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REGISTRATION

Cultivar

Registration of 'Hilliard' wheat

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Abstract

'Hilliard' (Reg. no. CV-1163, PI 676271), a soft red winter (SRW) wheat (*Triticum aestivum* L.) developed and tested as VA11W-108 by the Virginia Agricultural Experiment Station, was released in March 2015. Hilliard was derived from the cross '25R47'/'Jamestown'. Hilliard is widely adapted, from Texas to Ontario,

Abbreviations: FHB, Fusarium head blight; SRW, soft red winter.

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Registration by CSSA.

Canada, and provides producers with a mid-season, medium height, awned, semi-dwarf (*Rht2*) cultivar that has very high yield potential, good straw strength, and intermediate grain volume weight and quality. It expresses moderate to high levels of resistance to most diseases prevalent in the eastern United States and Ontario. In the 2016–2018 USDA-ARS Uniform SRW Wheat nurseries, Hilliard ranked first in grain yield in the southern nursery across all 3 yr (5,147–5,758 kg ha^{-1}). In the uniform eastern nursery, it ranked first for grain yield in 2016 (6,159 kg ha^{-1}) and 2017 (5,633 kg ha^{-1}) and second in 2018 (5,515 kg ha^{-1}). Grain volume weights of Hilliard were similar to overall trial averages in the uniform southern (73.4–75.2 kg hl^{-1}) and eastern (70–75.8 kg hl^{-1}) nurseries. Hilliard has soft grain texture with flour softness equivalent values varying from 58.1 to 61.7 g 100 g^{-1}. Straight grade flour yields on a Quadrumat Senior mill varied from 66.8 to 68.4 g kg^{-1}. Flour protein concentration varied from 7.0 to 9.1 g 100 g^{-1} and gluten strength from 108 to 128 g 100 g^{-1}, as measured by lactic acid solvent retention capacity. Cookie spread diameter varied from 18.3 to 18.6 cm.

1 | INTRODUCTION

'Hilliard' (Reg. no. CV-1163, PI 676271) soft red winter (SRW) wheat (*Triticum aestivum* L.) provides producers with a widely adapted, high-yielding, medium-stature, mid-season cultivar that has good straw strength and winter hardiness, and intermediate grain volume weight and end-use quality. Cultivars having a wide range of adaptation and high and stable performance across a broad production area are rare, as this requires plasticity in vernalization and photoperiod requirements as well as good winterhardiness. Hilliard has produced grain yields higher than trial averages from Quincy, FL, and Farmersville, TX, to Ithaca, NY, and Nairn, Ontario, and between. In the 2016–2018 Uniform Southern nursery, Hilliard ranked first among 33–40 entries evaluated over 22 to 23 diverse environments in 14 to 15 states. In the 2016–2018 Uniform Eastern nursery, Hilliard ranked first in 2 yr and second in the third year among 30–36 entries evaluated over 24 to 26 diverse environments in 13–14 states and Ontario, Canada. Wide adaptation and good performance also are dependent on a cultivar having resistance to diseases prevalent in diverse production areas. With the exception of stem rust (caused by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks. & E. Henn.), Hilliard expresses moderate or higher levels of resistance to the disease-causing organisms prevalent in the eastern United States. The cultivar name Hilliard was selected in honor of the developer's mother, Joy A. Hilliard, whose support, altruism, and love of gardening and plants has and continues to provide inspiration to excel. Marketing and distribution of Hilliard is being conducted by the Virginia Crop Improvement Association, Mechanicsville, VA 23116.

2 | METHODS

2.1 | Parentage, breeding history, and line selection

Hilliard was derived from the cross '25R47' (PI 631473)/'Jamestown' (PI 653731; Griffey et al., 2010). Jamestown is early heading, has high grain volume weight, is photoperiod sensitive at locus *Ppd-D1b*, and is moderately resistant to powdery mildew [caused by *Blumeria graminis* f. sp. *tritici* (DC) E.O. Speer], leaf rust (caused by *Puccinia triticina* Eriks.) (gene *Lr18*; Carpenter, Griffey, Malla, Chao, & Brown-Guedira, 2018), stripe rust (caused by *Puccinia striiformis* Westend.) (Carpenter et al., 2017), Hessian fly [*Mayetiola destructor* (Say) biotypes B, C, and D], *Wheat soil borne mosaic virus* (*Sbm1*), and Fusarium head blight (quantitative trait loci on chromosomes 1A and 1B), but has marginal milling and baking quality (USDA-ARS, 2016–2018, Uniform Southern Nursery). In contrast, 25R47 is mid-season heading, has average grain volume weight, is photoperiod insensitive at locus *Ppd-D1a*, and is moderately susceptible to leaf rust, stripe rust, and Fusarium head blight but has good milling and baking quality (Meier, 2019).

The cross from which Hilliard derived was made in spring 2004, and the F_1 generation was grown in the field as a single 1.2-m headrow in 2005 to produce F_2 seed.

The population was advanced from the F_2 to F_5 generation using a modified bulk breeding method. Wheat spikes were selected from the population in each segregating generation (F_2–F_4) on the basis of early maturity, short straw, absence of obvious disease, and desirable head shape and size. Selected spikes were threshed in bulk, and the seed was planted in 20.9-m^2 blocks at Blacksburg and/or Warsaw, VA, in the fall of each year. Spikes selected from the F_5 bulk were threshed individually and planted in separate 1.2-m headrows at Warsaw, VA. Hilliard was derived as a bulk of one of these $F_{5:6}$ headrows selected in 2010 and was evaluated as Entry 108 in non-replicated observation yield tests at Blacksburg and Warsaw, VA, in 2011 (data not presented).

2.2 | Evaluation in replicated yield trials

Hilliard was evaluated in Virginia Tech's replicated preliminary yield test at two locations in Virginia and by private company cooperators at one or more test sites in Missouri (1), Mississippi (1), Indiana (5), Illinois (1), Tennessee (1), and Virginia (2) in 2012 (data not presented). Hilliard was evaluated by university cooperators in the 2013 Mason Dixon Trial at eight sites in Kentucky, Maryland, North Carolina, and Virginia and in the Gulf Atlantic Wheat Nursery at seven sites in Arkansas, Florida, Georgia, Louisiana, North Carolina, Texas, and Virginia (data not presented). Hilliard has been evaluated over 7 yr (2013–2019) in Virginia's state variety trials (https://secure.hosting.vt.edu/www.grains.cses.vt.edu/). Hilliard was evaluated as VA11W-108 in the 2013–2014 USDA-ARS Uniform Southern and Uniform Eastern nurseries, each including three standard check cultivars, and it subsequently has been included as a common check in both nurseries starting with the 2015–2016 nurseries. Data reports for the 2013–2014 nurseries are available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/. Data from the 2016 through 2018 Uniform Southern and Eastern SRW Wheat Nurseries is summarized here (Tables 1–5) and also can be reviewed in more detail at the following site for 2016–2018 and subsequent years' data: https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/. Hilliard also was evaluated with two standard check cultivars at seven locations in Ontario's Pastry Orthogonal Trials in 2017 and 2018 (https://www.gocereals.ca/Nov_2018_Operating_Procedures_for_Registration_Purposes.pdf). A majority of these trials were conducted using randomized complete block designs with two to four replications, standard cultivar testing protocols, and recommended management practices that vary slightly from state to state (refer to websites listed above for specific details).

Plant traits assessed visually (e.g., winterkill, straw strength, and disease resistance) were rated using an ordinal scale from 0 (no visible symptoms) to 9 (severe symptoms) based on the intensity and severity of the affected plant area. Some disease ratings conducted using a modified Cobb scale (Peterson, Campbell, & Hannah, 1948) and reported in the uniform SRW wheat nurseries were converted to a 0–9 scale. Milling and baking quality evaluations of entries in the uniform nurseries used approved methods of the American Association of Cereal Chemistry (2000). A grain composite from multiple locations was provided by the nursery coordinators to the USDA-ARS Soft Wheat Quality Laboratory at Wooster, OH. Two hundred-gram samples of each genotype were milled using modifications to American Association of Cereal Chemists Method 26-50 as described by Finney and Andrews (1986). Near-infrared reflectance was used to estimate protein concentration and lactic acid solvent retention capacity, which predicts gluten strength (Method 56-11, American Association of Cereal Chemists, 2000). Baking quality of the flour samples was measured using the micro-sugar-snap cookie method (Method 10-52, American Association of Cereal Chemists, 2000).

All replicated yield tests in Virginia were conducted according to small grain production and management protocols recommended by Brann, Holshouser, and Mullins (2000). Conventional-till yield plots in the Virginia Uniform Southern and Eastern Nurseries were comprised of seven 2.74-m rows spaced 0.15 m apart at Warsaw and Blacksburg, with harvest areas of 4.2 m^2. These tests were planted at 22 seed per 0.304 m of row. Reaction to Fusarium head blight (FHB), caused by *Fusarium graminearum* (Schwabe), was assessed in replicated inoculated and mist-irrigated nurseries according to procedures similar to those of Chen et al. (2006). Analysis of variance was conducted on data from individual locations and across locations using SAS version 9.2 (SAS Institute). However, cooperators provided only mean data from their individual trials and, in some cases, data were not analyzed statistically. Mean comparisons of traits using a Fisher's least significant difference ($P = .05$) test were made to identify significant differences among genotypes.

2.3 | Seed purification and increase

During fall 2013, 400 $F_{9:10}$ headrows (1.2 m) of Hilliard were planted in an isolation block and evaluated for purity and trueness of type. Among these breeder seed headrows, 95 variant rows were identified and omitted prior to harvest. Upon evaluation of the breeder seed

TABLE 1 Agronomic performance of Hilliard and three check cultivars evaluated in the cooperative USDA-ARS Uniform Southern Soft Red Winter Wheat Nursery in 2016 ($N = 33$ entries), 2017 ($N = 36$), and 2018 ($N = 40$)

Cultivar	Grain yield	Yield rank	Volume weight	Days to heading	Plant height	Straw strength	Winterkill	Low soil pH[a]
	kg ha^{-1}		kg hl^{-1}	d	cm	0–9[b]	0–9	0–9
2016								
Hilliard	5,147	1	73.4	113	90.8	1.2	2.7	1.0
AGS 2000	3,648	27	72.4	106	90.2	2.7	6.1	2.3
Jamestown	4,414	17	75.8	103	83.8	1.4	4.8	1.7
26R41	4,820	10	72.5	116	82.3	0.7	1.3	1.0
Mean	4,327		73.8	110	88.5	1.9	3.7	2.1
LSD (0.05)	388		2.5	1.7	2.9	1.0	1.1	1.0
No. of sites	23		22	19	17	11	3	1
2017								
Hilliard	5,252	1	74.5	108	89.0	1.4	1.6	1.5
AGS 2000	4,018	34	73.8	105	89.1	2.5	1.8	1.0
Jamestown	4,319	24	76.9	101	81.7	1.5	1.3	2.0
26R41	5,132	4	73.5	110	80.7	1.2	1.5	1.0
Mean	4,512		74.4	107	85.2	2.0	1.5	1.8
LSD (0.05)	425		3.2	2.0	2.9	0.9		1.2
No. of sites	23		17	18	20	10	1	1
2018								
Hilliard	5,758	1	75.2	113	92.8	0.6		1.0
AGS 2000	4,893	32	75.0	111	91.1	3.2		1.0
Jamestown	4,829	35	76.1	109	84.2	1.3		2.0
26R41	5,567	4	73.9	115	84.4	1.3		1.5
Mean	5,163		75.1	113	88.8	1.3		1.8
LSD (0.05)	371		3.5	1.8	2.6	1.0		
No. of sites	22		18	16	19	9		1

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a]Tolerance to low soil pH. [b]The 0–9 rating scale indicates a genotype's resistance to winterkill and lodging, where 0 = highly resistant and 9 = highly susceptible.

headrows at anthesis, it was noted that rows varied for anther color: (a) yellow, (b) light red, and (c) purple. Therefore, the remaining 224 rows were harvested and threshed individually. Thirty-four of these rows were discarded on the basis of visually poorer seed quality or size. The 190 remaining breeder seed headrows were planted and evaluated for coleoptile color, and 11 additional rows were discarded because they were heterogeneous for coleoptile color. Among the selected rows, 89 rows noted as having yellow anther and white coleoptile color were subsequently planted and evaluated for purity and trueness of type in separate individual 4.2-m^2 plots in 2015. Seed harvested from 53 of the 89 Hilliard breeder seed plots was composited, and 111 kg of seed was provided to the Virginia Crop Improvement Association Foundation Seed Farm, from which 0.52 ha was planted during fall 2015 to initiate development of foundation seed.

3 | CHARACTERISTICS

3.1 | Botanical and agronomic characteristics

Botanical and morphological data were collected at the Eastern Virginia Agriculture Research and Extension Center for Plant Variety Protection, and a majority of the data presented here (Tables 1–5) is from the 2016–2018 Uniform Southern and Uniform Eastern Nurseries.

Juvenile plant growth of Hilliard is semi-erect. At the boot stage, Hilliard has green plant color and erect, twisted flag leaves. Coleoptiles are white and anthers are yellow in color. Stem internodes are hollow and peduncles are erect. Spikes and straw of Hilliard are creamy white in color at maturity, and the awned, inclined spikes are mid-dense and tapering in shape. Glumes are long and white,

TABLE 2 Agronomic performance of Hilliard and three check cultivars evaluated in the cooperative USDA-ARS Uniform Eastern Soft Red Winter Wheat Nursery in 2016 ($N = 30$ entries), 2017 ($N = 36$), and 2018 ($N = 30$)

Cultivar	Grain yield	Yield rank	Volume weight	Days to heading	Plant height	Straw strength	Winterkill	Low soil pH[b]
	kg ha^{-1}		kg hl^{-1}	d	cm	0–9[a]		0–9
2016								
Hilliard	6,159	1	75.8	125	96.1	0.6	1.7	1.7
Branson	5,660	3	74.3	125	92.2	1.2	1.0	3.3
MO080104	5,532	9	77.4	125	102.0	1.5	1.5	3.3
25R46	4,511	26	72.8	128	91.7	1.2	0.7	2.7
Mean	5,117		75.0	125	93.2	1.6	1.7	2.2
LSD (0.05)	364		2.6	1.2	2.3	1.1	0.9	0.9
No. of sites	24		23	20	19	11	5	1
2017								
Hilliard	5,633	1	75.5	120	90.3	0.3	1.6	1.5
Branson	5,023	19	74.5	119	87.6	0.9	3.2	4.0
MO080104	5,001	21	77.4	121	93.0	1.2	1.6	1.5
25R46	5,088	16	74.4	122	89.0	0.1	2.4	1.5
Mean	5,038		75.3	121	89.0	1.0	2.4	2.3
LSD (0.05)	327		3.2	1.3	2.4	1.0	2.1	1.6
No. of sites	26		22	18	23	7	2	1
2018								
Hilliard	5,515	2	70.0	128	90.4	1.3	0.4	0.5
Branson	5,326	6	69.0	127	85.6	1.0	0.3	4.0
MO080104	5,057	19	72.7	128	95.3	2.0	0.1	1.0
25R46	5,521	1	69.9	130	86.1	0.8	0.1	3.0
Mean	5,098		69.5	129	85.1	1.5	0.6	2.4
LSD (0.05)	264		1.0	0.8	3.5	1.1	1.9	1.4
No. of sites	26		23	17	20	10	2	1

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a]Tolerance to low soil pH. [b]The 0–9 rating scale indicates a genotype's resistance to winterkill and lodging, where 0 = highly resistant and 9 = highly susceptible.

with wanting shoulders and acuminate beaks. The soft red kernels are ovate in shape, with rounded cheeks and a medium brush. Hilliard has an average 1000-kernel weight of 40 g and a fawn seed phenol reaction color.

Spike emergence (days to heading from 1 January) of Hilliard ranges from 108 to 128 d in the southern and eastern soft wheat regions of the United States (Tables 1–2). Spike emergence of Hilliard is similar to that of 'Branson' (PI 639227) and MO-080104, 1 d earlier than Pioneer Brand '26R41' (PI 666368), and 9 d later than Jamestown. In Ontario, Canada, average spike emergence of Hilliard across 12 environments was 154 d. Plant height of Hilliard (89–96 cm) is 3–6 cm shorter than that of MO-080104 and 7–9 cm taller than Jamestown. Straw strength (0 = erect to 9 = completely lodged) of Hilliard (0.6–1.4) is very good and significantly ($P \leq .05$) better than that (2.5–3.2) of 'AGS 2000' (PI 612956). Winter hardiness (0 = no injury to 9 = complete kill) of Hilliard (0.4–2.7) is good and most similar to that of Branson (0.3–3.2).

3.2 | Field performance

Hilliard was evaluated in the 2016–2018 Uniform Southern and Eastern SRW Wheat Nurseries (Tables 1–2; USDA-ARS, 2014, 2016–2018). It ranked first in grain yield in the southern nursery across all 3 yr (5147–5758 kg ha^{-1}). In the uniform eastern nursery, it ranked first for grain yield in 2016 (6159 kg ha^{-1}) and 2017 (5633 kg ha^{-1}) and second in 2018 (5515 kg ha^{-1}). Grain volume weights of Hilliard were similar to overall trial averages in the uniform southern (73.4–75.2 kg hl^{-1}) and eastern (70–75.8 kg hl^{-1}) nurseries. In the Ontario Pastry Orthogonal Trials (Table 6), grain yields of Hilliard in 2017 (5390–8970 kg ha^{-1}) were

TABLE 3 Reaction of Hilliard and three other cultivars to powdery mildew (PM), leaf rust (LR), stripe rust (YR), stem rust (SR), *Septoria tritici* leaf blotch (LB), *Septoria nodorum* glume blotch (GB), Fusarium head blight (FHB), *Barley yellow dwarf virus* (BYD), *Wheat soil borne mosaic virus* (SBM), *Wheat spindle streak mosaic virus* (WSSM), and bacterial leaf streak (BLS) in the cooperative Uniform Southern Soft Red Winter Wheat Nursery in 2016–2018 (USDA-ARS)

Cultivar	PM 0–9[a]	LR 0–9	YR 0–9	SR %	LB 0–9	GB 0–9	FHB 0–9	BYD 0–9	SBM 0–9	WSSM 0–9	BLS 0–9
2016											
Hilliard	1.3	1.7	0.4	55	1.3	2.0	1.4	2.1			1.0
AGS 2000	4.8	1.7	4.6	23	4.4	3.0	4.1	3.1			4.0
Jamestown	1.3	1.5	0.9	50	4.8	3.5	1.2	2.0			4.0
26R41	1.7	2.0	0.4	70	2.3	4.0	1.0	2.2			1.0
Mean ($N = 33$)	2.5	1.7	2.2		3.1	3.7	1.8	2.3			2.1
LSD (0.05)	2.1	1.1	1.1		1.8	2.1	1.2	1.0			
No. of sites	3	8	11	2	4	1	5	7			1
2017											
Hilliard	0.7	1.3	0.1	35	2.1	4.5	0.5	3.0	1.0	2.5	2.0
AGS 2000	2.3	0.9	5.7	8	3.5	1.0	9.0	3.0	1.0	2.5	4.0
Jamestown	1.3	1.3	0.5	55	3.1	7.0	0.0	2.0	1.0	3.5	3.0
26R41	2.2	2.6	0.1	60	3.0	0.5	1.5	2.0	1.0	2.5	2.0
Mean ($N = 36$)	1.6	1.7	1.2		2.8	4.0	2.4	3.0	1.4	3.0	2.9
LSD (0.05)	2.0	1.2	1.6		1.5	2.9				2.1	
No. of sites	3	11	7	2	5	1	1	1	1	2	1
2018											
Hilliard	1.1	1.3	0.0	70	3.3	1.8	1.3	1.0	2.0	2.5	
AGS 2000	5.0	1.1	4.2	5	4.0	2.0	3.4	1.0	8.0	3.5	
Jamestown	2.0	1.4	0.0	75	4.5	3.6	1.3	0.0	3.0	2.5	
26R41	1.6	3.0	0.0	85	3.0	2.0	2.4	1.0	1.0	2.5	
Mean ($N = 40$)	2.6	1.4	0.9		3.4	2.7	2.4	1.2	3.5	2.7	
LSD (0.05)	2.0	2.3	1.9		1.5	1.5	1.9			1.1	
No. of sites	5	4	2	1	3	2	5	1	1	1	

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a] The 0–9 rating scale indicates a genotype's response to disease, where 0 = highly resistant and 9 = highly susceptible to powdery mildew, leaf rust, stripe rust, stem rust, leaf blotch, glume blotch, *Fusarium graminearum* (Schwabe), and bacterial leaf streak.

TABLE 4 Reaction of Hilliard and three check cultivars to powdery mildew (PM), leaf rust (LR), stripe rust (YR), stem rust (SR), *Septoria tritici* leaf blotch (LB), *Septoria nodorum* glume blotch (GB), Fusarium head blight (FHB), *Barley yellow dwarf virus* (BYD), *Wheat soil borne mosaic virus* (SBM), and *Wheat spindle streak mosaic virus* (SSM) in the cooperative Uniform Eastern Soft Red Winter Wheat Nursery in 2016 to 2018 (USDA-ARS)

Cultivar	PM 0-9[b]	LR 0-9	YR 0-9	YR-APR[a]	SR %	LB 0-9	GB 0-9	FHB 0-9	BYD 0-9	SBM 0-9	SSM 0-9
2016											
Hilliard	0.5	1.5	0.5	moderate	55	2.3	2.0	1.8	2.5		
Branson	2.2	3.8	0.7	moderate	55	4.0	3.0	2.6	2.0		
MO080104	2.3	5.3	2.4	moderate	65	4.8	6.0	0.7	3.2		
25R46	4.5	5.3	6.7	none	30	5.3	1.5	1.6	2.8		
Mean ($N = 30$)	2.6	3.1	3.2			4.8	4.1	1.7	2.4		
LSD (0.05)	1.5	1.5	1.1			2.2	1.7	1.3	1.2		
No. of sites	5	4	11		2	2	1	4	4		
2017											
Hilliard	1.0	2.8	0.7	high	40	3.4	4.5	2.5	1.0		1.0
Branson	0.3	5.3	0.7	moderate	30	4.3	1.0	3.0	0.9		1.5
MO080104	3.8	5.5	1.3	high	65	3.8	7.5	1.2	2.0		1.5
25R46	3.3	7.3	7.8	none	20	5.1	1.5	1.7	1.0		1.0
Mean ($N = 36$)	2.6	3.9	2.0			4.2	3.8	2.9	1.5		2.6
LSD (0.05)	2.0	1.5	2.3			2.2	1.8	2.0	1.2		2.8
No. of sites	2	7	3		2	3	1	2	3		2
2018											
Hilliard	1.2		0.0	high	60	5.5	2.0	2.4		3.0	2.5
Branson	1.0		0.0	moderate	90	7.0	4.3	3.4		1.0	2.5
MO080104	4.7		1.7	moderate	80	7.5	5.8	1.1		2.0	3.5
25R46	3.7		7.8	none	30	4.0	2.5	1.0		1.0	1.5
Mean ($N = 30$)	2.6		1.4			5.8	3.9	2.5		3.3	2.1
LSD (0.05)	2.0						1.5	1.2			1.1
No. of sites	3		1		2	1	2	5		1	1

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a]YR-APR = putative high-temperature adult-plant resistance postulated by Xianming Chen. [b]The 0–9 rating scale indicates a genotype's response to disease, where 0 = highly resistant and 9 = highly susceptible to powdery mildew, leaf rust, stripe rust, stem rust, leaf blotch, glume blotch, and *Fusarium graminearum* (Schwabe).

TABLE 5 Reaction of Hilliard to Fusarium head blight (FHB) in the 2013–2014 Southern Uniform Winter Wheat Scab Nursery

Cultivar	Head date	Incidence	Severity	FHB index[a]	FDK[b]	ISK index[c]	DON[d]
	Day of Year	%		0–100	%	0–100	mg kg^{-1}
Bess	134	48	23	13	18	21	9.4
Jamestown	130	52	22	14	18	22	7.9
Ernie	131	54	23	14	22	26	7.9
Hilliard	133	73	40	32	38	44	11.2
Coker 9835	135	88	62	56	51	63	20.4
Mean ($N = 62$)	133	61	33	22	29	32	6.4
LSD (0.05)	4	24	20	19	21	15	13
CV, %	1.4	20	31	43	37	24	58
No. of sites	5	7	10	7	7	4	5

[a]FHB index = FHB incidence (%) × FHB severity (%)/100. [b]FDK = percentage of Fusarium damaged kernels. [c]ISK index = (0.3 × FHB Incidence + 0.3 × FHB Severity + 0.4 × FDK). [d]DON = deoxynivalenol toxin in grain samples.

TABLE 6 Grain yields of Hilliard and two standard checks at seven sites in the 2017 and 2018 Ontario Pastry Orthogonal Trials

Cultivar	Grain yield								Proportion of trial mean
	Woodslee	Chatham	Ridgetown	Elora	Nairn (2017) St. Mary's (2018)	Palmerston	Ottawa	Trial mean	
	kg ha^{-1}								%
2016–2017									
Hilliard	6,260	6,680	8,970*	8,170*	5,390*	6,710*	6,860*	7,006	115
Ava	5,490	5,720	7,170	6,620	4,780	5,720	6,190	5,956	98
Branson	6,000	6,200	8,380	7,320*	4,890	5,760*	7,280*	6,547	108
Mean ($N = 37$)	5,860	5,950	7,640	6,880	4,630	5,350	6,150	6,066	
LSD (0.05)	450	870	850	370	290	390	610		
CV, %	6.6	6.8	7.9	4.5	4.7	7.4	6.6		
2017–2018									
Hilliard	5,630*	7,030	4,600	8,400	4,790	7,480	7,200	6,447	105
Ava	4,700	7,010	4,870	8,710*	4,760	7,500	6,430	6,283	103
Branson	5,510	7,000	4,940	7,890	4,630	7,460	5,870	6,186	101
Mean ($N = 43$)	5,100	6,930	4,660	8,110	4,530	7,120	6,390	6,120	
LSD (0.05)	430	860	420	530	550	580	1,090		
CV, %	7.2	8.9	6.4	6.6	8.7	5.8	12.1		

*Yields significantly higher than the trial mean at $P < .05$.

significantly ($P \leq .05$) higher than trial means at five locations and similar at two sites. In the 2018 trial, grain yields of Hilliard (4600–8400 kg ha^{-1}) were similar to trial averages at six locations and significantly ($P \leq .05$) higher at one site.

3.3 | Disease and insect resistance

Reaction of Hilliard to disease and insect pests has been evaluated at diverse environments in USDA-ARS nurseries (Tables 3 and 4) as well as in Virginia's state variety trials (Virginia Tech, 2013–2019; https://secure.hosting.vt.edu/www.grains.cses.vt.edu/). Hilliard is resistant to powdery mildew, with average ratings (0 = immunity to 9 = very susceptible) ranging from 0.5 to 1.3. It is moderately resistant to leaf rust with average nursery ratings ranging from 1.3 to 2.8. Seedlings of entries in the 2014 Uniform Eastern and Uniform Southern SRW Wheat Nurseries were evaluated for resistance to 10 races of leaf rust by the USDA-ARS Cereal Disease Laboratory in St. Paul, MN (USDA–ARS, 2014). It was resistant to nine races (KFBJG, MBDSB,

MCTNB, MFPSB, MHDSB, PBLQG, TBBGJ, TFBJQ, and TNBGJ) of *P. triticina* and susceptible to one race (TCRKG). Hilliard was postulated to have the resistance gene *Lr18* on the basis of its differential reaction to the 10 races, which also was confirmed via the presence of markers linked to *Lr18* (USDA-ARS, 2016–2018).

In other tests conducted by the Cereal Disease Laboratory, seedlings of Hilliard were susceptible to all 10 tested races of stem rust and ratings (severity and reaction type) of adult plants varied from 35 (moderately resistant–moderately susceptible) to 70 (susceptible) in field tests. In controlled environment trials conducted by the USDA-ARS Wheat Genetics, Quality, Physiology, and Disease Research Unit at Pullman, WA (USDA-ARS, 2014), seedlings of Hilliard were susceptible to five tested races (PSTv-4, PSTv-14, PSTv-37, PSTv-40, and PSTv-51) of stripe rust. However, infection type (0–9) scores for adult plants of Hilliard (2–3) indicate that it has high-temperature adult-plant resistance to stripe rust. In field trials of entries in the 2016–2018 Uniform Southern and Uniform Eastern nurseries conducted in the eastern United States and in the state of Washington, Hilliard had mean stripe rust disease scores (0–9) varying from 0 to 0.7 and 3.7 to 5.4, respectively. Hilliard is moderately resistant (1.0–3.0) to *Barley yellow dwarf virus*. It is moderately resistant to *Wheat spindle streak mosaic virus* (1.0–2.5) and to *Wheat soil borne mosaic virus* (1.0–3.0) and has gene *Sbm1* on the basis of marker data (USDA-ARS, 2016–2018). Hilliard is moderately resistant (1.0–2.3) to bacterial leaf streak caused by *Xanthomonas translucens* pathovar (pv.) *undulosa* (Table 3; USDA-ARS, 2014). Hilliard has a moderate to intermediate level of resistance to leaf blotches caused by *Septoria tritici* Roberge in Desmaz. (1.3–5.5) and *Parastagonospora nodorum* (Berk.) Castellani & E.G. Germano (4.0–5.8) and to glume blotch caused by *Septoria nodorum* (Berk.) Castellani & E.G. Germano (1.8–4.5). Hilliard is moderately resistant to FHB, with mean ratings (0–9) varying from 0.5 to 1.4 in the 2016–2018 Uniform Southern and from 1.8 to 2.5 in the Uniform Eastern SRW wheat nurseries. Hilliard also was evaluated for reaction to FHB in the 2013–2014 Southern Uniform Winter Wheat Scab Nursery (Table 5) at seven environments (https://scabusa.org/research_vdhr#vdhr-updates). Hilliard had values for FHB incidence (73%), FHB severity (40%), Fusarium damaged kernels (38%), and deoxynivalenol toxin (11.2 mg kg^{-1}) that were lower than those of the susceptible check (88%, 62%, 51%, and 16.6 mg kg^{-1}) cultivar Coker 9835 (PI 548846). On the basis of DNA marker data (USDA-ARS, 2016–2018), Hilliard inherited the FHB resistance quantitative trait loci on chromosome 1BS from Jamestown. In the 2014 Southern Scab Nursery (Table 5), FHB resistance of Jamestown was notably better than that of Hilliard, while they had similar FHB mean ratings in the 2014–2016 Uniform Southern SRW Wheat Nurseries (Table 3). This likely is due to Jamestown being earlier heading than Hilliard, all data from the scab nursery being collected from inoculated and mist-irrigated trials versus data from some non-inoculated field trials in the latter nurseries, and/or Jamestown may have additional quantitative trait loci for FHB resistance.

In one or more seedling growth chamber tests conducted by the USDA-ARS at West Lafayette, IN, Hilliard expressed resistance to Hessian fly [*Mayetiola destructor* (Say)] biotypes B, C, and D but was susceptible to biotypes O and L (Tables 3 and 4; USDA-ARS 2014). In field trials in 2014 and 2017 (USDA-ARS, 2014, 2016–2018), Hilliard expressed moderate resistance (4.5–5.5) to Hessian fly on the basis of visual scores (0–9) for plant stunting and dark green foliage.

3.4 | End-use quality

Advanced Quadrumat Senior milling and baking quality evaluations were conducted by the USDA-ARS Soft Wheat Quality Laboratory in Wooster, OH, on entries in the 2016–2018 Uniform Southern and 2017 and 2018 Uniform Eastern nurseries (Tables 7 and 8; USDA-ARS, 2016–2018). Flour softness equivalent values of Hilliard in the Uniform Southern (59.5–61.5 g 100 g^{-1}) and Uniform Eastern (58.1 and 61.7 g 100 g^{-1}) sets were higher than those of Jamestown (52.3–58.2 g 100 g^{-1}) and MO-080104 (54.8 and 57.1 g 100 g^{-1}), respectively. Straight grade flour yields of Hilliard in the Uniform Southern (66.8–67.8 g 100 g^{-1}) and Uniform Eastern (67.7 and 68.4 g 100 g^{-1}) sets were similar to those of Jamestown (66.2–67.1 g 100 g^{-1}) and MO-080104 (66.9 and 67.1 g 100 g^{-1}), respectively. Flour protein concentration of Hilliard in the Uniform Southern (7.0–8.3 g 100 g^{-1}) and Uniform Eastern (8.2 and 9.1 g 100 g^{-1}) sets were slightly lower than those of Jamestown (7.5–8.8 g 100 g^{-1}) and similar to MO-080104 (8.4 and 8.6 g 100 g^{-1}), respectively. Protein gluten strength, assessed via lactic acid solvent retention capacity, of Hilliard in the Uniform Southern (114–128 g 100 g^{-1}) and Uniform Eastern (108 and 120 g 100 g^{-1}) sets was similar to that of Jamestown (110–126 g 100 g^{-1}) and lower than that of MO-080104 (124 and 125 g 100 g^{-1}), respectively. Cookie spread diameters (mean of two cookies) of Hilliard in the Uniform Southern (18.3–18.6 cm) and Uniform Eastern (18.3 and 18.6 cm) sets were higher than those of Jamestown (17.3–18.3 cm) and similar to those of MO-080104 (18.0 and 18.6 cm), respectively. Additional quality data for Hilliard (VA11W-108) in the 2013–2018 Virginia State Variety Trials is at https://secure.hosting.vt.edu/www.grains.cses.vt.edu/.

TABLE 7 Milling and baking quality characteristics of Hilliard versus three check cultivars evaluated in the cooperative Uniform Southern Soft Red Winter Wheat Nursery in 2016–2018 (USDA-ARS)

Cultivar	Flour yield	Softness equivalent	Flour protein	Gluten strength[a]	Cookie diameter
	g 100 g^{-1}				cm
2016					
Hilliard	66.8[b]	61.5	8.1[b]	117[c]	18.3
AGS 2000 (Std.)	69.6	58.4	8.9	105	18.2
Jamestown	66.2[c]	57.4	8.8	123[b]	17.3[b]
26R41	69.0	63.1[b]	7.8[b]	113	18.0
Mean ($N = 33$)	67.5	57.7	8.7	111	18.1
SD	1.7	3.6	0.5	10.1	0.4
2017					
Hilliard	67.7[b]	60.5	8.3[b]	128[b]	18.5
AGS 2000 (Std.)	70.9	60.0	9.0	112	18.6
Jamestown	66.7[c]	58.2	8.7	126[b]	18.3
26R41	69.3	59.6	8.2[b]	121	18.3
Mean ($N = 36$)	68.7	57.9	8.4	119	18.6
SD	1.7	2.4	0.5	10.8	0.4
2018					
Hilliard	67.8[b]	59.5[b]	7.0[b]	114	18.6
AGS 2000 (Std.)	70.6	55.5	7.7	98	18.9
Jamestown	67.1[c]	52.3[b]	7.5	110	18.3[b]
26R41	69.7	58.1	6.7[b]	106	18.6
Mean ($N = 40$)	68.7	55.7	7.4	107	18.8
SD	1.6	2.9	0.5	15.9	0.6

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a]Gluten strength estimated by lactic acid solvent retention capacity assay (Approved Method 56-11, American Association of Cereal Chemists, 2000). [b]Trait value differs from that of the cultivar used as the quality check (Std.) by one standard deviation. [c]Trait value differs from that of the cultivar used as the quality check (Std.) by two standard deviations.

4 | AVAILABILITY

The Foundation Seed Division of Virginia Crop Improvement Association in Mt. Holly, VA, provided initial foundation seed of Hilliard to seed producers during fall 2015, and certified seed was first available to producers in fall 2016. Hilliard is protected under U.S. Plant Variety Protection, Certificate no. 201700019. Recognized seed classes include foundation, registered, and certified. A seed sample has been deposited in the USDA-ARS National Center for Genetic Resources Preservation and will become available for distribution after expiration of its U.S. Plant Variety Protection. Small quantities of seed for research purposes may be obtained upon request from the corresponding author for at least five years from the date of this publication. It is requested that appropriate recognition be given when Hilliard contributes to the development of new germplasm or cultivars.

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TABLE 8 Milling and baking quality characteristics of Hilliard versus three check cultivars evaluated in the cooperative Uniform Eastern Soft Red Winter Wheat Nursery in 2017 and 2018 (USDA-ARS)

Cultivar	Flour yield	Softness equivalent	Flour protein	Gluten strength[a]	Cookie diameter
	g 100 g^{-1}				cm
2017					
Hilliard	67.7	61.7	8.2	121	18.3
Branson (Std.)	69.0	63.0	8.0	120	18.5
MO080104	67.1[b]	57.1[b]	8.6	125	18.0[b]
25R46	68.1	59.2[b]	8.1	96[b]	18.6
Mean ($N = 36$)	68.2	56.8	8.6	112	18.5
SD	1.5	3.3	0.7	11.1	0.4
2018					
Hilliard	68.4[b]	58.1[b]	9.1[b]	108	18.6
Branson (Std.)	70.6	61.7	8.4	105	18.8
MO080104	66.9[c]	54.8[b]	8.4	124[b]	18.6
25R46	69.2	57.2[b]	7.7[b]	87[b]	19.0
Mean ($N = 30$)	69.5	56.9	8.6	102	18.9
SD	1.7	3.5	0.6	13.6	0.4

Note. Complete data summaries available at https://www.ars.usda.gov/pacific-west-area/aberdeen-id/small-grains-and-potato-germplasm-research/docs/uniform-nurseries/ for 2016 nursery and at https://www.ars.usda.gov/southeast-area/raleigh-nc/plant-science-research/docs/nursery-reports/main/ for 2017 and 2018 nurseries.

[a]Gluten strength estimated by lactic acid solvent retention capacity assay (Approved Method 56-11, American Association of Cereal Chemists, 2000). [b]Trait value differs from that of the cultivar used as the quality check (Std.) by one standard deviation. [c]Trait value differs from that of the cultivar used as the quality check (Std.) by two standard deviations.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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