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Registration of 'FourOsix' Hard Red Winter Wheat

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Abstract

'FourOsix' (Reg. no. CV-1153, PI 689753) hard red winter wheat (*Triticum aestivum* L.) was developed and released by the Montana Agricultural Experiment Station in 2018. FourOsix was derived from a composite of five single crosses of the predominant cultivar Yellowstone to advanced Montana breeding lines. FourOsix was developed using a modified bulk breeding method and selected as an $F_{5:6}$ headrow. FourOsix was tested under the experimental number MT1465 in Montana yield trials from 2014 to 2018. FourOsix is a high-yielding, winter-hardy hard red winter wheat cultivar with medium maturity, medium to high grain protein concentration, and excellent milling and baking quality. FourOsix was released for its excellent grain yield performance in winter wheat production environments of Montana, with earlier heading date, reduced plant height, improved grain volume weight, and improved stripe rust resistance relative to Yellowstone.

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'FourOsix' (Reg. no. CV-1153, PI 689753) hard red winter wheat (*Triticum aestivum* L.) was developed and released by the Montana Agricultural Experiment Station in 2018. "406" is the area code of Montana, and FourOsix was so named to denote the area of adaptation for the cultivar. FourOsix was released for its excellent combination of winter wheat production characteristics suited for Montana, including earlier maturity, reduced plant height, improved grain volume weight, and resistance to stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Erikss.; Pst) compared with the predominant cultivar Yellowstone (PI 643428, Bruckner et al., 2007).

Methods

Pedigree and Breeding History

FourOsix, tested as MT1465, was developed from a composite of five single crosses of Yellowstone to Montana breeding lines MT0684 (composite cross of five single crosses to XNH1881), MT06102 (composite cross of two single crosses to W94-137), MT06110 (SD93528/MT0409), MT06123 ('2174' [PI 602595]/MT9449//'BigSky' [PI 619166; Bruckner et al., 2003]), and 98X168-1 (MTS9720//PI 191303/'Elkhorn' [PI 596352; Anderson et al., 1998]). Each F_1 population was grown in the greenhouse at Bozeman, MT, in 2007. F_2 seed of the five single crosses was composited. Bulk populations (F_2 to F_5) were grown in consecutive years from 2008 to 2011 at Fort Ellis,

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Abbreviations: AACCI, American Association of Cereal Chemists International; IT, infection type; LY, location years; MSU, Montana State University; NRPN, Northern Regional Performance Nursery; Pst, *Puccinia striiformis* f. sp. *tritici*.

Williston, North Havre, and Bozeman, MT, with phenotypic mass selection for winter survival, reduced plant height, favorable head morphology, and kernel plumpness. In each generation, individual plants were selected and threshed in bulk; then the seed was sieved using appropriately sized screens to retain the plumpest seed fraction for replanting. One hundred and two heads were selected from the F_5 population in 2011 and grown as F_6 headrows at Fort Ellis in 2012. Headrow 06X272cE54 and 19 population cohorts were selected based on visual evaluation for uniformity, productivity, and acceptable agronomic type and were harvested in bulk.

Line Selection and Evaluation

In 2013, 06X272cE54 was tested in and selected from the Single Rep A Observation Nursery grown at Bozeman, Moccasin, and Fort Ellis, MT. Line 06X272cE54 was designated MT1465 and tested in the 2014 Montana State University (MSU) Preliminary A Yield Trial (4 location years [LY]), the 2015 MSU Advanced Yield Trial (5 LY), the MSU Intrastate Trial from 2016 to 2018 (25 LY), and the MSU Off-station Trial in 2017 and 2018 (30 LY). In 2017, MT1465 was an entry in the USDA Northern Regional Performance Nursery (NRPN) planted at approximately 20 sites across the northern Great Plains (USDA-ARS, 2017).

The Montana Intrastate Trial consisted of 49 entries arranged in a 7 × 7 partially balanced, incomplete block, triple lattice design (Cochran and Cox, 1957). Plot size, row number, and row spacing varied by location to accommodate local plot seeding equipment. Seeding rate was approximately 2.15 million kernels ha^{-1}. The Montana Off-station Trial consisted of 25 entries, arranged as a 5 × 5 partially balanced, incomplete block, triple lattice design, planted at 2.15 million kernels ha^{-1}. Grain yield, volume weight, plant height (distance from ground to top of spike excluding awns), and grain protein concentration were measured in all environments. Days to heading (50% of heads in plots completely emerged from boot) was recorded in most on-station trials. Winter survival (% plants surviving) and stripe rust (% severity) were recorded in environments where there was differential expression for these traits.

Milling and baking quality has been evaluated in multilocation Montana trials since 2014. Milling and baking characteristics were determined by the MSU Cereal Quality Laboratory using methods approved by the American Association for Cereal Chemists International (AACCI, 2000). Grain protein concentration was determined using an Infratec 1241 Grain Analyzer (Foss Analytical). Kernel hardness was determined using a single-kernel characterization system (SKCS-4100, Perten Instruments). Composite grain samples harvested from eight environments (2016 and 2017) of the Montana Intrastate Trial were milled on a Brabender Quadrumat Sr. mill (C.W. Brabender), and the flour was used to determine bake water absorption, mix time, and loaf volume (AACCI Method 10-10B). Polyphenol oxidase activity was determined using a modification of the AACCI 22-85.01 method (four kernel samples, 1 mL L-DOPA, micro-assay plate, no Tween-20, 45 min shaking). MT1465 was also assessed in the 2017 Hard Winter Wheat Quality Council evaluation (Wheat Quality Council, 2018).

Analysis of variance was conducted on data from individual environments and across environments using SAS version 9.2 (SAS Institute, 2009). Mean comparison of traits using a protected LSD ($\alpha = 0.05$) test was made to identify significant differences among genotypes. The genotype environment mean square was used to estimate the standard error of differences when comparing genotype means across environments.

Seed Purification and Increase

Purification and increase of FourOsix was initiated in 2016 when 126 F_9–derived F_{10} headrows were grown, evaluated for phenotypic uniformity, harvested individually, and bulked as breeder seed. Breeder seed of FourOsix was increased in 2017, and foundation seed was produced in 2018.

Characteristics

FourOsix is an awned, white-glumed, hard red winter wheat. In Montana, FourOsix has medium maturity, heading about 2 d later ($P < 0.05$) than 'SY Wolf' (PI 662050), at a similar date to 'Keldin' (PI 669490), 'SY Monument' (PI 672581), and 'Decade' (PI 660291, Riveland et al., 2011), and 2 to 3 d earlier than Yellowstone and 'Northern' (PI 676026, Berg et al., 2016) (Table 1). FourOsix is a semidwarf (75 cm, $n = 47$; *RhtB1b* [marker analysis, USDA-ARS, 2017]) cultivar, 2 to 6 cm shorter ($P < 0.05$) than Decade, Northern, Keldin, and Yellowstone and similar in height to SY Monument and SY Wolf (Table 1). In the 3 yr of field testing reported here, FourOsix showed reduced winter survival only in 2017 and 2018 at Sidney, averaging 47% survival over the 2 yr, compared with Decade (66%), SY Monument (54%), SY Wolf (44%), Northern (43%), and Keldin (43%; $LSD_{0.05} = 14\%$). FourOsix is well adapted to all areas of Montana, including eastern areas that require higher levels of winterhardiness.

Table 1. Mean performance of wheat cultivar FourOsix and check cultivars in 48 Montana environments, 2016–2018.

Cultivar	Grain yield	Volume weight	Heading date	Plant height	Grain protein	Stripe rust
	kg ha^{-1}	kg m^{-3}	d of year	cm	g kg^{-1}	% severity
Keldin	5113	790	158	77	121	50
SY Monument	4979	775	157	74	117	18
Northern	4865	780	161	77	126	33
Yellowstone	4811	773	160	81	122	51
FourOsix	4804	784	158	75	123	22
SY Wolf	4764	797	156	74	124	33
Decade	4381	777	158	77	127	75
$LSD_{0.05}$	235	6	1	2	2	29
No. of environments	48	48	18	47	47	2

FourOsix has been genetically uniform and stable over three generations of seed increase with few visually obvious plant variants. FourOsix contains a tall plant variant at a frequency less than 10 per 10,000 spikes and an awnless variant at a frequency less than 5 per 10,000 spikes.

Field Performance

In 48 LY of testing in the Montana Winter Wheat Intrastate and Off-station nurseries, average yield of FourOsix (4804 kg ha^{-1}) was similar to the yield of SY Monument, Northern, Yellowstone, and SY Wolf, lower ($P < 0.05$) than the yield of Keldin, and higher ($P < 0.05$) than the yield of Decade (Table 1). Volume weight of FourOsix (784 kg m^{-3} over 48 LY), was lower ($P < 0.05$) than SY Wolf, similar to Keldin, Northern, and Decade, and higher ($P < 0.05$) than SY Monument and Yellowstone (Table 1). Grain protein concentration of FourOsix was lower ($P < 0.05$) than Decade and Northern, similar to SY Wolf, Yellowstone, and Keldin, and higher ($P < 0.05$) than SY Monument.

Disease and Insect Resistance

Characterization of FourOsix for disease and insect resistance included data from Montana trials and evaluations by the Cooperative USDA-ARS Regional Testing Program. FourOsix is susceptible to wheat stem sawfly (*Cephus cinctus* Norton) and Hessian fly [*Mayetiola destructor* (Say)]. FourOsix is susceptible to prevalent races of stem rust [caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Erikss. & E. Henn.] based on seedling and field stem rust evaluations conducted by the USDA-ARS Cereal Disease Laboratory in 2015 and 2017 (USDA-ARS, 2017). FourOsix is susceptible to prevalent races of leaf rust (caused by *P. triticina* Erikss.) based on seedling evaluations of the 2017 NRPN (USDA-ARS, 2017).

FourOsix is resistant to stripe rust based on field observations in Montana (Table 1) and multiyear testing in Washington. FourOsix was tested in the Montana Intrastate Nursery for reactions to natural infections of Pst in Pullman and Mount Vernon, WA, from 2014 to 2017 and at two more locations in Walla Walla and Lind, WA in 2017 (NRPN). Infection type (IT; based on a scale of 0 to 9 where IT 0 to 3 is considered resistant, 4 to 6 intermediate, and 7 to 9 susceptible; Line and Qayoum, 1992) and severity (0–100%) were recorded for each entry. Across locations and over years, FourOsix had a highly resistant reaction (IT 2) to moderately resistant reaction (IT 5), with severity 5 to 20%. The resistance in FourOsix was either similar to or significantly higher than that of Yellowstone. In contrast, the susceptible check PS279 had a susceptible reaction (IT 8) with 80 to 100% severities in all years and locations, indicating adequate levels of stripe rust epidemics for reliable evaluations. In seedling tests at the low temperature cycle (4–20°C), FourOsix was highly resistant (IT 2) to races PSTv-14 and PSTv-51 and moderately resistant (IT 5) to races PSTv-14, PSTv-37, and PSTv-4. When tested at the high temperature cycle (10–30°C) at the adult-plant stage (Zadoks 45–60; Zadoks et al., 1974), FourOsix was highly resistant (IT 2) to races PSTv-14, PSTv-37, and PSTv-40. The reduced ITs of adult plants compared with seedlings in the tests with PSTv-14 and PSTv-37 indicate that FourOsix has a high level of high-temperature adult-plant resistance to stripe rust. In summary, FourOsix has both all-stage resistance effective against some races and high-temperature adult-plant resistance that is likely durable based on the general nature of this type of resistance.

End-Use Quality

Experimental milling using a Brabender Quadrumat Mill indicates that flour yield, flour protein concentration, and flour ash of FourOsix are relatively high compared with check cultivars (Table 2). FourOsix has strong dough mixing characteristics with high water absorption and a relatively long mixing time. Baking qualities of FourOsix are within acceptable ranges, with high loaf volume greater than that of Northern, Decade, SY Monument, Keldin, and SY Wolf (Table 2). FourOsix has relatively high polyphenol oxidase activity (Table 2), poor Asian noodle brightness (L24), and poor noodle color stability (data not shown). FourOsix carries the 2* subunit at the *Glu-A1* locus, the 7+8 subunits at the *Glu-B1* locus, and the 5+10 subunits at the *Glu-D1* locus (wheat flour protein analysis; Wheat Quality Council, 2018). FourOsix does not carry either the T1BL·1RS or T1AL·1RS translocation (marker analysis; USDA-ARS, 2017).

Availability

The Montana Agricultural Experiment Station will maintain breeder seed of FourOsix. US Plant Variety Protection for FourOsix has been sought. A research fee will be assessed on all registered and certified seed sales. All seed requests should be sent to the corresponding author during the period of protection by the Plant Variety Protection Certificate. Seed of this release is deposited in the USDA-ARS National Plant Germplasm System, where it will be available after the expiration of the Plant Variety Protection for research purposes, including development and commercialization of new cultivars.

Table 2. Average milling and baking quality attributes of FourOsix and check cultivars in 8 Montana environments, 2016–2017.

Cultivar	Polyphenol oxidase	SKCS hardness†	Flour			Bake		Loaf volume
			yield	protein	ash	mix time	absorption	
	Δ475		———	g kg^{-1}	———	min	g kg^{-1}	L
FourOsix	0.256	71	716	117	4.3	12.5	771	1.07
Northern	0.104	82	707	115	4.5	5.6	740	1.03
Decade	0.249	74	702	109	4.1	19.2	766	0.99
SY Monument	0.187	74	716	106	4.1	15.9	757	0.96
Keldin	0.328	65	700	107	4.4	9.0	739	0.96
SY Wolf	0.250	73	701	107	4.0	6.8	709	0.96
$LSD_{0.05}$	0.042	4	7	5	0.2	3.3	24	0.04

† Single kernel characterization system.

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