'Duster' Wheat: A Durable, Dual-Purpose Cultivar Adapted to the Southern Great Plains of the USA

J. T. Edwards, R. M. Hunger, E. L. Smith, G. W. Horn, M.-S. Chen, L. Yan, G. Bai, R. L. Bowden, A. R. Klatt, P. Rayas-Duarte, R. D. Osburn, K. L. Giles, J. A. Kolmer, Y. Jin, D. R. Porter, B. W. Seabourn, M. B. Bayles, and B. F. Carver*

ABSTRACT

Winter wheat (*Triticum aestivum* L.) cultivars that gain commercial acceptance in the U.S. southern Great Plains must provide a definitive grain-yield advantage, season-long dependability in dual-purpose management systems, effective resistance to foliar diseases, and tolerance to soil acidity. Our objective was to corroborate each of those strengths in the hard red winter (HRW) wheat cultivar 'Duster' (Reg. No. CV-1065, PI 644016), which was released in 2006 by the Oklahoma Agricultural Experiment Station and the USDA-ARS to complement 'Endurance' (Reg. No. CV-994, PI 639233) with added dough strength and resistance to *Wheat spindle streak mosaic*. Duster was selected from a double cross, W0405/NE78488//W7469C/TX81V6187, made within the former Pioneer HRW-wheat breeding program. Neither Duster nor its immediate parents are known to have a sib-pair or parent-offspring relationship with cultivars currently grown in the Great Plains. Duster is a descendent of an $F_{2:3}$ line identified in Oklahoma in 1991, from which pedigree selection produced two F_{13}-derived lines that were composited to constitute breeder seed. The experimental line OK93P656H3299-2C04 was tested in the 2005 and 2006 Southern Regional Performance Nursery, where it ranked first and fifth, respectively, for mean grain yield. Data from the Oklahoma Small Grains Variety Performance Tests were primarily used herein to demonstrate competitiveness for economic traits in a wide array of environmental conditions 5 yr following Duster's release.

J.T. Edwards, E.L. Smith, L. Yan, A.R. Klatt, D.R. Porter, M.B. Bayles, and B.F. Carver, Dep. of Plant and Soil Sciences, Oklahoma State Univ., Stillwater, OK 74078; R.M. Hunger and K.L. Giles, Dep. of Entomology and Plant Pathology, Oklahoma State Univ., Stillwater, OK 74078; G.W. Horn, Dep. of Animal Science, Oklahoma State Univ., Stillwater, OK 74078; M.-S. Chen, G. Bai, and R.L. Bowden, USDA-ARS, Hard Winter Wheat Genetics Research Unit, Kansas State Univ., 4008 Throckmorton Hall, Manhattan, KS 66506; P. Rayas-Duarte, Dep. of Biochemistry and Molecular Biology, Food and Agricultural Products Center, Oklahoma State Univ., Stillwater, OK 74078; R.D. Osburn, Oklahoma Crop Improvement Assoc., 2902 West 6th Ave., Stillwater, OK 74074; J.A. Kolmer and Y. Jin, USDA-ARS, Cereal Disease Lab., 1551 Lindig St., Univ. Minnesota, St. Paul, MN 55108; B.W. Seabourn, USDA-ARS, Center for Grain and Animal Health Research, 1515 College Ave., Manhattan, KS 66502. Registration by CSSA. Received 6 April 2011. *Corresponding author (brett.carver@okstate.edu).

Abbreviations: BYDV, *Barley yellow dwarf virus*; ELISA, enzyme-linked immunosorbent assay; FHS, first hollow stem; GS, glutenin subunits; HMW, High molecular weight; HRW, hard red winter; KAES, Kansas Agricultural Experiment Station; LMW, low molecular weight; OAES, Oklahoma Agricultural Experiment Station; OET, Oklahoma Elite Trial; OSGVPT, Oklahoma Small Grains Variety Performance Tests; OSU, Oklahoma State University; SBWMV, *Soilborne wheat mosaic virus*; SRPN, Southern Regional Performance Nursery; WSBM, wheat soilborne mosiac; WSSM, wheat spindle streak mosaic; WSSMV, *Wheat spindle streak mosaic virus*.

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Winter wheat (*Triticum aestivum* L.) production in the southern Great Plains is dominated by dual-purpose management schemes that provide a winter forage source for stocker cattle (*Bos taurus* L.) and grain production from the same crop. Relative emphasis on forage versus grain is highly impacted by a producer's personal preference, but factors intrinsic to a given crop season are also influential, such as forage availability before cattle turnout and the relative pricing of wheat versus beef. Wheat producers in the southern plains do not discriminate heavily among cultivars for dual-purpose capability, and most hard winter wheat breeding programs do not include dual-purpose adaptation as a selection criterion.

A breeding-oriented emphasis is justified, however, by the 40% lower rate of genetic gain observed for yield potential under dual-purpose (0.9% yr^{-1}) versus grain-only (1.3% yr^{-1}) production systems (Khalil et al., 2002). The yield difference between grain-only and dual-purpose systems (Winter and Thompson, 1990; Carver et al., 2001) can be attributed largely to the 4-wk earlier planting date essential to forage-biomass accumulation (Edwards et al., 2011). Hence producers who choose a cultivar for dual-purpose production may prioritize early stand establishment with rapid canopy closure.

The dual-purpose system provides an integral selection environment for the development and evaluation of experimental breeding lines (Thapa et al., 2010). Lines that reach candidate status are expected to excel in a grain-only system as well as they do in a dual-purpose system. The hard red winter (HRW) wheat cultivar 'Duster' (Reg. No. CV-1065, PI 644016) has been used as a dual-purpose standard for comparison in the Oklahoma State University (OSU) wheat improvement program since its release in 2006, because it demonstrates the essential qualities of (i) rapid stand establishment indirectly measurable as fall forage biomass accumulation, (ii) nonprecocious winter dormancy release measured as the date of the first hollow stem (FHS; Edwards and Horn, 2010), and (iii) excellent recovery from grazing measured as grain yield across multiple dual-purpose environments. Our objective was to corroborate each of these characteristics and to demonstrate desirable agronomic traits (acid-soil tolerance, foliar disease resistance) for added durability in the southern Great Plains with marketable end-use quality.

Duster was developed cooperatively by the Oklahoma Agricultural Experiment Station (OAES) and the USDA-ARS with the experimental designation OK93P656H3299-2C04 and released by the developing institutions in 2006. The cultivar is licensed exclusively to Oklahoma Genetics, Inc. (Stillwater, OK), a producer-operated organization that manages the distribution of Registered and Certified seed classes. The name Duster derives from field observations of rapid emergence under the conditions of marginal soil moisture that are often encountered with early planting.

Methods

Parentage, Breeding History, and Line Selection

Duster represents the culmination of 19 yr of breeding and line selection for agronomic fitness balanced with desirable end-use quality, and for phenotypic uniformity. Duster originated from the double cross W0405/NE78488//W7469C/TX81V6187 (B. Laskar, personal communication, 2006), which was produced in the former HRW-wheat breeding program of Pioneer Hi-Bred International (hereafter, Pioneer). No parent in this double cross led to a released cultivar, but a minimum of 50% of the parentages of W0405, NE78488, and W7469C can be attributed to a 'Newton' (CItr 17715; Heyne and Niblett, 1978) sister line, to 'Centurk' (CItr 15075; Schmidt et al., 1973), and to 'Scott City 3213', respectively. TX81V6187 was a parent of 'Ogallala' (PVP 9300292). Advancement of the F_1 and F_2 generations occurred within the Pioneer program and is not precisely known. The F_2 population was named by Pioneer as 89VN F2 617 16, so the double cross was presumed to be made in 1987.

Approximately 30,000 $F_{2:3}$ headrows were donated by Pioneer in 1990 and evaluated within the OSU wheat improvement program in 1991. The headrow population to which Duster traces back was labeled by Pioneer as VBJ0503. Two lines were selected from VBJ0503 for evaluation in a two-location, single-replicate observation nursery during the 1991–1992 season as $F_{2:4}$ lines. Only one was chosen for testing in subsequent generations and was eventually named OK93P656. This observation nursery was primarily intended to monitor foliar diseases, maturity, spike size, phenotypic uniformity, grain volume weight, kernel size, and wheat protein concentration and hardness.

OK93P656 was evaluated in replicated yield trials within the OSU wheat improvement program for three consecutive years (1993–1995; data not presented), with an increasing number of locations (three to six) per year and replicates per location (two or three) across years. These breeder trials were conducted as RCB experiments with no more than 30 entries per block. In parallel with the 1995 tests, OK93P656 was evaluated in a spaced-planted observation nursery at Stillwater, OK to identify plants with resistance to *Soilborne wheat mosaic virus* (SBWMV) and with adult-plant resistance to leaf rust (caused by *Puccinia triticina* Eriks.). Both disease reactions were determined under field conditions with natural infection. Five F_7 plants were harvested in 1995 and advanced for further observation as plant rows in 1996 at Stillwater, from which one $F_{7:8}$ line was identified with the desired level of SBWMV resistance. In 1997 and 1998, the $F_{7:9}$ and $F_{7:10}$ progeny lines, respectively, were evaluated in nonreplicated observation nurseries, from which consistent and uniform reactions were noted for wheat soilborne mosaic (WSBM) disease and leaf rust. Each year the line was advanced in bulk without further selection within the line.

The resulting $F_{7:11}$ line was named OK93P656-RMH3299 and placed in replicated yield trials at three locations in 1999 alongside reselections with other pedigrees featuring enhanced disease resistance. More extensive statewide testing was conducted in the two following years, 2000 and 2001. OK93P656-RMH3299 was also evaluated in the 2001 USDA-ARS Regional Germplasm Observation Nursery and the 2001 USDA-ARS Southern Regional Performance Nursery (SRPN), in which it performed relatively poorly and ranked 32nd among 45 entries across the Great Plains in grain yield (http://www.ars.usda.gov/sp2UserFiles/ad_hoc/54402000HardWinterWheatRegionalNurseryProgram/2001srpn.pdf; verified 27 Feb. 2011). Previous plant selections in 1996 should have been sufficient to generate the desired within-line uniformity for possible release, but since OK93P656-RMH3299 was closely monitored in 2001, only then was segregation noted for plant height and general appearance, including potential yield. The decision was made in 2001 to select within this line for improved uniformity of plant height and to identify selections with improved lodging resistance, yield performance, and kernel size. Its field resistances to WSBM and leaf rust and tolerance to acid soils were considered highly favorable attributes that justified this additional selection event.

Random heads were sampled from a breeder-seed increase plot in 2001 to generate a series of 288 headrows as $F_{13:14}$ lines in 2002. From this headrow population, which was grown at Stillwater, 26 lines were selected based on desirable height and larger kernel size. Each line was harvested in bulk and evaluated in a nonreplicated observation yield nursery at Stillwater and Lahoma, OK in 2003. Other traits monitored included plant height, heading date, straw strength, grain volume weight, and kernel size. Two lines (OK93P656H3299-84 and OK93P656H3299-99) were selected and advanced to the statewide Oklahoma Elite Trial (OET) nursery in 2004 and composited in equal proportions only for field testing. The two lines were reevaluated in the OET nursery in 2005, but as separate lines.

The replicated yield trials in 2005 confirmed that OK93P656H3299-84 and OK93P656H3299-99 were indistinguishable on the basis of plant type, plant height, grain yield performance, and grain volume weight; hence, all subsequent testing beginning in 2006 was based on the composite formed from equal proportions of seed by weight and given the experimental designation OK93P656H3299-2C04. The same composite line was entered in the 2005 SRPN, where it placed first out of 48 entries during a severe outbreak of stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Eriks.) (dominant race, PST-100) throughout the Great Plains (http://www.ars.usda.gov/SP2UserFiles/ad_hoc/54402000HardWinterWheatRegionalNurseryProgram/05SRPN.xls; verified 27 Feb. 2011), and in the 2006 SRPN, where it placed fifth out of 50 entries (http://www.ars.usda.gov/SP2UserFiles/ad_hoc/54402000HardWinterWheatRegionalNurseryProgram/06SRPN.xls; verified 27 Feb. 2011).

Seed Purification and Increase

In the 2003 observation nursery at Stillwater, each component $F_{13:15}$ line was harvested manually with a walk-behind binding reaper to prevent admixtures; only the three middle rows of a five-row plot (1.3 m wide) that had been end-trimmed to 3.1 m long were removed. This process of breeder-seed increase continued in 2004 at Stillwater (plot size of 1.3 m by 76 m) and in 2005 at Goodwell, OK (plot size of 3.8 m by 154 m) with supplemental irrigation for each component line separately, but with the use of a combine in 2005, preceded by cleanout between lines. The final increase in 2005 produced approximately 320 kg breeder seed per component line. No phenotypically distinguishable variants were observed in either line.

This seed source was used to plant a 2.8-ha foundation-seed increase of each line ($F_{13:18}$) near Ponca City, OK in 2006. Duster, formed by the combination of seed from OK93P656H3299-84 and OK93P656H3299-99, has been uniform and stable since 2006. The second year of foundation-seed increase in 2007 and the first year of registered-seed production were severely compromised by excessive rainfall at harvest, thus delaying its commercial availability by 1 yr.

Final Evaluation in Replicated Yield Tests

Duster was evaluated in the statewide OET in 2006 during the last year of its experimental status and as a check cultivar in the OET from 2007 to 2010. These tests were conducted as a RCBD with three replicates per site and no more than 35 entries per replicate. Small-plot experimental protocols were generally followed for either grain-only or dual-purpose experiments, as described fully for both management systems by Thapa et al. (2010), and without the use of starter fertilizer, seed treatment, or foliar fungicide. The plot area was fertilized before planting according to soil-test recommendations for a yield goal of approximately 3000–6700 kg ha^{-1}, depending on the grain-yield history of a particular site and adjusted for residual N in a 0–46-cm soil test. Plots were harvested with a Hege 125C plot combine (Hege Maschinen, Niederlassung, Germany) when the grain moisture content of the latest-maturing plots did not exceed approximately 120 g kg^{-1}.

Included in the OET were naturally low-pH field sites near Enid, OK (soil-water pH 4.3–4.7, 65–75 mg kg^{-1} KCl-extractable Al concentration, >10% Al saturation) from 2008 to 2010 and near Braman, OK in 2009 (soil-water pH 4.7). The Uniform Wheat Variety Trials coordinated by Texas AgriLife Research also were included at the Enid site in 2009 and 2010. Protocols used in those replicated yield trials were identical to those described for the OET, except that a visual rating was collected from each replicate plot to score acid-soil tolerance on a scale of 0 (no apparent symptoms caused by low pH) to 5 (highly susceptible response). Two ratings are presented here in juvenile plant stages (Feekes 3.0) and during ripening stages (Feekes 11.1–11.4). The 2009 OET was not replicated at the Enid site. Grain yield was measured in 2009 at Braman and in 2010 at Enid as described above.

Duster was also evaluated in the OSU-directed Oklahoma Small Grains Variety Performance Tests (OSGVPT) before and after its release (2006–2010). Most of the agronomic data presented here, including reaction to *Barley yellow dwarf virus* (BYDV), was taken from these trials, for which the complete reports are available at http://wheat.okstate.edu/varietytesting/index.htm (verified 28 Feb. 2011). Each year featured a representative sample of conventional-till and no-till tests, dual-purpose and grain-only tests, and two tests with a single application of a foliar fungicide between Feekes growth stages 9 and 10. All tests were conducted as an RCBD with four replicates. Decisions regarding grazing pressure, fertilization practices, and insect and weed control reflected standard management practices for a given area of the state. All plots received in-furrow fertilizer (9-23-0) applied as $(NH_4)_2HPO_4$ at planting. Conventional-till plots contained eight rows spaced 15 cm apart, and no-till plots had seven rows spaced 19 cm apart. Wheel tracks between plots were included in the plot area for grain-yield calculations, resulting in a plot width of 1.5 m. Plot length was 6.7 m, and plots were trimmed to 5.2 m with the combine before harvest. Plots were harvested with a small-plot combine (Wintersteiger, Salt Lake City, UT) when the grain moisture content of all cultivars was less than 120 g kg^{-1}. Plots were sown at 67 kg ha^{-1} for grain-only tests and 134 kg ha^{-1} for dual-purpose tests.

A separate set of tests was established within the OSGVPT for the specific purpose of estimating fall forage production at Stillwater and El Reno, OK during harvest years 2006–2010. Weather conditions prevented the reporting of forage data from both locations in all years. An RCBD was used at each conventional-till site, with four replicates per site. All plots comprised eight rows spaced 15 cm apart and sown at 135 kg ha^{-1} in mid-September each year. Plots at the El Reno site were 6.7 m long, and plots at the Stillwater site were 3.4 m long. All plots received in-furrow fertilizer (9-23-0) applied as $(NH_4)_2HPO_4$ at seeding. Forage yield was estimated in mid-December each year by clipping two 0.5-m by two-row samples at random locations within each plot. Samples were dried for approximately 10 d at 50°C and then weighed. Site-specific information on fertility, planting dates, and harvest dates, along with the complete reports from which forage yield data are presented here, is available at http://www.wheat.okstate.edu/varietytesting/forageyield/index.htm (verified 28 Feb. 2011).

Evaluation of Agronomic, Disease, and Insect Characteristics

As part of the OSGVPT, nonreplicated plots of all wheat cultivars tested within a given year were sown at Stillwater in early September to record data on phenology, physiology, and disease incidence and severity. Plot dimensions, seeding density, and fertility management were identical to that described above for the dual-purpose variety performance tests. Plots were not mowed or grazed and were checked for occurrence of FHS with a procedure similar to that described by Edwards and Horn (2010) approximately every 3 d beginning in mid-February and continuing until all cultivars had reached the FHS stage of growth. Approximately 15–20 plants were removed from interior rows at a random location within each plot. A subsample of 10 plants composed an experimental unit, and the largest tiller of each plant was split longitudinally to record the length of hollow stem present at the base. Cultivars were considered at the FHS stage of growth when the average length of hollow stem present in the subsample $\geq$1.5 cm.

Heading dates were collected from one to two replicates per site in the OET or nonreplicated observation nurseries at Goodwell (supplemental irrigation and rainfed), Lahoma, and Stillwater. Heading date was determined as the day of year by which 50% of the spikes in a plot had emerged completely from the boot. Plant height was measured as the distance from ground level to the spike tip, excluding awns, and recorded in single-replicate plots from 11 (2009) and 9 (2010) environments of the variety performance tests. Lodging ratings were collected in breeding nurseries in environments subject to moderate or severe lodging of susceptible types on a scale of 1 (erect) to 5 (flat).

Duster and several check cultivars were evaluated for the presence of SBWMV and *Wheat spindle streak mosaic virus* (WSSMV) for multiple years in the OET. Nonreplicated and replicated observation nurseries were grown in the field near Stillwater, where symptoms of WSBM and wheat spindle streak mosaic (WSSM) disease were consistently observed during Feekes stages 5.0 to 7.0. Planting location and procedures, rating system, and tissue collection and analysis using the enzyme-linked immunosorbent assay (ELISA) were generally followed as previously reported (Hunger et al., 1991). Testing of samples for presence of SBWMV was conducted via an indirect sandwich ELISA with polyclonal antibody as a capture antibody and monoclonal antibody as a probe antibody (Bahrani et al., 1988). ELISA testing of samples for the presence of WSSMV was conducted with a double antibody sandwich ELISA kit (Agdia, Elkhart, IN) according to the manufacturer's instructions (https://orders.agdia.com/InventoryD.asp?loc=IN&collection=SRA%2043001&attribute_Size=1000; verified 28 Mar. 2011). Interpretation of ELISA data relied on the determination of positive and negative ELISA values by comparing values from tested material with values obtained from (i) resistant and susceptible wheat cultivars and (ii) positive (known SBWMV-infected foliage) and negative (buffer) controls. Guidelines discussed by Sutula et al. (1986) were followed.

Stripe rust reactions were evaluated one time in each of 2 yr in the field near Rossville, KS—on 23 May 2009 and on 22–24 May 2010 (Feekes stage 10.5.4)—with race PST-100 for supplemental inoculation. Entries were planted in short rows 1.5 m in length spaced 30 cm apart. Every third drill pass (1.5 m wide) was planted to the highly susceptible experimental line KS89180B to serve as a disease spreader. Inoculated plants of a highly susceptible cultivar were transplanted within the spreader rows of KS89180B in mid-April, followed by mechanical inoculation of KS89180B plants with an oil suspension of urediniospores applied weekly via an ultralow volume sprayer during Feekes stages 5.0–10.0. Symptoms of stripe rust were recorded as infection type based on a 1–9 scale (Line and Qayoum, 1991), whereas disease severity was scored as a percentage of the flag leaves infected. Replicated data were obtained by multiple inclusions of Duster and selected check cultivars in seven to eight OSU entry sets per year.

Reactions to leaf rust and to powdery mildew [caused by *Blumeria graminis* (DC) E.O. Speer f. sp. *tritici*] were reported from OET nurseries (2005–2010) in north central Oklahoma, which were dependent on natural infection, or from greenhouse seedling tests described by Martin et al. (2003) for leaf rust and by Chen et al. (2009c) for powdery mildew. All other disease evaluations were performed at the USDA-ARS Cereal Disease Laboratory (St. Paul, MN) and the USDA-ARS Center for Grain and Animal Health Research (Manhattan, KS).

Duster and selected check cultivars were evaluated in the greenhouse for reaction to Hessian fly (*Mayetiola destructor* Say) by the USDA-ARS Center for Grain and Animal Health Research. The Hessian fly population was derived from field collections in Scott County, KS and contained primarily biotype GP, with a small portion virulent to cultivars containing various resistance genes (Chen et al., 2009a). Reactions to other insects were performed by the USDA-ARS Wheat, Peanut and Other Field Crops Research Unit (Stillwater, OK).

Evaluation of End-Use Quality

Grain samples were collected from a single replicate of OET experiments deemed to produce sound grain with no detectable preharvest moisture damage or postharvest insect damage. Using approved methods of the American Association of Cereal Chemists (AACC, 2000), evaluations were conducted at the OSU Wheat Quality Laboratory for measuring wheat protein and kernel hardness by near-infrared reflectance spectroscopy, milling quality by means of the Perten single kernel characterization system 4100 (Perten Instruments, Segeltorp, Sweden), and flour yield by the Brabender Quadrumat Senior mill (C.W. Brabender, South Hackensack, NJ). Physical dough tests were conducted with a computer-assisted mixograph using a 10-g bowl (method 54-40.02, AACC, 2000). Mixing tolerance was rated subjectively on a scale of 0 (very poor tolerance) to 6 (exceptional tolerance). Mixing tolerance was also determined as bandwidth of the mixogram at 2 min past peak development and as a stability value calculated from slopes of the rising and descending portions of the curve.

Potential loaf volume was measured by the sodium dodecyl sulfate sedimentation test (Lorenzo and Kronstad, 1987) on two 4.3-g flour subsamples per experimental unit and reported as specific sedimentation volume, that is, as the ratio of actual sedimentation volume to actual protein percentage in the flour. Baked straight-dough loaf volume was measured from grain samples composited across locations within a year using 100-g pup loaves according to approved methods (AACC, 2000). Two bakes were conducted per sample, but only the final bake was reported, following water optimization on the first sample.

High-molecular-weight (HMW) and low-molecular-weight (LMW) glutenin subunits (GS) were differentiated using sodium dodecyl sulfate polyacrylamide gel electrophoresis and 18% acrylamide resolving gels according to Singh et al., 1991. The LMW-GS were further identified according to Branlard et al., 2003 and Shan et al., 2007 with 'Jagger' (PI 593688; Sears et al., 1997), 'TAM 111' (PI 631352; Lazar et al., 2004), 'Endurance' (PI 639233; Carver et al., 2006b), and 'Chinese Spring' (CItr 14108) as standards.

Statistical Analyses

Using a mixed model the ANOVA for grain yield, forage biomass, and grain-volume weight data from the variety performance tests was conducted within years or pooled across years, and management systems if appropriate, for only the reported cultivars. All effects were considered random except for cultivars and systems. All mixed-model analyses were conducted using the MIXED procedure of SAS version 9.2 (SAS Institute, Cary, NC), and least squares cultivar means were computed therein. The LSD values were calculated from standard error estimates generated from pairwise comparisons in the MIXED output. The CV was derived from an ANOVA using a general linear model in SAS. Grain-yield data from single low-pH environments were subjected to a simple ANOVA of all entries in a given trial. Agronomic, disease, and quality data were analyzed according to a two-tailed, two-sample *t* test with equal sample size and equal variance if appropriate or with unequal sample size and equal variance. All tests of significance were conducted at the nominal 0.05 level unless otherwise indicated.

Characteristics

Duster exhibits an erect to semierect vegetative growth habit that is consistent across a typical range of plant densities and across vegetative growth stages and is similar to that of the cultivar 'Jagalene' (PVP 200200160) but with a finer canopy texture. Duster is more erect than Endurance (semiprostrate) but is similar in canopy texture. Duster's coleoptile lacks anthocyanin pigment, and its length is intermediate to moderately short (Edwards, 2008). Flag leaves of Duster at the boot stage are green, recurved, and twisted and have a waxy bloom. Spikes of Duster are oblong and middense with white awns and are inclined at harvest maturity. The glumes are white, nonpubescent, and long and narrow, with oblique shoulders of medium width and acuminate beaks of medium width. Its kernels are red, hard textured, and elliptical, with a narrow, shallow crease, rounded cheeks, and a large germ. The brush is collared and medium in length. Duster kernels exhibit visual characteristics conforming to the HRW Wheat market class, being of a 'Sturdy' (CItr 13684; Atkins et al., 1967) type (M. Eustrom, USDA-GIPSA, personal communication, 2006).

Results

Comparisons of Grain Yield and Forage Biomass

Regionwide assessment of the grain-yield performance of Duster was accomplished in the 2005 and 2006 SRPN, which comprised 34 (2005) and 30 sites (2006) throughout the Great Plains, including sites in Missouri, Iowa, Illinois, and Indiana. It was the highest-ranking entry (4100 kg ha^{-1}) among 48 entries in the 2005 nursery; it was similar to 'OK Bullet' (PI 642415; Carver et al., 2006a) at 3910 kg ha^{-1} but significantly greater than that of 'Fannin' (PVP 200500220) at 3760 kg ha^{-1}. In the 2006 nursery, it was the fifth-highest-ranking entry (3490 kg ha^{-1}) among 50 entries and was significantly greater than either 'Fuller' (PVP 200800130; 3350 kg ha^{-1}) or 'PostRock' (PVP 200600239; 3360 kg ha^{-1}).

The OSGVPT included Duster either as a candidate cultivar or as a released cultivar since 2006. The 5-yr mean grain yield of Duster significantly exceeded that of the cultivars it was intended to replace or complement (Table 1). Duster's 5-yr mean grain yield exceeded those of Jagger by 20% and Endurance by 5%. Severe and extended drought stress diminished the differences between the cultivars in 2006. Duster did not exceed Endurance in those years in which grain yield was highly influenced by early spring freezes (2007 and 2009). Duster's superiority to 'Overley' (PVP 200400205) did not become evident until 2008, when

Table 1. Statewide grain-yield performance of Duster and four hard red winter wheat check cultivars in the Oklahoma Small Grains Variety Performance Tests, 2006–10.

Cultivar	2006	2007	2008	2009	2010	2006–10
	kg ha^{-1}					
Duster	2360	2990	4250	2590	3320	3130
Endurance	2210	3000	3940	2670	2980	2990
Overley	2390	3070	3360	1990	2730	2700
Jagalene	2450	2400	3420	2270	2350	2590
Jagger	2450	2420	3560	2000	2550	2600
LSD (0.05)	100	100	100	80	90	40
CV%	10.9	10.4	8.9	11.1	9.9	10.1
No. of observations†	300	340	415	460	415	1930
Notable yield-limiting factors	severe drought stress	spring freeze, leaf rust	leaf rust	spring freeze, leaf rust	stripe rust	

†Summed number of cultivars (as listed), trials, and replicates per cultivar-trial.

Table 2. Least-squares means for grain yield of Duster and four hard red winter wheat check cultivars in paired dual purpose (DP) and grain only (GO) experiments in the Oklahoma Small Grains Variety Performance Tests, 2006–10.

	2006		2007		2008		2009		2010		2006–10	
Cultivar	DP	GO	DP	GO	DP	GO	DP	GO	DP	GO	DP	GO
	kg ha^{-1}											
Duster	1800	2400	1330	1910	5390	5470	1670	2360	3860	3050	2810	3040
Endurance	1600	2260	1310	1790	4810	4920	1830	2200	3310	2660	2570	2760
Jagalene	1540	2420	700	1340	4070	3860	1060	1260	2030	1510	1880	2080
Overley	1510	2210	1130	2060	3650	3660	1030	1010	2490	2170	1960	2220
Jagger	1550	2360	630	1410	4520	3940	950	920	2630	1770	2060	2080
LSD within systems (0.05)	NS		180		680		490		460		300	
LSD across systems (0.05)	NS		470		NS		NS		460		290	
CV%	13.7		15.8		18.9		42.3		12.8		24.3	
No. of observations†	35		120		115		120		40		430	

†Summed number of cultivars (as listed), trials, and replicates per cultivar-trial.

genes for leaf rust resistance in Overley (notably *Lr39*; Sun et al., 2009) no longer provided effective resistance.

Considering only those locations that featured contiguous dual-purpose and grain-only experiments, Duster's grain yield exceeded that of Jagalene and Jagger in both management systems in all years but 2006, and it exceeded that of Overley in all years but 2006 and 2007 (Table 2). Averaged across the 5-yr period (2006–2010), Duster's yields in the dual-purpose system were 36% greater than that of Jagger, 43% greater than that of Overley, and 49% greater than that of Jagalene. Similar differentials were found in the grain-only systems. In contrast, no significant yield differential was detected between Duster and Endurance in most years reported (Table 2).

Duster's grain-yield advantage in dual-purpose environments was coupled with superior forage biomass accumulation, exceeding the same four check cultivars compared for grain yield by 12–24% (Table 3). Genetic differences in forage biomass are typically difficult to discern among winter wheat cultivars. The range in biomass means for Endurance, Jagalene, and Overley was only 120 kg ha^{-1} averaged across the 5-yr reporting period, yet the forage biomass of Duster was 360 kg ha^{-1} greater than the mean of those three cultivars. One attribute favorable to fall forage biomass after early sowing is the low expression of high-temperature germination sensitivity found in Duster, which is similar to that of Jagger (Edwards, 2008).

Key Agronomic Traits

A desired adaptation component for southern and central Great Plains wheat production, with or without the integrated feature of cattle grazing, is the timely (and consistent) transition from vegetative to reproductive development. The FHS stage was employed as an indicator of this transition, because its onset quantitatively demarcates the growth stage (Feekes stage 5) for removing cattle from wheat pasture to optimize the profitability of the dual-purpose system. Duster reached the FHS stage 10 d later than either Jagger ($P < 0.01$) or Overley ($P < 0.05$) or did so within the interval delimited by Jagalene and Endurance (Table 4). As expected, Duster reached heading proportionately later than Overley, but about the same time as Endurance, in the 2 yr (2007, 2008) for which comparisons were available in statewide breeding nurseries. Mean heading dates ($n = 11$) were 118 ± 2 d (Overley), 122 ± 2 d (Duster), and 121 ± 2 d (Endurance) from 1 January. Other regionwide comparisons were extracted from the 2005 and 2006 SRPN (http://www.ars.usda.gov/Research/docs.htm?docid=11932; verified 23 Sept. 2011). In 2005 ($n = 12$), Duster headed 140 ± 2 d from 1 January, which was similar to OK Bullet (139 ± 3 d), Fannin (138 ± 3 d), and 'TAM 107' (PI 495594;

Table 3. Least-squares means for fall forage biomass of Duster and four hard red winter wheat check cultivars measured at two Oklahoma locations in 4 yr.

Cultivar	2006	2007	2008	2009	2006–9
	kg ha^{-1}				
Duster	3240	2840	4060	2530	3040
Endurance	3040	2590	3310	2210	2720
Jagalene	3100	2980	3560	2240	2600
Jagger	2820	1820	3660	2080	2440
Overley	2910	2210	3790	2480	2710
LSD (0.05)	270	350	580	400	190
CV%	9.0	15.4	11.1	17.1	13.1
No. of observations†	40	40	20	40	140

†Four replications per trial × two trials per year × five cultivars, except for only one trial in 2008.

Table 4. Occurrence of the first hollow stem stage for Duster and four hard red winter wheat check cultivars at Stillwater, OK from 2007 to 2010.

					2007–10		
Cultivar	2007	2008	2009	2010	Mean	SD	Range
	d after 31 December					d	
Duster	64	78	66	76	71	7.0	14
Endurance	74	80	67	76	74 NS	5.4	13
Jagalene	57	78	63	66	66 NS	8.8	21
Overley	57	64	61	62	61*	2.9	7
Jagger	57	66	58	62	61**	4.1	9

*Significant at the 0.05 probability level for the difference between Duster and the particular check cultivar.

**Significant at the 0.01 probability level for the difference between Duster and the particular check cultivar.

Porter et al., 1987; 137 ± 3 d). In 2006 (n = 16), Duster headed 125 ± 4 d from 1 January, similar to PostRock (124 ± 4 d) and Fuller (123 ± 4 d) but 4 d later than TAM 107 (121 ± 4 d). Hence Duster is described as reaching FHS relatively late and having an intermediate heading date.

This developmental pattern is consistent with allele identities at three loci of the known flowering genes in winter wheat: *VRN-A1* on chromosome 5A, *PPD-D1* on chromosome 2D, and *VRN-D3* on chromosome 7D. The combination of certain alleles at these loci and the duration of their effects have been used to describe developmental-phase variation in winter wheat (Chen et al., 2009b, 2010). Given the *a* allele confers accelerated development at *VRN-A1* and *VRN-D3* but delayed development at *PPD-D1*, both Jagger and Overley have alleles *VRN-A1a*, *PPD-D1a*, and *VRN-D3a*. Duster and Endurance have alleles *VRN-A1b*, *PPD-D1b*, and *VRN-D3b*, whereas Jagalene has alleles *VRN-A1b*, *PPD-D1b*, and *VRN-D3a*.

Table 5. Response to low soil pH (<4.7) at two north central Oklahoma locations from multiple evaluations of Duster and selected hard red winter wheat check cultivars in the Oklahoma Elite Trial (OET) and Texas Uniform Variety Trial (UVT) in harvest years 2008–10.

				Grain yield†		
	Visual score 2008–10			Braman, OK	Enid, OK 2010	
Entry	Comparisons	Juvenile	Adult	2009	OET	UVT
	no.	0–5‡		kg ha^{-1}		
Duster	—	1.1	0.3	4420	3750	3420
Endurance	17	1.1 NS	0.7 NS	4370	3150	2960
Centerfield	11	1.9*	1.6**	3610	2710	—
OK Bullet	17	2.2**	2.4**	3660	2500	1950
Fuller	17	4.1**	3.5**	3180	1970	2300
TAM 203	6	4.5**	4.8**	—	1340	1580
LSD (0.05)	—	—	—	560	560	600
CV%	—	—	—	10.9	12.4	12.7

*Significant at the 0.05 probability level for the difference between Duster and the particular check cultivar.

**Significant at the 0.01 probability level for the difference between Duster and the particular check cultivar.

†Yield not measured in harvest year 2008.

‡0 = no apparent symptoms; 5 = highly susceptible to acid soil conditions.

Another desirable characteristic for southern Great Plains wheat production is tolerance to Al toxicity, or in less discrete terms, field tolerance to acid soil conditions. Under farmer conditions at Enid, Duster produced tolerance ratings equivalent to those of Endurance but progressively better than those of 'Centerfield' (PI 644017; moderately resistant), OK Bullet (intermediate to moderately resistant), Fuller (moderately susceptible), and 'TAM 203' (PVP 200900163; very susceptible) (Table 5). In the same trials, these visual ratings corresponded with the higher grain yield of Duster compared with Centerfield, OK Bullet, Fuller, and TAM 203 and with the equivalent grain yield of Endurance. The greater acid-soil tolerance of Duster produced a 148% increase in grain yield over TAM 203 in acid-soil conditions. Averaged across all other sites (n = 8) in the 2010 OET where soil acidity was not the primary yield determinate, the yield advantage of Duster versus TAM 203 was 11% (P < 0.05).

The underlying mechanism of Duster's acid-soil tolerance was partly determined by controlled-environment and molecular-marker assays. Duster exhibited the same root-tip staining pattern as the resistant control, 'Atlas 66' (CItr 12561; Heyne, 1958), when Al-treated (0.36 mM Al) root tips were submerged in a solution containing 0.2% (w/v) hematoxylin and 0.02% (w/v) KIO_3.

Additionally, a total of five molecular-marker loci (*Xssr3a*, *Xssr3b*, *Xwmc331*, *Xgdm125*, and *ALMT1-UPS4*) from chromosome arm 4DL were analyzed in Duster and compared with those in Atlas 66, which contains a functional allele of the Al-induced malate transporter gene (*ALMT1*), which significantly contributes to Al tolerance (Zhou et al., 2007). Among the five markers, *ALMT1-UPS4*, from the promoter region of *ALMT1*, provides a diagnostic marker for a functional *ALMT1* allele. Only *Xgdm125* revealed the same allele in Duster and Atlas 66. Although *ALMT1-UPS4* amplified a different fragment in Duster (1012 bp) than that in Atlas 66 (720 bp), the 1012-bp allele is also considered a diagnostic Al-tolerant allele at *ALMT1* (Bai, unpublished data, 2011). Thus Duster carries a functional Al-resistance allele on 4DL.

Duster is an intermediate semidwarf (*RhtB1b*), equal in plant height (71 cm, n = 20) to Jagalene (71 cm) and Overley (72 cm, P > 0.05), but taller than Jagger (69 cm, P < 0.01) and shorter than Endurance (74 cm, P < 0.01) and OK Bullet (75 cm, P < 0.01). Duster does not contain the *Xgwm261* marker allele indicative of *Rht8* (Bai, unpublished data, 2011). Straw strength for Duster is intermediate to moderately weak, with a mean rating of 3.0 ± 0.3 (n = 12) on a scale of 1 to 5 (increasing values represent decreasing strength), which is less than Endurance (2.1 ± 0.2) and OK Bullet (1.5 ± 0.2).

Disease and Insect Resistance

The HRW wheat cultivars released by the OAES and the Kansas Agricultural Experiment Station (KAES) during the past decade generally featured an effective level of resistance to SBWMV or WSSMV or both. Except for the long-term OET check cultivar 'Chisholm' (PI 486219; Smith et al., 1985), the cultivar responses presented in Table 6 support that trend. Duster, however, was the only cultivar reported in Table 6 to always receive a resistant ELISA-based rating across the 4-yr reporting period. Visual ratings for Duster for the WSBM-WSSM complex were also always 1, the highest level of resistance (Table 6). Replicated data for the reaction to BYDV were limited to one environment in Oklahoma where disease symptoms were explicit. In the 2010 variety performance test at Lahoma, the incidence of BYDV across each plot was rated on a percentage scale. Ratings for Duster (16%; n = 10) were similar (P > 0.05) to those for Centerfield (9%), Endurance (11%), and 'Everest' (12%;

Table 6. Responses of Duster and selected hard red winter wheat check cultivars to field infection by stripe rust (2009, 2010) at Rossville, KS and visual ratings for reactions to wheat soilborne mosaic and wheat spindle streak mosaic diseases at Stillwater, OK.†

	Stripe rust reaction 2009–10				Virus visual rating 2007–10		ELISA interpretation SBWMV‡				ELISA interpretation WSSMV‡			
Entry	Comparisons	Infection type	Severity	Virus comparisons	Early March	Mid-March	2007	2008	2009	2010	2007	2008	2009	2010
	no.	1–9§	%	no.	1–4¶									
Duster	15	4.4	51	8	1.0	1.0	R	R	R	R	R	R	R	R
Chisholm	2	2.5*	42 NS	8	2.8**	2.9**	S	S	S	MR	S	R	S	MR
Endurance	9	4.9 NS	66 NS	8	1.8**	1.9**	R	R	R	R	R	S	I	MR
Centerfield	4	4.3 NS	45 NS	8	1.3 NS	1.4 NS	R	R	R	R	R	S	I	MR
OK Bullet	7	4.7 NS	18**	8	1.5*	1.4 NS	R	R	I	R	R	R	R	R
Billings	6	2.5**	2**	8	1.4 NS	1.3 NS	R	R	R	MR	R	S	I	R
Fuller	6	4.7 NS	19**	6	1.3 NS	1.7*	—	R	R	MR	—	R	R	MR

*Significant at the 0.05 probability level for the difference between Duster and the particular check cultivar.

**Significant at the 0.01 probability level for the difference between Duster and the particular check cultivar.

†Quantitative data are means across multiple nurseries and/or years for the given number of comparisons.

‡R, resistant; MR, moderately resistant; I, intermediate; and S, susceptible. SBWMV, *Soilborne wheat mosaic virus*; WSSMV, *Wheat spindle streak mosaic virus*.

§1 = resistant; 9 = highly susceptible.

¶1 = resistant; 4 = highly susceptible.

PVP 201000387) but significantly lower ($P < 0.01$) than those for OK Bullet (64%), Fuller (73%), Jagalene (82%), and Jagger (85%). These results are consistent with opportunistic observations made in Oklahoma and other states as summarized at http://www.wheat.okstate.edu/varietytesting/varietycharactericstics/pss2142web2010.pdf (verified 23 Mar. 2011).

Under field conditions in Kansas in inoculated stripe rust screening nurseries with heavy disease pressure, Duster exhibited 51% disease severity with an intermediate infection type (4.4) averaged across 2 yr (Table 6), a pattern similar to that of Endurance but less desirable than that of 'Billings' (PI 656843). In contrast, susceptible types, such as the check KS89180B, consistently produced a disease severity exceeding 95%, with infection types of 8 or 9. Comparisons only with Fuller and OK Bullet were confounded by their divergent reactions between 2009 and 2010, owing to the late-season arrival of *Yr17*-virulent race(s) in 2010. For example, Fuller produced disease severities of 1–2% with infection types of 1 or 2 in 2009 (similar to Billings), followed by severities of 20–60% and infection type of 8 in 2010. Grain-yield performance in the 2010 variety performance tests (Table 1) and the 2005 SRPN (highest-ranking entry), both years when stripe rust was widespread throughout the southern and central Great Plains, indicate that Duster exhibits an effective and yield-competitive level of stripe rust resistance. Duster does not contain the resistant alleles at *cMWG682* and *TaVrga-A1* associated with the presence of the VPM-1 segment containing *Yr17* on the short arm of chromosome 2A as discovered in Jagger (Fang et al., 2011). Duster does, however, share the same marker allele as Jagger at the locus named *QYr.osu-5A* and centered on *Xgwm156* on the long arm of chromosome 5A, which confers adult-plant resistance to multiple races of stripe rust (Fang et al., 2011).

Based on the infection types of *P. triticina* virulence phenotypes, Duster was postulated to have *Lr3* and *Lr11* (Table 7). Duster had the highest infection types to phenotypes with virulence to *Lr3* and *Lr11*. Genotyping of Duster confirmed the presence of a resistant haplotype for three polymorphic marker sites in the *Lr34/Yr18* gene (Cao et al., 2010). In breeder nurseries with field inoculation, Duster was resistant to leaf rust (0tr up to 5R on the modified Cobb scale; Peterson et al., 1948), producing ratings of 0–1 on a scale of 0 (no visible symptoms) to 4 (severe symptoms) from 2005 to 2010. In OSU greenhouse seedling tests in December 2010, it showed a resistant reaction to a bulk collection of urediniospores from susceptible lines and cultivars grown at Lahoma in spring 2010.

When tested at the seedling stage against races QFCSC, QTHJC, RCRSC, RKQQC, TPMKC, and TTTTF of *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks. E. Henn., Duster showed resistance to QFCSC (the predominant race in Great Plains), MCCFC, and TPMKC. The gene(s) conferring resistance to these races is not determined. Duster was susceptible to the other races at the seedling stage. In

Table 7. Infection types of *Puccinia triticina* virulence phenotypes on seedlings of the hard red winter wheat cultivar Duster.

	Virulence phenotype†								
Line	THBJ	MJBJ	SBDG	TGBG	MHDS	KFBJ	MCDS	MCRK	TNRJ
Duster	;‡	;1-	0;	;	0;	;1-	;	23	3
TcLr3 RL6002	3+	3+	;	3+	3+	3+	3+	3+	3+
TcLr11 RL 6053	;2	;2	;2–	;2–	2–	;2–	2–	3	3+
Thatcher	3+	3+	3+	3+	3+	3+	3+	3+	3+

†*P. triticina* virulence phenotypes as described by Long and Kolmer (1989).

‡Infection types: ; = hypersensitive flecks; 1 = small uredinia surrounded by necrosis; 2 = small uredinia surrounded by chlorosis; 3 = moderate size uredinia with no chlorosis or necrosis; 4 = large uredinia with no chlorosis or necrosis. + and – designate larger and smaller infection types. Mixtures of infection type are listed with the most common first.

a field stem rust nursery inoculated with a bulk of races QFCSC, QTHJC, RCRSC, RKQQC, and TPMKC in St. Paul, MN, Duster was moderately resistant to moderately susceptible with a rating of 30MR-MS. Compared with the susceptible check 'McNair 701' (CItr 15288), which had a rating of 70S, Duster may have intermediate adult-plant resistance to stem rust.

Based on 2-yr greenhouse and field evaluations in Manhattan, KS, Duster is highly susceptible to Fusarium head blight (caused by *Fusarium graminearum* Schwabe). The percentage of affected spikelets averaged 97% and 70% in the greenhouse and field. Duster is susceptible to *Wheat streak mosaic virus* on the basis of data obtained from the 2006 SRPN and limited field observations in Oklahoma. Based on field observations in Oklahoma, it exhibits a moderately resistant to resistant adult-plant reaction to powdery mildew, although greenhouse seedling tests have produced a susceptible reaction with inoculum representing *B. graminis* present in the Stillwater area.

Since 2006, Duster has consistently shown a high level of seedling resistance to Hessian fly populations collected in west-central Kansas and a high level of field resistance to endemic biotypes in north central and southwest Oklahoma. In multiyear OET experiments conducted in moderately to heavily infested Oklahoma wheat fields (up to 10 flies/tiller), Duster had the lowest average fly intensities (0.31/tiller) while ranking first in yield among 30 entries. In fact, fly intensities never reached economically significant levels in any plot seeded with Duster (Alvey, 2009). Based on greenhouse seedling-screening tests, Duster is susceptible to greenbug Biotype E [*Schizaphis graminum* (Rondani)] and to Russian wheat aphid (*Diuraphis noxia* Kurdjumov).

Grain Volume Weight and End-Use Quality

From a 5-yr period of the variety performance tests, Duster's (749 kg m^{-3}) grain volume weight was higher than those of Endurance, Jagalene, and Jagger but similar to that of Overley (Table 8). The difference (18 kg m^{-3}) between the volume weight of Jagger and that of Duster is equivalent to 1.4 pounds per Winchester bushel, a significant decline by U.S. grain-grading standards. Other measures of physical and functional grain quality were provided for grain samples produced in the 2006–2010 OET and collected from multiple test sites per year. The wheat protein concentration of Duster (125 g kg^{-1}) was intermediate to those of Endurance and Billings. Duster had a significantly lower kernel weight and diameter compared with the moderate size of Endurance and the above-average size of Billings. Duster produced a distinctive mixing curve indicative of above-average dough-strength characteristics, including a high bandwidth and low rate of incline and decline of the curve, that is, lower mixogram stability value than Endurance and Billings (Table 9).

Duster does not contain either the T1BL-1RS or T1AL-1RS translocation. At the HMW-GS loci, Duster contains alleles *Glu-A1b* (subunit 2*), *Glu-B1u* (subunits 7*+8), and *Glu-D1d* (subunits 5+10), and at the LMW-GS loci, the alleles *Glu-A3a*, *Glu-B3h*, and *Glu-D3a*. Duster's glutenin-allele composition is almost identical to that of the KAES hard white wheat cultivar 'Lakin' (Shan et al., 2007), with

Table 8. Least-squares means for grain volume weight of Duster and four hard red winter wheat check cultivars in all available experiments (2006–10) and in paired dual purpose (DP) and grain only (GO) experiments (2007–10) in the Oklahoma Small Grains Variety Performance Tests.

Cultivar	2006–10	2007–10 DP	2007–10 GO
		kg m^{-3}	
Duster	749	711	722
Endurance	742	711	712
Jagalene	744	682	689
Overley	749	697	729
Jagger	731	681	689
LSD (0.05)	2	15	15
LSD between systems (0.05)	—	15	
CV%	2.0	3.6	
No. of observations†	1735	295	

†Summed number of cultivars (as listed), trials, and replicates per cultivar-trial.

Table 9. Comparisons of Duster versus hard red winter wheat check cultivars Endurance and Billings for wheat milling, dough rheology, and bread-baking characteristics during harvest years 2006–10 in Oklahoma.

Trait (unit of measurement)	Comparisons	Duster	Endurance	Billings
Wheat protein (g kg^{-1})	32	125	122*	129**
NIR hardness index (score)	32	74	67**	73 NS
SKCS† kernel hardness (score)	32	79	64**	69**
SKCS kernel weight (mg)	32	25.8	28.5**	31.8**
SKCS kernel diameter (mm)	32	2.33	2.39*	2.54**
Flour extraction (g kg^{-1})	32	627	631 NS	628 NS
Mixograph peak time (min)	32	4.9	4.1**	4.5 NS
Mixograph tolerance rating‡	32	3.7	2.8**	3.6 NS
Mixograph bandwidth (mm)	32	17.0	13.9*	16.8 NS
Mixograph stability	32	4.1	7.9**	6.1**
Adjusted sedimentation volume (mL)	32	6.3	6.3 NS	7.1**
Loaf volume (cc)	5	796	801 NS	851*
Bake water absorption (g kg^{-1})	5	651	654 NS	650 NS
Crumb grain score‡	5	4.4	4.3 NS	3.9 NS

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

†SKCS, single kernel characterization system.

‡Based on scale of 0 = poor to 6 = excellent.

the slight exception of band 9 of Lakin's 7+9 pair (*Glu-B1c*). The *Glu-B1u* allele designation follows that of Wrigley et al. (2009) and is consistent with the more frequently encountered subunits 7*+8.

Discussion

Across an extensive sample of environments, Duster had superior grain yield and grain-yield consistency compared with cultivars currently grown in Oklahoma. Most noteworthy is that its yield advantage reliably carries over from grain-only to dual-purpose systems, the latter being the hallmark of forage-livestock production in the southern and central Great Plains. The wheat/stocker cattle dual-purpose enterprise will assume even greater importance if beef production shifts globally from grain-based to forage-based production systems, as predicted by Phillips et al. (2011).

Duster's grain yield was equal to or better than that of Endurance, a cultivar selected (and named) for superior adaptation to dual-purpose systems (Carver et al., 2006b), but exceeded Endurance in other attributes. Multiple characteristics of Duster apposite to dual-purpose wheat producers include (i) high stockpile fall-forage potential that predetermines stocking density, (ii) nonprecocious winter dormancy release essential to continued winter grazing, and (iii) excellent grazing recovery reflected in grain production after winter grazing. The 10-d difference between Duster and either Jagger or Overley in reaching FHS provides an opportunity for increased cattle gains from a longer grazing duration and associated increased economic returns from the dual-purpose enterprise (Redmon et al., 1996), yet with superior dual-purpose grain yield potential.

The actual FHS date varied for Duster as much as 14 d from the earliest to the latest year in the reporting period of 2006–2010. However, the difference between the FHS date for Duster and an early-FHS cultivar (Jagger) varied among years by only 7–14 d. Knowledge of the FHS date for Jagger in any given year would provide dual-purpose managers approximately 7-d advance notice to terminate grazing on Duster wheat pasture. Although the FHS and heading-date stages are correlated (Edwards et al., 2007), the extended grazing period of Duster did not appear to carry a yield penalty associated with its later heading date (4 d later than Overley).

Duster's versatility in grain-only and dual-purpose systems, in addition to its resilience to biotic and abiotic stress factors, has resulted in gradual commercial acceptance since the cultivar was released in 2006. Wheat acreage in Oklahoma occupied by Duster has risen from <0.2% in 2007 to 16.4% in 2011 (http://www.nass.usda.gov/Statistics_by_State/Oklahoma/Publications/Oklahoma_Wheat_Varieties/index.asp; verified 22 Mar. 2011). This trend is probably aided by Duster's high level of and consistent resistance to the SBWMV-WSSMV complex in north central Oklahoma, its adult-plant resistance to leaf rust, stripe rust, and powdery mildew, its tolerance of soil acidity, and its resistance to the GP biotype of Hessian fly.

Leaf rust resistance in Duster is conferred by the gene combination of *Lr3*, *Lr11*, and *Lr34*. Thatcher*2/Duster F_3 lines that lacked the three named genes nevertheless had adult-plant resistance in greenhouse tests (Kolmer, unpublished data, 2011), so Duster must contain some other effective adult-plant resistance gene(s) for leaf rust. Duster provides a desirable genetic background for *Lr34* that is currently in low frequency among HRW wheat cultivars (Kolmer et al., 2009). Gene *Lr11* may contribute to Duster's resistance and could be enhanced by the presence of *Lr34*. The virulence of *Lr11* is currently low in the Great Plains, but it has been high in the past (Kolmer et al., 2007). Virulence of *Lr11* is common in the southeast soft red winter region. A desirable level of resistance to stripe rust also was evident in Duster, given the results presented here and other results that show no change in reaction since 2005 in Oklahoma (field disease-severity ratings less than 20%). Stripe rust resistance in Duster is probably conferred by the combination of *Yr18* and an unnamed gene on chromosome 5A. Lastly, its superior yielding ability in and tolerance to acid soil conditions is especially attractive to wheat producers in the southern Great Plains who hold short-term leases with landowners unwilling to accept or share the cost of long-term lime applications and where transport of lime materials may be cost prohibitive.

Availability

Oklahoma Foundation Seed Stocks, Inc. (OFSS, Inc., 2902 West sixth Avenue, Stillwater, OK 74074-1555) provides foundation seed of Duster to members of Oklahoma Genetics, Inc., to whom the cultivar is licensed and by whom a research and development fee is assessed on all registered and certified seed sales. Duster is protected under the U.S. Plant Variety Protection Act with the Certification Only option (PVP 200700391). The OAES maintains breeder seed production. Seed of Duster has been deposited with the National Plant Germplasm System, where it will be available upon expiration of PVP, 20 yr after the date of publication. Requests for small quantities of seed (<5 g) may be forwarded to the corresponding author during the period of PVP protection.

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