from greenhouse and field observations in Nebraska). NI04421 is susceptible to Hessian fly and *Wheat streak mosaic virus* (data obtained from the SRPN, 2006 and field observations in Nebraska). It is susceptible to common bunt (syn., stinking smut; caused by *Tilletia* spp.), and seed treatments are recommended.

End-Use Quality

The milling and baking properties of NI04421 were determined on grain harvested during 4 yr by the Nebraska Wheat Quality Laboratory (Table 2). In these tests, Wesley, an excellent milling and baking wheat, was used for comparison. The average grain and flour protein contents of NI04421 (146 and 118 g kg^{-1}) were similar to or less than those of Wesley (147 and 126 g kg^{-1}) for the corresponding years.

Table 2. Comparison of NI04421 to Wesley from 2004 to 2008 for characteristics as determined by the Wheat Quality Laboratory at the University of Nebraska.†

Year	Flour yield	Grain protein	Flour protein	Ash content	Mixograph mix time	Mixograph tolerance	Loaf volume	External appearance	Crumb grain	Crumb texture	Overall bake
	g kg^{-1}				min	0–7‡	cm^3	0–6§			
						NI044421					
2004	711	138	127	4.10	4.9	—	920	4.5	4.5	4.5	4.5
2006	722	157	116	4.67	4.7	5.0	818	4.3	4.3	4.8	4.6
2007	711	131	120	4.15	3.6	4.8	800	4.5	4.5	5.0	4.8
2008	737	150	119	4.23	4.6	4.5	820	4.8	4.5	5.0	4.8
Mean	723	146	118	4.35	4.4	4.8	813	4.5	4.4	4.9	4.7
						Wesley					
2004	736	151	139	—	5.3	—	1040	5.0	3.5	3.0	3.3
2006	729	167	157	4.27	5.0	5.0	903	4.5	5.0	5.0	5.0
2007	733	140	139	4.33	3.6	4.3	800	4.0	4.8	5.0	4.8
2008	760	136	111	5.33	4.0	4.8	880	5.0	5.0	6.0	5.6
Mean	741	147	126	4.64	4.2	4.7	861	4.5	4.9	5.3	5.1
LSD (0.05)¶	13	10	8	0.39	0.6	0.3	69	0.3	0.4	0.7	0.5

†Source: Baenziger et al., 2011; 2005 excluded due to limited grain; all reported values were measured at a 140 g H_2O 1000 g^{-1} flour basis.

‡0 = weak; 7 = very tolerant.

§0 = unacceptable; 6 = excellent.

¶For comparing the mean values of NI04421 and Wesley.

The slightly lower grain protein content was confirmed by the Nebraska cultivar performance trials, in which NI04421 was similar to or lower than Wesley in all regions. The average flour extraction on the Buhler Laboratory Mill (Buhler, Uzwil, Switzerland) for NI04421 (723 g kg^{-1}) was lower than for Wesley (741 g kg^{-1}), and the flour ash content (4.35 g kg^{-1}) was lower than that of Wesley (4.64 g kg^{-1}). The dough-mixing properties of NI04421 were strong, with a Mixograph mix-time peak of 4.4 min and mix-time tolerance of 4.8, which were similar to the values for Wesley, which had a mix-time peak of 4.2 min and mix-time tolerance of 4.7. The average baking absorption for NI04421 (608 g H_2O kg^{-1}) was slightly higher than that of Wesley (600 g H_2O kg^{-1}) for the corresponding years. The average loaf volume of NI04421 (813 cm^3) was lower than Wesley's (861 cm^3). The mean scores for the external appearance, internal crumb grain, and texture ranged from 4.4 to 4.9, which were good but slightly less than those of Wesley, which ranged from 4.5 to 5.3. The overall end-use quality characteristics for NI04421 are acceptable and similar to many commonly grown wheat cultivars that are well received by the milling and baking industries.

Seed Purification and Increase

Seed purification of NI04421 began in 2005 and continued through 2009 by means of visual identification and manual removal of variants, which were primarily tall, awnless, or red-chaffed off-types, in bulk seed increases grown under rainfed conditions at Lincoln and Ithaca, NE. NI04421 has been uniform and stable since 2007. Less than 1% of the plants were rogued from the breeder's seed increase in 2007. The rogued variant plants were taller (by 8–15 cm), had larger beak length, or bronze chaff. Up to 2% variant plants may be encountered in subsequent generations.

Availability

The Nebraska Foundation Seed Division, University of Nebraska-Lincoln, Lincoln, NE 68583 has had foundation seed available under the marketing name Husker Genetics brand Robidoux to qualified certified-seed enterprises since 2010. The seed classes will be Breeder, Foundation, Registered, and Certified. Registered seed will be a nonsalable class. NI04421 has been submitted for U.S. Plant Variety Protection under P. L. 10577 with the certification option. 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 5 yr 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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