

Registration of 'Snowmass' Wheat

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ABSTRACT

'Snowmass' (Reg. No. CV-1050, PI 658597) hard white winter wheat (*Triticum aestivum* L.) was developed by the Colorado Agricultural Experiment Station and released in July 2009 through a marketing agreement with the Colorado Wheat Research Foundation. In addition to researchers at Colorado State University (CSU) and Kansas State University (KSU), USDA-ARS researchers at Manhattan, KS, St. Paul, MN, and Pullman, WA, participated in its development. Snowmass was selected from the cross KS96HW94//Trego/CO960293 made in 1999 at Fort Collins, CO, with the initial F₁ between Trego and CO960293 made by KSU at Hays, KS. KS96HW94 is an unreleased experimental line from KSU with the pedigree 'Arlin' (PI 564246)/KS89H20. Trego is a hard white winter wheat cultivar released by KSU in 1999. CO960293 is an unreleased experimental line from CSU from which the germplasm release CO960293-2 was selected. Snowmass was selected as an F_{6,7} line in July 2006 and assigned experimental line number CO03W054-2. Snowmass was released because of its superior grain yield under nonirrigated production conditions in eastern Colorado; its resistance to *Wheat streak mosaic virus*, stripe rust (*Puccinia striiformis* f. sp. *tritici*), and stem rust (*P. graminis* f. sp. *tritici*); and its superior milling and bread-baking quality.

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Abbreviations: CSU, Colorado State University; GI, germination index; KSU, Kansas State University; WSMV, *Wheat streak mosaic virus*.

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researchers at Colorado State University (CSU) and Kansas State University (KSU), USDA-ARS researchers at Manhattan, KS, St. Paul, MN, and Pullman, WA, participated in its development. Snowmass was selected from the cross KS96HW94//Trego/CO960293 made in 1999 at Fort Collins, CO; the initial F₁ cross between Trego and CO960293 was made by KSU at Hays, KS. KS96HW94 is an unreleased experimental line from KSU with the pedigree 'Arlin' (PI 564246)/KS89H20. Trego is a hard white winter wheat cultivar released by KSU in 1999 (PI 612576; Martin et al., 2001). CO960293 is an unreleased experimental line from CSU from which the germplasm release CO960293-2 was selected (PI 615160; Haley et al., 2002). Snowmass was selected as an F_{6,7} line in July 2006 and assigned experimental line number CO03W054-2. Snowmass was released because of its superior grain yield under nonirrigated production conditions in eastern Colorado; its resistance to wheat streak mosaic virus, stripe (caused by *Puccinia striiformis* f. sp. *tritici*) and stem rust (caused by *P. graminis* f. sp. *tritici*); and its superior milling and bread-baking quality.

Methods

Snowmass was developed using a modified bulk-breeding method. The initial F₁ cross between Trego and CO960293 was made at Hays, KS, in summer 1999. All other early generation population and line development was done in the greenhouse or an irrigated field-testing location at Fort Collins, CO. The three-way cross, designated as cross population X99420, was made in the greenhouse in fall 1999. The topcross F₁ seed was harvested in January 2000 and planted in a field nursery in mid-February 2000. The topcross F₁

plants were hand harvested in bulk in July 2000, and the F_2 seed was planted in an unreplicated bulk nursery in September 2000. In July 2001, the F_2 population was harvested in bulk with a small-plot combine. A nonselected subsample of the grain was planted in September 2001 in an unreplicated F_3 bulk nursery under sprinkler irrigation at Fort Collins, CO, and under nonirrigated conditions at Akron, CO. In July 2002, population X99420 was subject to random sampling of approximately 200 spikes at maturity. Selected spikes were threshed individually and planted in a sprinkler-irrigated headrow nursery in September 2002. Experimental line CO03W054 was selected from the headrow nursery as an $F_{3:4}$ line in July 2003.

CO03W054 was tested in unreplicated preliminary yield trials in 2004 and in replicated advanced yield trials in 2005. In July 2005, CO03W054 was subject to reselection by random sampling of 40 spikes from a plot growing at Fort Collins. These head selections were threshed individually and planted in a sprinkler-irrigated headrow nursery in fall 2005. Based on the performance of CO03W054 in the replicated CSU Elite Trial in 2006, CO03W054-2 (Snowmass) was selected in July 2006 from the headrow nursery as an $F_{6:7}$ line. In 2007 Snowmass was grown along with other CO03W054 reselections in small strip increases at Fort Collins. Based on the performance of CO03W054 in the 2007 CSU Elite Trial, Snowmass was evaluated with CO03W054 and four other CO03W054 reselections and other check entries in 2008. Based on its performance in 2008, Snowmass was advanced for further testing in 2009 in the CSU Elite Trial, statewide nonirrigated variety trials, and the Southern Regional Performance Nursery.

Seed purification of Snowmass began in the 2007 crop year using visual identification and manual removal of tall and red-chaffed off-types from a small strip increase ($F_{6:8}$) grown under irrigation at Fort Collins. A subsample of grain harvested from the increase in 2007 was used to plant a 0.03-ha breeder-seed increase ($F_{6:9}$) in 2008. This increase was rogued as in 2007 and was used to plant a 4.0-ha foundation-seed increase ($F_{6:10}$) in Yuma, AZ, and a 1.8-ha foundation-seed increase near Milliken, CO, in 2009. These increases were rogued as in previous years.

All statistical analyses were done using SAS-JMP Version 8.0.1 (SAS Institute Inc., Cary, NC). Agronomic, disease and insect resistance, and end-use quality data were analyzed with the Student's paired *t*-test. Data on yield and grain volume weight from the CSU Elite Trial and statewide variety trials were subjected to combined analyses of variance according to a mixed model with genotypes as fixed factors and location-year combinations and replications within location-year combinations as random factors. Only entries common to the trials across all location-years were included. Tukey's HSD test ($\alpha = 0.05$) was used to compare the least squares means for genotype effects.

Characteristics

Agronomic and Botanical Description

Snowmass is an awned, white-glumed, hard white winter wheat. Snowmass has medium maturity, 146.8 d to heading from Jan. 1, which is similar to 'Hatcher' (PI 638512; Haley et al., 2005) and 2.1 d later ($P < 0.05$; $n = 32$) than 'Ripper' (PI 644222; Haley et al., 2007). Snowmass is medium-tall (84.3 cm), 6.4 cm taller ($P < 0.05$; $n = 50$) than Hatcher and 6.9 cm taller ($P < 0.05$; $n = 50$) than Ripper. The coleoptile length of Snowmass (70.9 mm; $n = 4$) is similar to that of Hatcher (72.7 mm, $P > 0.05$) and shorter than that of Ripper (86.3 mm, $P < 0.05$). The straw strength of Snowmass is moderate (6.8 [$n = 10$] on a scale of 1–9, where 1 = erect, 9 = flat scale), similar to that of Hatcher (5.2, $P > 0.05$) but less than that of Ripper (2.9, $P < 0.05$) and 'Thunder CL' (PI 655528, Haley et al., 2009) (1.3, $P < 0.05$). The preharvest sprouting tolerance of Snowmass, which was assessed through determination of a germination index (GI; Mares et al., 2005) from field-grown samples, is moderate (GI = 0.31; $n = 4$). Snowmass is less tolerant than 'Danby' (PI 648010) (GI = 0.12; $P < 0.05$) and Hatcher (GI = 0.16; $P < 0.05$), similar to Ripper (GI = 0.21; $P > 0.05$) and more tolerant than Thunder CL (GI = 0.42; $P < 0.05$). No objective data are available for the winter hardiness of Snowmass, but field observations and performance under dry soil conditions during recent winters in Colorado suggest that it is at least adequate for successful production in the central Great Plains region.

Snowmass has a semierect juvenile growth habit with a green plant at the boot stage and a coleoptile that lacks anthocyanin pigment. The flag leaves of Snowmass are erect, twisted, and show a waxy bloom at the boot stage. Snowmass has middense (laxidense), inclined, and tapering heads with white awns. Glumes are white, nonpubescent, and of medium length and width with oblique, narrow shoulders and narrow, acuminate beaks. Snowmass has kernels that are ovate, white, and hard textured with a medium length noncollared brush, a rounded cheek, a narrow and shallow crease, a midsize germ, and a medium-brown phenol reaction.

Disease and Insect Resistance

Snowmass has been characterized for disease and insect resistance in Colorado and through cooperative evaluations of the USDA Regional Testing Program. Snowmass was susceptible to moderately susceptible to stem rust (races QFCS, QTHJ, MCCF, RCRS, RKQQ, TPMK, TTTT, and TTKSK) in greenhouse seedling evaluations. Snowmass displayed a moderately resistant infection response (30MR) (compared with 70S for the susceptible checks) in stem rust field nurseries at St. Paul, MN in 2008. Snowmass does not consistently express the pseudoblack chaff trait associated with *Sr2*, but it shows the presence of three microsatellite markers associated with *Sr2*, including *stm559tgag* (Hayden et al., 2004) and both *X3B028F08* and *X3B042G11* (McNeil et al., 2008). The susceptibility in greenhouse seedling evaluations, low severity in field evaluations, and the presence of *Sr2*-linked molecular markers suggest that Snowmass

carries the *Sr2* gene for adult-plant stem rust resistance. Greenhouse seedling evaluations with leaf rust (*Puccinia triticina* Eriks.) suggest that Snowmass is susceptible to most common leaf rust races in the United States (MFPS, MHDS, TNRJ, MLDS, THBJ, KFBJ, TDBG, and TMGJ). Under natural field infection with unknown leaf rust races in Castroville, TX (2008 and 2009) and Stillwater, OK (2009 only), Snowmass showed an intermediate reaction (20MS to 30S), compared with 80S for the susceptible checks, suggesting the presence of adult-plant resistance. Snowmass does not show the presence of molecular markers associated with the adult-plant resistance genes *Lr34* (*SWM10*, Bossolini et al., 2006; *csLV34*, Lagudah et al., 2006) or *Lr37* (*Ventriup-LN2*; Helguera et al., 2003). In greenhouse seedling evaluations under low temperatures, Snowmass was susceptible (infection types 8 to 9, on a scale of 0–9, where 0 = resistant, and 9 = susceptible scale) to races PST-37, PST-45, PST-100, PST-116, and PST-127 of stripe rust. In greenhouse adult-plant tests under higher temperatures, Snowmass was resistant (infection types 2 to 3) to races PST-100, PST-116, and PST-127. In field tests at three locations in Washington in 2009 (Pullman, Mt. Vernon, Walla Walla) under natural stripe rust infection, Snowmass showed a resistant reaction (infection types 2 to 3, severities ranged from 15 to 40%), whereas the susceptible checks showed infection type 8 and had 60 to 100% severities. Similar observations of seedling susceptibility and adult-plant resistance have been recorded in greenhouse tests in Manhattan, KS, and in field tests at Rossville, KS. The susceptibility of seedlings at low temperatures and the resistance of adult-plants in greenhouse and field tests at higher temperatures suggest that Snowmass has high-temperature adult-plant resistance to stripe rust.

Other evaluations in Colorado or through the USDA Regional Testing Program have shown that Snowmass is moderately susceptible to *Barley yellow dwarf virus* and *Wheat soilborne mosaic virus*, heterogeneous for resistance to a collection of endemic biotypes of the Hessian fly [*Mayetiola destructor* (Say)] (Chen et al., 2009), and susceptible to greenbug Biotype E [*Schizaphis graminum* (Rondani)]. In greenhouse seedling-screening tests in Colorado, Snowmass was susceptible to the Russian wheat aphid (*Diuraphis noxia* Kurdjumov) Biotype 1 and Biotype 2. Snowmass carries a source of temperature-sensitive near-immunity (Seifers et al., 2006) to *Wheat streak mosaic virus* (WSMV) originating from CO960293, the line from which germplasm release CO960293–2 was selected (Haley et al., 2002). Reselection CO03W054–2 (Snowmass) was made in 2007 because of heterogeneity of reaction to WSMV observed within CO03W054 at a single field location in Colorado in 2007. Independent tests at Fort Collins, CO, and Hays, KS, have both shown that approximately 80% of the plants in Snowmass exhibited a characteristic resistant reaction at 18°C and a susceptible reaction at 24°C following mechanical inoculation with the Sidney 81 isolate of WSMV. It is unknown if the plants showing susceptibility in Snowmass lack the gene conferring resistance or are showing variable expressivity.

Field Performance

Snowmass was tested at 12 nonirrigated trial locations of the CSU Elite Trial in 2009. In the combined analysis across locations, the grain yield of Snowmass (4279 kg ha⁻¹) was the second highest of the checks in the trials, similar ($P > 0.05$) to that of Ripper (4440 kg ha⁻¹) and 'Bill Brown' (PI 653260, Haley et al., 2008) (4249 kg ha⁻¹) and greater ($P < 0.05$) than that of Hatcher (3870 kg ha⁻¹) and Danby (3927 kg ha⁻¹). In these trials, Snowmass had an above-average grain volume weight (777 kg m⁻³), which was similar ($P > 0.05$) to that of Danby (785 kg m⁻³), Bill Brown (773 kg m⁻³), and Hatcher (771 kg m⁻³) and greater than that of Ripper (759 kg m⁻³; $P < 0.05$).

Snowmass was tested at 16 trial locations of the nonirrigated Colorado Uniform Variety Performance Trial during 2008 (tested as CO03W054, 6 locations) and 2009 (tested as CO03W054–2, 10 locations). In the combined analysis across location-years, the grain yield of Snowmass (3626 kg ha⁻¹) was the second highest in the trials, similar ($P > 0.05$) to that of Ripper (3640 kg ha⁻¹), Bill Brown (3534 kg ha⁻¹), Hatcher (3441 kg ha⁻¹), and Danby (3375 kg ha⁻¹). In these trials, Snowmass had above average grain volume weight (781 kg m⁻³), similar ($P > 0.05$) to that of Danby (784 kg m⁻³), Bill Brown (782 kg m⁻³), and Hatcher (777 kg m⁻³) but greater than that of Ripper (768 kg m⁻³; $P < 0.05$).

Snowmass was tested in the 2009 Southern Regional Performance Nursery. Averaged across 11 locations in the High Plains region, Snowmass was the fifth highest-yielding entry in the trial (4518 kg ha⁻¹; 46 total entries).

End-Use Quality

Milling and bread-baking characteristics of Snowmass and common check entries were determined using approved methods of the American Association of Cereal Chemists (AACC, 2000) in the CSU Wheat Quality Laboratory. Multiple location-year samples from the 2005, 2006, 2007, and 2008 growing seasons were available to enable comparison between Snowmass and Hatcher, Danby, and Thunder CL as checks. The values for milling-related variables were generally good for Snowmass compared with those of the checks, having comparable kernel characteristics and grain protein concentration (Table 1). Slightly lower flour extraction (with the Brabender Quadrumat Senior [C.W. Brabender, South Hackensack, NJ]) was observed for Snowmass (644 g kg⁻¹; $P < 0.05$) compared with that of the checks, although the observed differences were very small. The values for baking-related variables were generally superior for Snowmass compared with those of the checks, particularly Hatcher and Danby (Table 1). In Mixograph (National Manufacturing, Lincoln, NE) tests optimized for water absorption, Snowmass had a longer mixing time and better tolerance compared with those of the checks. In straight-dough pup-loaf baking tests, Snowmass had a similar bake-water absorption, a longer bake-mix time, and greater loaf volume and crumb grain score compared with those of Hatcher and Danby. The concentration of polyphenol oxidase in the grain of Snowmass was similar ($P > 0.05$) to that of the check entries (Table 1).

Table 1. Milling, dough-mixing, and bread-baking characteristics of Snowmass and check entries across multiple evaluations from the 2005, 2006, 2007, and 2008 growing seasons in Colorado.

Trait (unit of measurement)	Comparisons	Snowmass	Hatcher	Danby	Thunder CL
SKCS [†] kernel weight (mg)	53	29.3	29.7ns	27.9*	27.9*
SKCS kernel diameter (mm)	53	2.60	2.56ns	2.52*	2.55*
SKCS kernel hardness (score)	53	71.3	64.9*	71.9ns	68.0*
Flour extraction (g kg ⁻¹)	33	644	659*	657*	666*
Grain protein (g kg ⁻¹)	55	132	131ns	135*	130ns
Mixograph peak time (min)	27	7.1	4.6*	3.0*	5.3*
Mixograph tolerance [‡]	27	5.6	4.0*	1.1*	4.0*
Bake mix time (min)	31	7.0	3.9*	2.7*	4.7*
Bake water absorption (g kg ⁻¹)	31	643	640 ns	632ns	633ns
Loaf volume (L)	31	1.01	0.94*	0.87*	1.00ns
Crumb grain [‡]	31	4.5	4.0*	2.5*	4.3ns
Grain polyphenol oxidase (A 475 nm) [§]	12	0.37	0.48ns	0.49ns	0.37ns

*Significance of the difference between Snowmass and the check cultivar based on a Student's paired t-test at the 0.05 probability level; ns, not significant.

[†]SKCS, single kernel characterization system.

[‡]Mixograph tolerance and crumb grain score scales: 6 = outstanding, 0 = unacceptable.

[§]Spectrophotometric absorbance at 475 nm (L-Dopa method, AACCC approved method 22–85.01).

Availability

The Colorado Agricultural Experiment Station will maintain breeder seed of Snowmass. Multiplication and distribution rights of other classes of certified seed have been transferred from the Colorado Agricultural Experiment Station to the Colorado Wheat Research Foundation, 4026 South Timberline Rd., Fort Collins, CO 80525. Snowmass has been submitted for U.S. Plant Variety Protection (PVP) under Public Law 91–577 with the Certification Only option. Seed of Snowmass has been deposited with the National Plant Germplasm System, where it will be available for distribution on expiration of PVP. Recognized seed classes will include the foundation, registered, and certified seed classes.

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