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CULTIVAR

'GA 03564-12E6': A High-Yielding Soft Red Winter Wheat Cultivar Adapted to Georgia and the Southeastern Regions of the United States

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Abstract

Soft red winter wheat (SRWW) (*Triticum aestivum* L.) is a major crop in the southeastern region of the United States and in Georgia. Although wheat acreages have been decreasing in Georgia and the SE region in recent years, more than 100,000 ha were grown to SRWW in 2015. Newly released cultivars must have high yield potential, excellent resistance levels to predominant diseases and insects, and good quality to capture and maximize regional market value. One objective of the SRWW breeding program at the University of Georgia (UGA) is to develop and release SRWW cultivars adapted to the SE wheat region with high yield, quality, and pest resistance. 'GA 03564-12E6' (Reg. No. CV-1122, PI 677366) SRWW was developed by the UGA small grains breeding program and the SUNGRAINS cooperative and released by the UGA College of Agricultural and Environmental Sciences and licensed to Limagrain Cereal Seeds as L11544 in 2015. GA 03564-12E6 was released primarily for its wide adaptation to the SE region with high grain yield, excellent Hessian fly resistance, and excellent grain volume weight. Additionally, GA 03564-12E6 has good resistance to races of leaf rust and stripe rust predominant in Georgia and the SE United States. It has good resistance to powdery mildew (caused by *Blumeria graminis* f. sp. *tritici*) and *Soil-borne wheat mosaic virus* and has acceptable SRWW milling and baking quality. However, it is susceptible to Fusarium head blight (FHB) or scab [caused by *Fusarium graminearum* Schwabe; teleomorph *Gibberella zeae* (Schwein.) Petch].

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Efficient and stable wheat production is important to the agricultural economy of Georgia and the SE region. The development of superior new soft red winter wheat (SRWW) cultivars is a key element to sustain future wheat productivity in Georgia and the surrounding southeastern (SE) region of the United States. To be accepted and widely grown, newly released cultivars must possess genes that confer high yield, good resistance to predominant diseases, and acceptable milling and baking quality to maximize regional market values. Therefore, the objective of the University of Georgia (UGA) SRWW breeding program, in collaboration with the Southeastern University GRAINS (SUNGRAINS) breeding programs (including The University of Arkansas, University of Florida, University of Georgia, Louisiana State University Agricultural Center, North Carolina State University, and Texas A&M University), is to develop and release SRWW cultivars adapted to the SE region of the Unite States and for Georgia wheat growers. GA 03564-12E6 (Reg. No. CV-1122, PI 677366) SRWW was developed at the UGA in collaboration with the SUNGRAINS and was released in 2015 by the UGA Agricultural Experiment Station. GA 03564-12E6 was released primarily for its high

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Abbreviations: AYT, advanced yield trials; GAWN, Gulf Atlantic Wheat Nursery; SE, southeastern; SGPT, Small Grain Performance Trials; SRWW, soft red winter wheat; SUNGRAINS, Southeastern University GRAINS; SUNPRE, SUNGRAINS preliminary regional nursery; UGA, University of Georgia; USW, Uniform Southern Wheat.

yield, excellent Hessian fly [*Mayetiola destructor* (Say)] resistance, and resistance to leaf rust (caused by *Puccinia triticina* Erikss.), stripe rust [caused by *Puccinia striiformis* Westend f. sp. *tritici* Eriks & Henn (Syn. *P. glumarum* Erik. and Henn.)], powdery mildew (caused by *Blumeria graminis* f. sp. *tritici*), and *Soil-borne wheat mosaic virus*. GA 03564-12E6, however, has medium susceptibility to Fusarium head blight (FHB) [caused by *Fusarium graminearum* Schwabe (telomorph *Gibberella zeae* (Schwein.) Petch)], comparable to 'AGS 2035' (PI 658066), '26R94' (PI 652450), and 'SS 8641' (PI 674197). GA 03564-12E6 has wide adaptation to wheat production systems in Georgia and the adjacent SE states. GA 03564-12E6 was licensed to Limagrain Cereal Seeds and is commercialized under the name of L11544.

Methods

Early Generation Development

GA 03564-12E6 is derived from the cross of SS 8641/4/'AGS 2000'*3/931433//'2684'/3*AGS 2000 made in greenhouse in fall 2004. SS 8641 was developed by the UGA small breeding program and was initially designated as GA96229-3A41 prior to its release in 2006. While 931433 is a UGA SRWW high-yielding experimental line, SS 8641 was used in the GA 03564-12E6 cross due to its stripe rust (Yr17) and leaf rust (Lr37) resistance. 2684 is PIONEER-BRAND-2684 cultivar released by Pioneer in 1994 and was used for its powdery mildew resistance. AGS 2000 (PI 612956) is a SRWW cooperatively developed and released by the Georgia and Florida Agricultural Experiment Stations in 1999. AGS 2000 was used in the GA 03564-12E6 cross because it has a combination of high yield, excellent milling and baking quality, good disease resistance, and medium maturity. The F_1 plants following the last cross were grown in the field in Plains, GA, in the 2005–2006 crop cycle. The pedigree method was subsequently used to advance the segregating populations that lead to GA 03564-12E6 from the 2006–2007 to 2009–2010 crop cycles. Individual spikes were selected in the F_2 to F_5 generations at Plains on the basis of reaction to diseases including leaf and stripe rusts and to Hessian fly, and agronomic merits including plant vigor, height, lodging, and earliness.

Line Selection and Evaluation

GA 03564-12E6 was first evaluated for its performance in the preliminary yield trials in 2011 at Plains and Griffin, GA (data not reported). Subsequently, it was evaluated in advanced multistate (Georgia, Alabama, and Mississippi) trials in 2012 (Table 1). From 2013 to 2015, GA 03564-12E6 was evaluated in Georgia's Small Grain Performance Trials (SGPT) (Table 2). At the regional level, GA 03564-12E6 was evaluated in 2012 at

Table 1. Average of grain yield and volume weight, heading date, and plant height, and reactions to leaf, stripe rusts and *Soil-borne wheat mosaic virus* of GA 03564-12E6 and commonly grown soft red winter wheat cultivars included in advanced yield trials in Georgia (Plains, Calhoun, and Griffin), Alabama, and Mississippi in 2012.

Entry	Grain yield	Grain volume weight	Heading date	Plant height	Leaf rust	Stripe rust	*Soil-borne wheat mosaic virus*
	kg ha^{-1}	kg m^{-3}	Julian	cm	0–9†	0–9†	0–9‡
GA 03564-12E6	6086 a§	750 b	86 a	84 b	0 a	0 b	0 b
AGS 2035	5461 c	780 a	82 b	91 a	0 a	0 b	0 b
SS 8641	5656 b	743 b	88 a	86 b	0 a	0 b	0 b
USG 3120	5898 a	771 a	80 b	86 b	1 a	3 a	7 a
Disease highest rating¶	–	–	–	–	6 b	8 c	7 c
No. of environments	5	5	5	5	5	5	5

† Leaf rust, stripe rust, and powdery mildew score: 0 = resistant, 9 = very susceptible.

‡ *Soil-borne wheat mosaic virus* score: 0 = none, 9 = severe.

§ Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

¶ Indicates the highest disease score of the most susceptible genotype in the trial.

Table 2. Average of grain yield and volume weight, days to heading, and plant height, and reactions to Hessian fly and diseases of GA 03564-12E6 and commonly grown soft red winter wheat cultivars included in Georgia's Small Grain Performance Trials, 2013–2105.

Entry	Grain yield†			Grain volume weight	Days to heading	Plant height	Hessian fly	Leaf rust	Stripe rust	Powdery mildew	FHB severity‡
	GA statewide	South GA	North GA								
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg m^{-3}	Julian days	cm	%	0–9§			%
GA 03564-12E6	5252 a¶	5073 a	5524 a	762 a	99 ab	99 b	6 c	0 b	0 b	1 c	23 c
AGS 2035	4521 b	4555 b	4474 b	756 a	97 b	107 a	10 bc	0 b	1 b	3 b	31 bc
SS 8641	5196 a	4853 a	5707 a	727 b	101 a	102 b	17 b	0 b	0 b	0 c	39 b
26R94	5062 a	4912 a	5324 a	772 a	98 ab	107 a	2 c	2 b	0 b	2 bc	33 b
Disease highest rating#	–	–	–	–	–	–	51 a	8 a	8 a	6 a	66 a
No. of environments	15	9	6	15	15	15	8	15	15	15	15

† South GA = Plains, Tifton, and Midville; North GA = Griffin and Calhoun.

‡ FHB (Fusarium head blight) severity percentages as described by Stack and Frohberg (2000).

§ Leaf rust, stripe rust, and powdery mildew score: 0 = resistant, 9 = very susceptible.

¶ Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

# Indicates the highest disease score of the most susceptible genotype in the trial.

four locations in the SUNGRAINS preliminary regional nursery (SUNPRE) in Georgia, North Carolina, Louisiana, and Arkansas (Table 3). In 2013, it was also evaluated at six locations in the advanced SUNGRAINS Gulf Atlantic Wheat Nursery (GAWN) (Table 4). In 2014, GA 03564-12E6 was evaluated in the Uniform Southern Wheat (USW) nursery grown in 21 locations in the SE region (Tables 5 and 6).

All yield trials including advanced yield trials (AYT), SGPT, SUNPRE, GAWN, and USW were arranged in a randomized complete block design with three to four replicates. The experimental unit plot consisted of seven rows, 3 m long and 15 cm apart. The AYT were grown in five locations (three sites in Georgia—Griffin, Plains and Calhoun—and one location each in Alabama and Mississippi), while the other trials were grown at many locations across the SE region.

Disease reaction data of GA 03564-12E6 compared to commonly grown cultivars were collected on the AYT, SGPT, GAWN, and USW yield trials indicated above (Tables 1, 2, 4, 5, and 6). Leaf and stripe rust data were collected for all the later yield trials, and powdery mildew and scab data were collected at SGPT, GAWN and USW trials (Tables 2, 4, and 5); *Soil-borne wheat mosaic virus* at AYT (Table 1); and Hessian fly in Georgia in Plains and Griffin from 2013 to 2015 (Table 6). A scale of 0 to 9, where 0 = resistant and 9 = very susceptible, was used to score disease severity of leaf and stripe rusts, powdery mildew, and *Soil-borne wheat mosaic virus*. Hessian fly resistance was determined on the basis of the number of insect larvae per 20 plants sampled randomly. Fusarium head blight evaluations were done using average disease severity as described by Stack and Frohberg (2000) in 19 location-years of SGPT and GAWN trials. However, a scale of 0 to 9, where 0 = no disease was observed and 9 = 100% infected spikes, was used to evaluate FHB disease severity in USW trials grown in 19 environments. In all evaluations, the disease severity scores reflected FHB type II resistance (Rudd et al., 2001), that is, resistance to disease spread across spikelets in infected spikes. Plant lodging was evaluated on a scale of 0 to 9, where 0 = completely erect and 9 = completely lodged at harvest. Rusts and powdery mildew were evaluated on a scale of 0 to 9, where 0 = very resistant and 9 = very susceptible. Softness equivalence, the percentage break flour (through 94-mesh screen) of the total flour weight (break flour plus middlings), was determined as described by Finney and Andrews (1986).

Seed Purification and Increase

GA 03564-12E6 was produced in 2011 from a small block (10 m^2) planted in Griffin from remnant seed of a $F_{5:6}$ headrow and was rogued thoroughly for aberrant types including awnless, late, early, and tall plants. Seed increase of GA 03564-12E6 continued through 2013, when a small strip (50 m^2) of GA 03564-12E6 was planted in Plains and rogued thoroughly for aberrant types. In 2014, three large increase strips (100 m^2) of GA 03564-12E6 were planted at Plains. The purity of GA 03564-12E6 was maintained throughout the increase process via visual elimination of off-type (taller, different spike color, and absence of awns) plants.

Statistical Analysis

Data analysis of GA 03564-12E6 was conducted using SAS version 9.4 (SAS Institute, 2010). Agronomic data including grain yield and grain volume weight from the Georgia state and regional yield trials were subjected to analysis of variance across locations and years for repeated entries. We used PROC

Table 3. Average of grain yield and volume weight, heading date, and plant height of GA 03564-12E6 and commonly grown soft red winter wheat cultivars included in the regional SUNGRAINS preliminary (SUNPRE) trials planted in Arkansas, Georgia, Louisiana, and North Carolina, 2012.

Entry	Grain yield	Grain volume weight	Heading date	Plant height
	kg ha^{-1}	kg m^{-3}	Julian days	cm
GA 03564-12E6	5266 a†	767 a	83 b	84 b
AGS 2035	4344 c	757 b	85 ab	91 a
USG 3555	4170 c	722 c	84 ab	71 c
USG 3120	4600 b	767 a	86 a	89 a
No. of environments	4	4	4	4

† Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

Table 4. Average of grain yield and volume weight, days to heading, and plant height, and reactions to leaf and stripe rusts, powdery mildew, and Fusarium head blight (FHB) of GA 03564-12E6 and commonly grown SRWW cultivars in the multistate advanced SUNGRAINS Gulf Atlantic Wheat Nursery, 2013.

Entry	Grain yield	Grain volume weight	Days to heading	Plant height	Leaf rust	Stripe rust	Powdery mildew	FHB severity†
	kg ha^{-1}	kg m^{-3}	Julian days	cm		0–9‡		%
GA 03564-12E6	5447 a§	747 a	105 b	89 b	0 b	0 a	1 b	35 b
AGS 2060	4902 b	741 a	103 b	94 a	1 b	2 a	4 a	23 c
SS 8641	5434 a	727 b	110 a	91 ab	0 b	0 a	0 b	46 b
USG 3555	4855 b	709 c	109 a	84 c	3 a	1 a	2 b	19 c
Disease highest rating¶	–	–	–	–	6	5	6	46 a
No. of environments	4	4	4	4	4	4	4	4

† FHB severity percentages as described by Stack and Frohberg (2000).

‡ Leaf rust, stripe rust, and powdery mildew scores: 0 = resistant, 9 = very susceptible.

§ Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

¶ Indicates the highest disease score of the most susceptible genotype in the trial.

MIXED procedure to estimate genotypic adjusted mean within location and year-location combination. A mean comparison of traits between genotypes was performed by using protected LSD ($P = 0.10$) test, where genotype × environment mean square was used to estimate the standard error of differences between genotype means across environments.

Characteristics

Agronomic and Botanical Description

GA 03564-12E6 is an awned, medium-early maturing, semidwarf SRWW. It has a dense head type with a plant height ranging from 83 cm registered (Table 4) to 99 cm (Table 2). Overall, GA 03564-12E6 had similar plant height to 'USG 3120' (PI 672163) (Table 1 and 5), SS 8641(Tables 1, 2, and 4), and 'Jamestown' (PI 653731) (Table 5) but was significantly shorter than AGS 2035 (Tables 1, 2, and 3), 26R94 (Table 2), USG 3120 (Table 3), 'AGS 2060' (PI 655075) (Table 4), and AGS 2000 (Table 5). GA 03564-12E6 was taller only than USG 3555 (PI 654454) (Tables 3, 4, and 5).

GA 03564-12E6 had similar heading date to several checks, including SS 8641 in AYT and SGPT (Tables 1 and 2), AGS 2035 and 26R94 in SGPT (Table 2), AGS 2060 in GAWN trials (Table 4), and AGS 2000, USG 3555, Jamestown, and USG 3120 in USW (Table 5) trials. However, it was later than AGS 2035 and USG 3120 in AYT (Table 1) and earlier than USG 3120 in SUNPRE (Table 3) and SS 8641 and USG 3555 in GAWN trials (Table 4). Plant lodging was recorded in USW trials 2014 (Table 5). Results from 21 location-year environments indicate that GA 03564-12E6 was moderately resistant to lodging, with relatively low scores (1.4), not significantly different from the checks (1.4–1.8).

GA 03564-12E6 possesses an erect early stage plant growth habit with a blue-green plant color at the boot stage. It has an erect, not twisted flag leaf and shows a waxy canopy at the boot stage. Spike heads are inclined and of strap shape with white glumes, nonpubescent, medium long, and medium wide. The shoulders are rounded and narrow and the beaks are acute and medium length. Seed is elliptical, red, and soft textured with a short noncollared brush, a rounded cheek, a small width and depth crease, and midsize germ.

GA 03564-12E6 was observed for more than eight crop cycles (F_5–F_{13} generations) from 2011 to 2015. It was uniform and stable during the several generations of seed increase (seed increases from 2011 to 2014, breeder seed increase in 2015). We expect that GA 03564-12E6 will remain stable in its essential and distinctive characteristics when sexually reproduced. It may, however, present variants that are limited to (i) taller plants

Table 5. Average of grain yield and volume weight, days to heading, plant height, and lodging, and reactions to leaf and stripe rusts, powdery mildew, and Fusarium head blight (FHB) of GA 03564-12E6 and commonly grown SRWW cultivars included in the Uniform Southern Wheat nursery planted in Georgia and other locations in the southeastern region, 2014.

Entry	Grain yield	Grain volume weight	Days to heading	Plant height	Lodging	Leaf rust	Stripe rust	Powdery mildew	FHB reaction
	kg ha^{-1}	kg m^{-3}	Julian days	cm	0–9†	———— 0–9‡ ————			0–9§
GA 03564-12E6	5716 a¶	741 a	120 ab	83 b	1.4 a	0.7 b	0.7 c	0.0 a	4.4 b
AGS 2000	4929 c	707 b	120 ab	91 a	1.8 a	0.9 b	5.4 a	1.0 a	4.9 ab
USG 3555	4909 c	709 b	121 a	79 c	1.4 a	3.4 a	1.1 c	0.0 a	4.3 b
Jamestown	4963 c	741 a	119 ab	81 bc	1.7 a	2.2 a	0.3 c	0.5 a	3.2 c
USG 3120	5333 b	737 a	118 b	86 ab	1.4 a	0.6 b	2.8 b	0.5 a	5.7 a
No. of environments	21	21	21	21	21	19	19	19	19

† Lodging score: 0 = completely erect, 9 = completely lodged at harvest.

‡ Leaf rust, stripe rust, and powdery mildew scores: 0 = resistant, 9 = very susceptible.

§ FHB reaction: 0 = none, 9 = severe.

¶ Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

Table 6. Means of flour yield and softness equivalent quality parameters of GA 03564-12E6 and commonly grown soft red winter wheat cultivars and their reactions to Hessian fly in the Uniform Southern Wheat nurseries planted in Georgia and the southeastern region in 2014.

Entry	Flour yield†	Softness equivalence†	Hessian fly‡	
			Griffin, GA	Plains, GA
	g kg^{-1}	%	———— % ————	
GA 03564-12E6	690 a§	55 b	10 c	2 c
AGS 2000	700 a	59 a	–	–
USG 3555	670 b	55 b	–	–
Jamestown	690 a	59 a	–	–
USG 3120	670 b	57 ab	–	–
AGS 2035	–	–	5 c	16 b
SS 8641	–	–	23 b	11 bc
Gore	–	–	35 a	47 a
No. of environments	21	21	3	3

† Flour yield and softness equivalent data, as described by Finney and Andrews (1986), were generated by the USDA-ARS Wheat Quality Laboratory, Wooster, OH.

‡ Hessian fly severity = % of infested plants.

§ Values within a column followed by the same letter are not significantly different at the $\alpha = 0.10$ probability level.

(5–30 cm) that occur at a frequency of less than 1 in 12,000 plants and (ii) awnless plants at a trace frequency of less than 1 in 2000 plants. The variants in GA 03564-12E6 are within commercially acceptable limits for all described traits.

Disease Reactions

GA 03564-12E6 was tested for rusts, FHB, powdery mildew, Hessian fly, and some soil-borne diseases in different test trials from 2012 to 2015. In AYT grown in 2012 in three locations in Georgia, GA 03564-12E6 was very resistant (score of 0) to both leaf and stripe rusts, comparable to resistant checks AGS 2035 and SS 8641; USG 3120 showed a medium susceptible reaction to stripe rust (score 3) while still resistant to leaf rust (Table 1). In the same trials, susceptible genotypes showed scores of 6 and 8 to leaf and stripe rusts, respectively. The resistance of GA 03564-12E6 to leaf and stripe rusts was confirmed in 36 additional location-years in SGPT, GAWN, and USW trials (Tables 2, 4, and 5). In all these environments, GA 03564-12E6 was resistant (scores 0 to 0.7), similar to resistant checks included in the trials (scores <2), including AGS 2035, SS 8641, 26R94, and AGS 2060. In USW trials, AGS 2000 and USG 3120 were susceptible (5.4 and 2.8, respectively) to stripe rust while resistant to leaf rust (0.9 and 0.6, respectively) (Table 5). Similarly, USG 3555 and Jamestown were moderately resistant to leaf rust (3.4 and 2.2, respectively) but resistant (1.1 and 0.3, respectively) to stripe rust (Table 5). A similar reaction of USG 3555 to leaf rust (3) was expressed in GAWN trials (Table 4). The most susceptible checks in these trials scored above 6 and 5 for leaf and strip rusts, respectively, showing the high severity of rusts infections during these tests.

Powdery mildew resistance was evaluated in 36 location-years, including SGPT, GAWN, and USW trials (Tables 2, 4, and 5). In these tests, GA 03564-12E6 showed excellent resistance to powdery mildew (scores 0–1), whereas very susceptible checks had scores of 6. Most commonly grown checks, including SS 8641, 26R94, USG 3555, AGS 2000, and USG 3120, were also resistant (score 0–2) (Tables 2, 4, and 5). AGS 2035 and AGS 2060 were relatively less resistant (scores 3–4) than GA 03564-12E6.

Fusarium head blight reaction of GA 03564-12E6 and checks was also reported from SGPT, GAWN, and USW nurseries grown on 36 location-years during 2013 to 2015. Data from the SGPT showed GA 03564-12E6 to be moderately susceptible, with disease severity of 23%, significantly ($P < 0.10$) lower than the severity levels observed on all other checks (Table 2). However, data from the GAWN trials (Table 4) showed that GA 03564-12E6 had high FHB severity (35%), similar to SS 8641 (46%), but significantly higher ($P < 0.10$) than AGS 2060 (23%) and USG 3555 (19%). Similar reaction of GA 03564-12E6 to FHB was confirmed in USW trials, where it scored 4.4, similar to the moderately susceptible check AGS 2000 (4.9), USG 3555 (4.3), and USG 3120 (5.7). Jamestown, which is a more FHB resistant cultivar, had significantly ($P < 0.10$) lower scores (3.2).

GA 03564-12E6 also showed good resistance to Hessian fly, a serious pest in Georgia and the SE region. Based on data collected from the SGPT at Griffin, Plains, and Tifton, GA, from 2013 to 2015 (8 location-years), GA 03564-12E6 had 6% plant infestation, comparable to the resistant checks AGS 2035 and 26R94, but had significantly ($P < 0.10$) lower infestation than SS 8641 and the most susceptible checks, which had scores of 51% (Table 2). Similarly, data from the USW trials grown in six environments in Georgia showed that 10 and 2% plant infestation of GA 03564-12E6 in Griffin and Plains, GA, respectively. In the same trials, 5 and 16%, 23 and 11%, and 35 and 47% plant infestations were recorded, respectively, on AGS 2035, SS 8641, and 'Gore' at Griffin and Plains (Table 6).

Soil-borne wheat mosaic virus was reported only in 2012 in the AYT trials (Table 1). The reaction of GA 03564-12E6 was very resistant (score 0), similar to AGS 2035 and SS 9641 but significantly different ($P < 0.10$) from the reaction of susceptible checks (score 7), including USG 3120.

Grain Yield Performance and Quality Parameters

Overall, GA 03564-12E6 performed well, with generally high yield compared with most commonly grown SRWW cultivars grown in Georgia and parts of the SE region of the United States. It also has a high grain volume weight in tests across years and locations. In its early testing and based on five location-years of testing in the AYT in 2012, GA 03564-12E6 yielded 6086 kg ha^{-1}, similar ($P < 0.10$) to previously released Georgia cultivar USG 3120 (5897 kg ha^{-1}) (Table 1). However, GA 03564-12E6's grain yield was significantly ($P < 0.10$) higher than GA cultivars AGS 2035 (5656 kg ha^{-1}). The grain volume weight of GA 03564-12E6 in the AYT was 750 kg m^{-3}, similar ($P < 0.10$) to SS 8641 (743 kg m^{-3}) but significantly less ($P < 0.10$) than both AGS 2035 (780 kg m^{-3}) and USG 3120 (771 kg m^{-3}). Further testing of GA 03564-12E6 in the SGPT across 15 location-years in Georgia from 2013 to 2015 showed that its grain yield (5252 kg ha^{-1}) was significantly higher ($P < 0.10$) than that of AGS 2035 (4521 kg ha^{-1}) (Table 2) but not significantly different ($P < 0.10$) than the checks SS 8641 (5196 kg ha^{-1}) and 26R94 (5026 kg ha^{-1}) (Table 2). In general, GA 03564-12E6 seems to perform better in northern Georgia (5524 kg ha^{-1}, in six location-years) than in southern Georgia (5073 kg ha^{-1}, nine location-years) (Table 2). Similar performance was also shown by other checks, except AGS 2035, which showed slightly better yields in southern (4555 kg ha^{-1}) than in northern Georgia (4474 kg ha^{-1}). Grain volume weight of GA 03564-12E6 in the SGPT was higher (762 kg m^{-3}) than SS 8641 (727 kg m^{-3}) but similar to AGS 2035 (756 kg m^{-3}) and 26R94 (772 kg m^{-3}) (Table 2).

In the preliminary regional SUNGRAINS trials, GA 03564-12E6's yield and grain volume weight (5266 kg ha^{-1}) was significantly higher ($P < 0.10$) than all checks including AGS 2035 (4344 kg ha^{-1}), USG 3555 (4170 kg ha^{-1}), and USG 3120 (4600 kg ha^{-1}) (Table 3). Similarly, GA 03564-12E6's grain volume weight in the SUNPRE trials was 767 kg m^{-3}, significantly higher ($P < 0.10$) than AGS 2035 (757 kg m^{-3}) and USG 3555 (722 kg m^{-3}) but similar to USG 3120 (767 kg m^{-3}) (Table 3). In advanced SUNGRAINS GAWN trials grown in the same four locations as SUNPRE, GA 03564-12E6's yield and grain volume weight were 5447 kg ha^{-1} and 747 kg m^{-3}, similar ($P < 0.10$) to SS 8641's yield (5434 kg ha^{-1}) and AGS 2060's grain volume weight (741 kg m^{-3}) (Table 4). However, GA 03564-12E6's yield was significantly higher ($P < 0.10$) than AGS 2060 (4902 kg ha^{-1}) and USG 3555 (4855 kg ha^{-1}). Similarly, its grain volume weight was superior ($P < 0.10$) to SS 8641 (727 kg m^{-3}) and USG 3555 (709 kg m^{-3}) (Table 4).

In an extensive regional trial (USW) grown in 2014 across 21 locations of the SE region of the United States, GA 03564-12E6 had significantly superior ($P < 0.10$) grain yield (5716 kg ha^{-1}) compared with the checks AGS 2000 (4929 kg ha^{-1}), USG 3555 (4909 kg ha^{-1}), Jamestown (4963 kg ha^{-1}), and USG 3120 (5333 kg ha^{-1}) (Table 5). Its grain volume weight (741 kg m^{-3}) was similar ($P < 0.10$) to Jamestown (741 kg m^{-3}) and USG 3120 (737 kg m^{-3}) but significantly higher ($P < 0.10$) than AGS 2000 (707 kg m^{-3}) and USG 3555 (709 kg m^{-3}) (Table 5).

Grain quality of GA 03564-12E6 expressed in flour yield and softness equivalence (Table 6) was performed on seed collected from the regional USW trial grown over 21 locations in 2014. The data show that overall GA 03564-12E6 had similar ($P < 0.10$) flour yield (69%) as AGS 2000 (70%) and Jamestown (69%) but greater ($P < 0.10$) than both USG 3555 and USG 3120 (67%) (Table 6). Grain softness equivalence (Finney and Andrews, 1986) of GA 03564-12-E6 was similar ($P < 0.10$) to USG 3555 (55%) and USG 2035 (57%) but significantly lower ($P < 0.10$) than AGS 2000 and Jamestown (59%) (Table 6).

Availability

Breeder seed of GA 03564-12E6 will be maintained by the Georgia Seed Development Commission, (2420 S. Milledge Ave. Athens, GA 30605). Multiplication and distribution rights of other classes of certified seed have been transferred from the UGA to the UGA Research Foundation (UGARF), 150 B Coverdell Center, 500 D. W. Brooks Dr., Athens, GA. Seed has been deposited in the USDA-ARS National Laboratory for Genetic Resources Preservation, where it will become available for distribution. Small quantities of seed for research purposes may be obtained immediately from the corresponding author. Seed distribution of GA 03564-12E6 for research purposes will be done according to the provisions of the Wheat Worker's Code of Ethics (Annual Wheat Newsletter, 1995).

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