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CULTIVAR DESCRIPTION

AAC Warman Canada Western Red Spring wheat

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Abstract: AAC Warman (BW1025) is a high-yielding Canada Western Red Spring (CWRS) wheat adapted to production in western Canada. AAC Warman was 3% higher yielding than Unity, the highest yielding check in the Central Bread Wheat Cooperative registration trials (2014–2016). Within the same test, AAC Warman was 11% higher yielding than Carberry, a popular CWRS wheat variety across the Canadian prairies. AAC Warman matured 3 d earlier than Carberry and a day later than Unity, the earliest maturing check. AAC Warman was shorter than Unity and had better stem strength compared with Unity; however, the lodging score for AAC Warman was higher than the mean of the checks. Over 3 yr of testing (2014–2016), the test weight and thousand-kernel weight of AAC Warman was similar to Carberry. The grain protein content of AAC Warman was 0.3% lower than both Unity and Carberry. AAC Warman was rated moderately resistant to *Fusarium* head blight (*Fusarium graminearum* Schwabe) and loose smut [*Ustilago tritici* (Pers.) Rostr.], resistant to leaf rust (*Puccinia triticina* Erikss.) and stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Erikss. & E. Henn), moderately susceptible to stripe rust (*Puccinia striiformis* Westend.) and common bunt [*Tilletia caries* (DC.) Tul. & C. Tul.], and intermediately resistant to leaf spot complex. AAC Warman was resistant to orange wheat blossom midge (*Sitodiplosis mosellana* Géhin). Based on its milling and baking performance over 3 yr (2014–2016), as evaluated by the Grain Research Laboratory, Canadian Grain Commission, AAC Warman was registered under the CWRS market class.

Key words: Triticum aestivum L., CWRS, grain yield, quality, disease resistance, orange blossom wheat midge, *Fusarium* head blight, deoxynivalenol, cultivar description.

Résumé : AAC Warman (BW1025) est une variété de blé roux de printemps de l'Ouest canadien (CWRS) à haut rendement, acclimatée à l'ouest du Canada. Le rendement de ce cultivar dépasse de 3 % celui de Unity, le témoin qui a obtenu le meilleur rendement lors des essais d'homologation de la Central Bread Wheat Cooperative entre 2014 et 2016. Durant ces essais, AAC Warman a donné 11 % plus de grain que Carberry, une variété CWRS populaire dans les Prairies canadiennes. AAC Warman parvient à maturité trois jours avant Carberry et un jour après Unity, le témoin le plus précoce. AAC Warman est plus court que Unity et sa tige, plus robuste. Toutefois, le cultivar obtient une cote supérieure à la moyenne des témoins pour la verse. Au terme des trois années d'essais (2014–2016), le poids spécifique et le poids de mille grains d'AAC Warman étaient semblables à ceux de Carberry. Le grain d'AAC Warman renferme 0,3 % moins de protéines que celui de Unity et de Carberry. AAC Warman résiste modérément à la fusariose de l'épi (*Fusarium graminearum* Schwabe) et au charbon nu [*Ustilago tritici* (Pers.) Rostr.]; la variété résiste à la rouille des feuilles (*Puccinia triticina* Erikss.) et à la rouille de la tige (*Puccinia graminis* Pers. f. sp. *tritici* Erikss. & E. Henn), est modérément sensible à la rouille jaune (*Puccinia striiformis* Westend.) et à la carie [*Tilletia caries* (DC.) Tul. & C. Tul.], et résiste de façon intermédiaire au complexe de la tache foliaire. AAC Warman résiste à la cédidomyie du blé (*Sitodiplosis mosellana* Géhin). En raison des résultats pour le rendement à la mouture

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et à la boulange obtenus lors des trois années d'essais (2014-2016) au Laboratoire de recherches sur les grains de la Commission canadienne des grains, AAC Warman a été homologué dans la catégorie marchande des blés CWRS. [Traduit par la Rédaction]

Mots-clés : Triticum aestivum L., CWRS, rendement grainier, qualité, résistance à la maladie, cécidomyie du blé, fusariose de l'épi, désoxynivalénol, description de cultivar.

Introduction

The majority of hexaploid spring wheat grown in western Canada falls under the Canada Western Red Spring (CWRS) class (www.grainscanada.gc.ca). This is predominantly because of steady yields, optimum disease resistance, and excellent milling and baking attributes. The steady market demand for exports and its suitability as a rotation crop makes wheat the desirable cereal crop for farmers. With increasing global food demand, constantly changing pathogens, and diminishing farming-worthy land, there is a need to make incremental genetic gains in wheat. For agricultural sustainability, continued efforts are needed to develop improved wheat varieties.

AAC Warman is a hard red spring wheat cultivar developed by Agriculture and Agri-Food Canada (AAFC) at the Brandon Research and Development Centre, Brandon, MB, Canada. It was granted Plant Breeders Rights on 28 April 2017 under registration number 8449 by the Canadian Food Inspection Agency, Ottawa, ON. AAC Warman meets the end-use quality specifications of the CWRS class and is best adapted to Canadian prairie growing conditions.

Pedigree and Breeding Methods

AAC Warman was derived from the cross of BB07A × A637/Kane. The female parent, BB07A × A637, was a double-haploid (DH) line derived from the cross between Alsen (Frohberg et al. 2006) and 96B42-E3C, where Alsen is a hard red spring wheat variety and 96B42-E3C is a breeding line from the Cereal Research Centre (CRC), AAFC, Winnipeg, MB. Alsen (ND 674//ND 2710/ND 688), released by the North Dakota Agricultural Experiment Station in 2000, was developed by incorporating the *Fusarium* head blight (FHB) resistance from Sumai 3 into an adapted background that also had good stem and leaf rust resistance, yield, and quality characteristics. The male parent, Kane (BW342), was derived from a cross between AC Domain and McKenzie (Fox et al. 2007). McKenzie hard red spring wheat is the first DH wheat cultivar registered in Canada (Graf et al. 2003). Kane is a hard red spring wheat with good pre-harvest sprouting resistance and a high flour extraction rate. This complex cross was developed to generate a high-yielding, high-protein CWRS wheat variety adapted to the eastern Canadian prairies with broad resistance to leaf and stem rust, improved resistance to FHB, and resistance to orange wheat blossom midge. AAC Warman tested positive for markers linked to genes *Lr21*, *Lr23*, *Sr7a*, *Sr9b-2*, *YrR61*, *Fhb4B*, and *Sm1*. It also tested positive for the marker linked to gene *PHS-4A*, conferring post-harvest sprouting resistance similar to AC Domain.

AAC Warman was developed using the modified pedigree breeding method. The final cross for AAC Warman was made at CRC, AAFC in 2007. In 2007–2008, a set of 30 F_1 seeds were grown in a pair of 1.5-m rows near Leeston, New Zealand. The F_2 seeds harvested from Leeston were grown near Portage la Prairie, MB, as 3-m rows with 40 seeds per row. A set of 200 spikes was collected from each of the 3-m rows and tested for sprouting tolerance in rain simulators. The F_2-derived sprouting-tolerant lines were further selected based on yield and (or) protein content, disease resistance, and grain quality up to the F_6 generation. The F_6-derived heads were then tested in advanced yield trials at multiple locations and further testing was done based on disease and grain/flour quality attributes. Finally, the line BG48A0-3-3-16 was tested in the Central Bread Wheat Cooperative (CBWC) registration trials as BW1025 for 3 yr (2014–2016). A detailed description of the breeding history and breeder seed development is given in Table 1.

Agronomic data collection

The CBWC registration trial consisted of 30 entries tested at up to 11 locations within Manitoba and Saskatchewan using a rectangular lattice design with six groups with five entries per group and three replicates. The agronomic check cultivars included in the CBWC trials are Unity, Glenn, Carberry, and AAC Viewfield. The yield data from all three replicates were collected from all locations. The final plot yields at similar moisture contents were converted to yield per unit area (kg ha^{-1}). Days to maturity was recorded as days from seeding to when seeds resisted denting from a fingernail (16%–18% moisture), and data from all the replicates were collected multiple times per week. Plant height was measured in centimeters from the ground to the top of the spikes, excluding the awns after the extension growth had ceased. Lodging was recorded on a 1–9 scale, where 1 was upright and 9 was completely lodged. Test weight was measured on cleaned grain samples and reported as kilograms per hectolitre. Kernel weight was measured using a minimum of 200 undamaged kernels and recorded as milligrams per kernel.

Disease testing

The line BW1025 was evaluated for disease reaction to leaf, stem, and stripe rust, FHB, common bunt, and loose smut in CBWC trials between the years 2014 and 2016.

Table 1. Breeding history of AAC Warman (BW1025) hard red spring wheat.

Name	Gen.	Year	Details
BG48A	F_0	2007	Final cross made in a growth cabinet.
BG48A	F_1	2007–2008	30 F_1 seeds grown in a pair of 1.5-m rows near Leeston, New Zealand.
BG48A-N	F_2	2008	F_2 seeds grown as 50 3-m rows, ~40 seeds/row grown near Portage la Prairie, MB. 200 spikes were harvested for sprouting test at Indian Head, SK.
BG48A-NP	$F_{2:3}$	2008–2009	200 selected lines were grown in the Indian Head greenhouse.
BG48A-NP-3-I	$F_{2:4}$	2009	15 lines were grown in a 1-m row nursery near Portage la Prairie. Selection for agronomics, seed appearance, resistance to rusts and common bunt, protein concentration, flour yield, and mixograph.
BG48A-NP-3-IP-3	$F_{2:5}$	2009–2010	57 lines were grown near Palmerston North (PN), New Zealand, as hills. Selection for agronomics and leaf rust resistance.
BG48A-NP-3-IP-3-N	$F_{2:6}$	2010	15 lines were tested in a single replicate yield test at one location (Portage la Prairie). Selections based on agronomic and disease parameters, 30 spikes harvested per selected line and sent as 1 spike/row to PN.
BG48A-NP-3-IP-3-NP-16	$F_{6:7}$	2010–2011	28 lines were grown near PN in 1.5-m rows. Selection for agronomics and leaf rust resistance as well as quality parameters from F_6 seeds.
BG48A-NP-3-IP-3-NP-16	$F_{6:8}$	2011	9 lines were tested in unreplicated yield tests at two locations (Brandon, MB; Saskatoon, SK) Selection based on agronomics, disease resistance and quality.
BG48A-NP-3-IP-3-NP-16	$F_{6:9}$	2012	3 lines in the Central Bread Wheat (CBW) “A” test. Yield test: two replicates at five locations (Glenlea, Portage la Prairie, Brandon, and Morden, MB; Indian Head).
BG48A-NP-3-IP-3-NP-16	$F_{6:10}$	2013	1 line in the CBW “B” test. Yield test: three replicates at eight locations (Glenlea, Brandon, and Morden; Saskatoon, Indian Head, Melfort, and Kernen, SK; Beaverlodge, AB).
BW1025	$F_{6:11–13}$	2014–2016	1 line progressed to the CBW Cooperative registration test. Yield test: three replicates at various locations/years (Portage la Prairie, Brandon, Souris, and Dauphin, MB; Indian Head, Pense, Kamsack, Melfort, and Kernen, SK). In 2014, the Glenlea site was removed.
Breeder seed production			
BW1025	$F_{6:11}$		Breeder seed spikes: 250 random spikes were selected from a rogued increase plot grown at Indian Head.
BW1025	$F_{6:12}$		Breeder seed isolation rows: 250 lines were grown in 1 m rows grown near Brandon with a 10 m isolation distance from any other wheat.
BW1025	$F_{6:13}$		Breeder seed rows: 15-m rows grown at Indian Head with a 10 m isolation distance from other wheat. 150 rows were grown. Lines were rogued for uniformity and 67 lines were pulled. Approximately 150 kg of breeder seed was produced.

Field nurseries inoculated with either a macroconidial spore suspension (University of Manitoba, Carman, MB) or corn spawn [Morden Research and Development Centre (MRDC), Morden, MB] inoculum, with an equal proportion of four isolates (M1-07-2/15ADON; M3-07-2/15ADON; M7-07-1/3ADON; M9-07-1/3ADON) of *Fusarium graminearum* Schwabe, were used to evaluate tolerance to FHB. The visual rating index (VRI = % incidence × % severity/100) was recorded as described by Gilbert and Woods (2006) and the incidence severity deoxynivalenol (DON; ISD) rating was calculated as (0.2 × mean incidence + 0.2 × mean severity + 0.6 × mean DON). Reactions to leaf (*Puccinia triticina* Eriks.) and stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Erikss. & E. Henn) diseases were assessed using the modified Cobb scale (Peterson et al. 1948) in inoculated field nurseries at MRDC. Experiments were also conducted in the greenhouse to evaluate seedling reactions to four leaf rust races, MBDS (12-3), MGBJ (74-2), TJBJ (77-2), and MBRJ (128-1) (McCallum and Seto-Goh 2006), and six stem rust races, TMRTF (C10), RKQSC (C63), TPMKC (C53), RTHJF (C57), QTHJF (C25), and RHTSC (C20) (Fetch 2005; Jin et al. 2008). Natural field infections were used to assess the disease severity and reaction to stripe rust (*Puccinia striiformis* Westend.) near Lethbridge, AB (Randhawa et al. 2012). Common bunt [*Tilletia caries* (DC.) Tul. & C. Tul.] resistance was recorded at the Lethbridge Research and Development Centre, Lethbridge, AB, using a composite of races L1, L16, T1, T6, T13, and T19, and planting inoculated seed into cold soil (Gaudet and Puchalski 1989; Gaudet et al. 1993). The reaction to loose smut [*Ustilago tritici* (Pers.) Rostr.] was assessed by inoculating wheat spikes with a composite of races T2, T9, T10, and T39 (Menzies et al. 2003) and rating the progeny

Table 2. Yield (kg ha^{-1}) of AAC Warman (BW1025) and check cultivars in the Central Bread Wheat Cooperative (2014–2016) tests.

	Zone 1[a]			Zone 2[b]			All sites			
							2014–2016		2015–2016	
Cultivar	2014	2015	2016	2014	2015	2016	kg ha^{-1}	% Unity	kg ha^{-1}	% Unity
Unity	5275	4645	3758	4861	3377	4754	4386	100	4166	100
Glenn	4536	4285	3661	4592	3184	4129	4043	92	3848	92
Carberry	4589	4342	3646	4415	3263	4350	4066	93	3910	94
AAC Viewfield	—	4574	3331	—	3454	4450	—	—	3973	95
AAC Warman	5352	4747	4027	5058	3257	5029	4522	103	4293	103
Mean of checks	4800	4462	3599	4623	3320	4421	4165	95	3974	95
$LSD_{0.05}$	618	530	416	484	385	491	434	—	538	—
No. of tests	3	4	5	4	5	6	27	—	20	—

Note: LSD, least significant difference appropriate to make comparisons of AAC Warman to Unity, Glenn, Carberry, and AAC Viewfield; $P \leq 0.05$, includes the appropriate genotype × environment interaction.

[a]Zone 1 test locations: 2014 — Brandon, Dauphin, Portage la Prairie; 2015 — Dauphin, Portage la Prairie, Souris; 2016 — Brandon, Souris, Morden, Neepawa, Fort Whyte.

[b]Zone 2 test locations: 2014 — Kernen, Indian Head, Melfort, Pense; 2015 — Kamsack, Kernen, Indian Head, Melfort, Pense; 2016 — Kamsack, Melfort, Pense, Indian Head, Kernen, Waldheim.

plants grown in a greenhouse from the infected seeds. The reaction to midge (*Sitodiplosis mosellana* Géhin) feeding damage was assessed by visually inspecting the midge-damaged kernels on mature spikes. Sixty spikes (20 spikes per replicate from three replicates) were collected per entry and were analyzed under a dissecting microscope for larval feeding damage symptoms. Based on the type of damage, the entries were classified as resistant, susceptible, or undamaged.

Grain and flour quality evaluation

Evaluation of end-use quality was conducted by the Grain Research Laboratory (GRL) of the Canadian Grain Commission (CGC) in Winnipeg, MB. Protein content and grade of the check cultivars were used as criteria to prepare composite samples from all test locations, which were subsequently used in tests to measure grain protein (%), flour protein (%), protein loss (%), falling number (s), α-amylase activity (amylograph; BU), clean flour yield (%), flour yield (0.50 ash; %), flour ash (%), starch damage (%), farinograph properties, and dough development properties using standard analytical methods as outlined in the Prairie Recommending Committee for Wheat, Rye and Triticale operating procedures (PRCWRT 2015).

The PROC MIXED module (SAS version 9.4, SAS Institute Inc., Cary, NC) with years, environments, and their interactions treated as random effects, and cultivar as a fixed effect, was used to generate the least significant difference (LSD) for analyzing the improvements of AAC Warman over the check cultivars.

The end-use quality data are non-replicated observations within years.

Performance

The 2014–2016 CBWC registration trials had Unity (BW362) (Fox et al. 2010), Glenn (ND747) (Mergoum et al. 2006), Carberry (BW874) (DePauw et al. 2011) and AAC Viewfield (BW965) as the recommended checks. Based on 27 site–years of testing over 3 yr, AAC Warman was higher yielding than Carberry (10%), Glenn (11%), and Unity (3%) (Table 2). Two years (2015–2016) of comparisons (20 sites) showed that AAC Warman was 8% higher yielding than AAC Viewfield.

AAC Warman matured 3 d earlier than Carberry and was earlier than all checks except Unity (Table 3). AAC Warman was 1 cm shorter in height and had better lodging resistance compared with Unity (Table 3). The test weight and kernel weight of AAC Warman were similar to Carberry (Table 3). The grain protein content of AAC Warman was 0.3 units lower than Unity and 0.6 units lower than Carberry in 2015–2016 (Table 3).

AAC Warman had adequate resistance to diseases prevalent in the Canadian prairies. AAC Warman was rated moderately resistant to FHB by the disease evaluation team of the Prairie Grain Development Committee. Over 3 yr of testing (2014–2016), AAC Warman expressed mostly resistant reactions to FHB at Carman and Morden (Table 4). It consistently had lower DON levels compared with all the agronomy checks in the inoculated nurseries (Table 4). AAC Warman was resistant to the prevalent races of leaf and stem rusts but was moderately susceptible to stripe rust. It was also rated intermediately resistant to the "Ug99" family of stem rust (Table 5). AAC Warman was moderately resistant to loose smut, susceptible to bunt, and intermediately resistant to leaf spot diseases (Table 6). AAC Warman was also resistant to orange blossom wheat midge based on phenotypic data on midge tolerance and the presence of the *Sm1* gene (Table 6).

Grain protein, milling, and flour baking properties of AAC Warman were tested by GRL. End-use quality assessment (AACC 2000) was done on a composite sample

Table 3. Summary of agronomic traits of AAC Warman (BW1025) and check cultivars in the Central Bread Wheat Cooperative (2014–2016) tests.

	Maturity (d)		Height (cm)		Lodging score[a] (1–9)		Test weight (kg hL^{-1})		Kernel weight (mg $kernel^{-1}$)		Protein (%)	
Cultivar	2014–2016	2015–2016	2014–2016	2015–2016	2014–2016	2015–2016	2014–2016	2015–2016	2014–2016	2015–2016	2014–2016	2015–2016
Unity	92	92	98	94	3.0	2.9	78	77	31.5	31.5	15.0	15.1
Glenn	95	94	91	89	1.8	1.7	80	80	31.9	31.9	14.9	15.2
Carberry	96	95	84	83	1.7	1.8	78	77	31.9	31.9	15.0	15.4
AAC Viewfield	—	95	—	78	—	1.5	—	77	—	29.7	—	15.5
AAC Warman	93	93	97	95	2.6	2.6	78	78	31.9	31.8	14.7	14.8
Mean of checks	94	94	91	86	2.2	2.0	79	78	31.8	31.4	15.0	15.2
$LSD_{0.05}$	1.9	1.5	4.6	3.6	1.0	1.0	—	—	—	—	—	—
No. of tests	26	19	26	18	19	15	27	19	27	19	27	19

Note: LSD appropriate to make comparisons of AAC Warman to Unity, Glenn, Carberry, and AAC Viewfield. $P \leq 0.05$, includes the appropriate genotype × environment interaction.

[a]Lodging score on a scale of 1–9, where 1 = vertical and 9 = flat.

Table 4. *Fusarium* head blight (FHB) VRI[a], DON, and ISD[b] for AAC Warman (BW1025) and check cultivars in the Central Bread Wheat Cooperative (2014–2016) tests.

	2014					2015			2016		
	VRI	DON	VRI	DON	ISD	VRI	DON	ISD	VRI	DON	ISD
Cultivar	PEI		Carman								
Unity	35	17.3	25.9I	6.6	6.1MR	31.5I	12	9.6	23.3I	11.2	8.8
Glenn	43.7	15.5	3.2R	9.2	6.6I	3.9R	12	8.3	9R	8	6.4
Carberry	50	14	20.2I	8.6	7.2I	15.1MR	9.5	7.6	11.8MR	17.2	12
AAC Viewfield	—	—	—	—	—	21.5I	15	11.1	31.8MS	43.5	28.6
AAC Warman	42.7	14.3	3.8R	9.5	7.0I	6.6R	8.6	6.5	7.4R	7.2	5.8
	Ottawa		Morden								
Unity	43	14.4	64.0S	43.7	29.4MR	50.0I	18.3	13.8MR	41.2MR	25.5	18.0MR
Glenn	28	15.6	47.5I	36.9	25.0MR	32.0MR	23.5	16.4MR	12.9R	17.6	12.5R
Carberry	35	17.2	38.3I	40.7	27.0MR	41.0MR	15.2	11.8MR	39.8MR	22.1	15.9MR
AAC Viewfield	—	—	—	—	—	46.0I	22.7	16.4MR	53.0MS	41.8	28.1MS
AAC Warman	33	9.9	54.7MS	33.6	23.2R	30.7MR	11.4	9.0R	15.3R	11.5	8.9R

Note: Disease rating class: R, resistant; MR, moderately resistant; I, intermediate; MS, moderately susceptible, S, susceptible. DON, deoxynivalenol.

[a]VRI, visual rating index: (percentage of infected heads × percentage of diseased florets on infected heads)/100.

[b]ISD, incidence severity DON: visual incidence + visual severity + DON = (0.2 × mean incidence + 0.2 × mean severity + 0.6 × mean DON).

Table 5. Rust disease severities and ratings of AAC Warman (BW1025) and check cultivars in the Central Bread Wheat Cooperative (2014–2016) tests.

	Leaf rust			Stem rust			Stripe rust				UG99		
Cultivar	2014	2015	2016	2014	2015	2016	2014	2015	2016	2016	2014	2015	2016
Unity	32MR	37I	30M	3MR	20I	10MR	83S	40S	60S	95S	15M	40M	80S
Glenn	20MR	6R	25MR	1R	10MR	5R	30I	2R	17MR	35I	10MS	25M	80S
Carberry	0R	4R	0.3R	3MR	5R	2R	5R	2R	10MR	25I	20S	15M	70S
5603HR	52MS	—	—	1R	—	—	25MR	—	—	—	—	—	—
AAC Viewfield	—	10R	10R	—	15MR	5R	—	15I	25I	15MR	—	3MS	30MS
AAC Warman	0R	2R	0.3R	1R	5R	15MR	25MR	30MS	50MS	75S	30M	—	40M

Note: Disease response categories: R, resistant (1%–10%); MR, moderately resistant (11%–30%); I, intermediate (31%–39%); MS, moderately susceptible (40%–60%); S, susceptible (>60%).

Table 6. Bunt, smut, leaf spot, and midge ratings of AAC Warman (BW1025) and check cultivars in the Central Bread Wheat Cooperative (2014–2016) tests.

	Common bunt			Loose smut		Leaf spots			Midge[a]	
Cultivar	2014	2015	2016	2014	2015	2014	2015	2016	2015	2016
Unity	0R	0R	2R	6R	4R	7I	7.0I	10S	6:1:4	4:1:5
Glenn	21MS	8R	16I	0R	4R	7I	6.0MR	10S	0:9:1	0:7:3
Carberry	2R	0R	0R	9R	0R	7I	8.3MS	10S	0:9:1	0:8:2
AAC Viewfield	—	26MS	19I	—	2R	—	7.0I	9MS	0:10:1	0:9:1
AAC Warman	28MS	50S	29MS	24MR	16R	7.5I	7.3I	10S	3:0:7	3:0:7

Note: Disease response categories: R, resistant; MR, moderately resistant; I, intermediate; MS, moderately susceptible; S, susceptible.
[a]Midge rating, R:S:U (Resistant:Susceptible:Undamaged).

formulated from trial locations with grain samples representative of the best hard red spring wheat grades available. A predetermined quantity of final grain was made by varying the proportion of grain from each location to achieve a final protein concentration approximating the average for the crop in the given year. AAC Warman met the milling and baking performance of the CWRS class of wheat. Grain protein (%) was similar to Unity and lower than the other checks (Table 7). AAC Warman had lower protein loss compared with all other checks. Flour protein (%) was similar to Glenn and falling number was similar to Carberry. Amylograph (BU), clean flour yield (%), flour ash (%), and starch damage were higher than Carberry, whereas flour yield (0.05 ash; %) was lower than Carberry (Table 7). Water absorption measured on the farinograph directly relates to the amount of bread that can be produced from a given weight of wheat flour. The farinograph absorption was similar to or higher than Carberry within the tested years (2014–2016), and dough stability was higher than the mean of the checks in 2014 and 2016 (Table 8). Baking quality was assessed using the Canadian short process (Preston et al. 1982) for 2014 and 2015 and the Lean No Time test (Dupuis and Fu 2016) in 2016. AAC Warman loaf volume (cm^3) was higher than the mean of the checks in 2014–2015 and the loaf top ratio was better than all checks in 2016 (Table 8).

Other Characteristics

The morphological characteristics were recorded using experimental field plots grown in 2016 and 2017 at Saskatoon, SK.

Seedling characteristics

Coleoptile colour: absent or very weak.
Juvenile growth habit: semi-erect to intermediate.
Seedling leaves: medium to dark green; glabrous.
Tillering capacity (at low densities): moderately high.

Adult plant characteristics

Growth habit: semi-erect to intermediate.
Flag leaf attitude: intermediate.
Flag leaf: light to medium green; slightly curved to recurved; glabrous sheath and blade; slightly waxy blade; long and narrow width; glabrous margins.
Culm: straight; glabrous; slight waxiness.

Spike characteristics

Shape: erect and oblong.
Length: short.
Density: medium.
Attitude: erect.
Colour: tan at maturity.
Awns: awned.

Table 7. Wheat and flour analytical data for AAC Warman (BW1025) and check cultivars from the Central Bread Wheat Cooperative (2014–2016) tests.

Cultivar	Grain protein (%)	Flour protein (%)	Protein loss (%)	Falling no. (s)	Amylo-graph (BU)	Clean flour yield (%)[a]	Flour yield (0.50 ash) (%)	Flour ash (%)	Starch damage (%)
2014									
Unity	13.7	12.7	1.0	380	675	76.7	77.5	0.43	7.2
Glenn	13.6	12.7	0.9	290	375	73.8	77.5	0.43	7.9
Carberry	13.8	12.8	1.1	300	215	75.3	78.0	0.42	6.7
AAC Viewfield[b]	—	—	—	—	—	—	—	—	—
Mean of checks	13.7	12.7	1.0	323	421	75.3	77.7	0.40	7.3
AAC Warman	13.4	12.7	0.8	295	315	74.8	78.0	0.42	7.5
2015									
Unity	15.1	14.6	0.5	450	695	76.0	75.5	0.47	7.7
Glenn	15.3	14.4	0.8	320	500	75.0	77.0	0.44	8.3
Carberry	15.6	14.3	1.3	360	400	75.0	78.0	0.42	7.1
AAC Viewfield[b]	15.9	14.8	1.1	320	420	74.9	77.0	0.44	7.1
Mean of checks	15.5	14.5	0.9	362	503	75.2	76.9	0.40	7.6
AAC Warman	15.2	14.6	0.6	300	345	76.1	75.5	0.47	7.9
2016									
Unity	13.2	12.4	0.8	405	755	76.5	77.0	0.44	8.3
Glenn	13.8	13.0	0.8	325	525	74.4	76.5	0.45	8.7
Carberry	14.3	13.3	1.0	370	350	75.4	76.5	0.45	7.4
AAC Viewfield[b]	13.8	13.0	0.8	370	455	75.3	77.5	0.43	7.2
Mean of checks	13.8	12.9	0.9	367	521	75.4	76.9	0.40	7.9
AAC Warman	13.4	12.7	0.7	335	470	75.9	76.0	0.46	8.4

Note: End-use quality testing was performed by the Grain Research Laboratory (GRL) of the Canadian Grain Commission (CGC) on a composite sample of each cultivar. American Association of Cereal Chemists methods were followed by GRL, CGC for determining the various end-use quality traits on a composite of 6–10 locations each year.

[a]See Dexter and Tipples (1987). All millings at GRL, CGC are performed in rooms with environmental control maintained at 21 °C and 60% relative humidity. Common wheat is milled on an Allis-Chalmers laboratory mill using the GRL sifter flow as described by Black et al. (1980). Flour yield is expressed as a percentage of cleaned wheat on a constant moisture basis.

[b]AAC Viewfield data are from 2015 and 2016.

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Table 8. Dough properties and baking qualities for AAC Warman (BW1025) and check cultivars from the Central Bread Wheat Cooperative (2014–2016) tests.

	Dough properties							Baking quality				
	Farinograph				Extensograph			CSP/lean no time				
Cultivar	Abs. (%)[a]	DDT (min)	MTI (BU)	Stability (min)	Ext. area	Ext. R_{max}	Ext. length	Abs. (%)	Mixing time (min)	Mixing energy (W hr kg^{-1})	Loaf volume (cm^3)	Loaf top ratio
2014												
Unity	63.6	4.00	40	6.0	85	367	18.2	68	4.6	11.5	1000	—
Glenn	64.3	4.50	25	8.5	126	596	17.1	68	6.3	15.4	990	—
Carberry	61.9	5.75	45	7.5	105	415	19.8	66	4.9	10.6	960	—
AAC Viewfield	—	—	—	—	—	—	—	—	—	—	—	—
Mean of checks	63.3	4.75	37	7.3	105	459	18.4	67	5.3	12.5	983	—
AAC Warman	62.9	4.25	30	8.5	109	516	18.1	67	5.9	15.0	995	—
2015												
Unity	65.3	5.75	45	6.0	87	355	19.5	69	3.4	9.1	1005	—
Glenn	65.6	8.00	30	9.5	151	691	18.5	70	5.5	13.6	980	—
Carberry	63.9	6.00	30	8.0	108	418	20.8	68	4.5	11.6	985	—
AAC Viewfield	64.5	8.25	30	9.5	117	449	20.5	69	4.5	11.4	980	—
Mean of checks	64.8	7.00	34	8.3	116	478	19.8	69	4.5	11.4	988	—
AAC Warman	64.8	7.75	40	7.5	114	463	19.8	69	4.5	11.1	1005	—
2016												
Unity	63.6	4.75	—	6.0	73	300	19.0	70	2.9	8.3	795	0.55
Glenn	65.6	5.50	—	9.5	122	624	16.4	73	3.8	10.5	910	0.67
Carberry	63.7	5.50	—	5.5	90	353	20.5	71	3.0	8.3	790	0.55
AAC Viewfield	63.6	5.75	—	7.5	91	358	20.3	71	3.1	7.8	825	0.51
Mean of checks	64.1	5.38	—	7.1	94	409	19.1	71	3.2	8.7	830	0.57
AAC Warman	63.4	5.50	—	8.0	93	451	16.6	70	3.6	9.6	865	0.69

Note: CSP, Canadian short process (Preston et al. 1982) and lean no time (Dupuis and Fu 2016); DDT, farinograph dough development time measured in minutes; MTI, farinograph mixing tolerance index, expressed in Brabender units (BU); Ext., external.

[a]Abs., absorption; AACC (2000).

Spikelet characteristics

Glumes: short length and medium to narrow width; glabrous; oblique to rounded shoulder shape; beak medium in length with acuminate shape.

Lemma: slightly curved.

Kernel characteristics

Type: hard; light to medium red in colour.

Size: medium size; medium length; narrow to medium width; oval shape; rounded cheeks; medium to long brush hairs; narrow and medium deep crease.

Embryo: medium size; round.

Maintenance and Distribution of Pedigreed Seed

Breeder seed of AAC Warman was produced using 250 random spikes from a rogued increase plot grown at Indian Head, SK, in 2016. Spikes were analysed for signs of midge damage and were discarded based on evidence of midge feeding. Two hundred and fifty lines were grown in isolation for breeder seed in 1-m rows with a 10 m isolation distance from any other wheat near Brandon, MB, in 2015. One hundred lines were removed due to non-uniform plant phenotype, low seed amounts, or piebald kernels. One hundred and fifty Breeder Seed rows were grown as 15-m-long rows maintaining a 10 m isolation distance from other wheat at Indian Head in 2016. An additional 67 rows were further discarded. The remaining uniform plots were inspected and bulk harvested, producing 150 kg of Breeder Seed. Multiplication and distribution of all other pedigreed seed classes will be handled by SeCan, Box 30, Elstow, SK S0K 1M0, Canada (www.secan.com). AAC Warman is a midge-resistant variety, and to maintain the effectiveness of the *Sm1* gene against wheat orange blossom midge, the certified seed will include AAC Tisdale as a 10% interspersed susceptible refuge.

Author Contributions

S.L. Fox made the initial cross for AAC Warman. S. Kumar performed selections and progression of lines to finally select AAC Warman (BW1025). S. Kumar analysed the registration trial data, generated varietal identification data for Variety Registration and Plant Breeders' Rights, including the necessary documentation, and wrote the manuscript. The other authors contributed agronomic and disease evaluation data from the registration trials.

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References

AACC. 2000. Approved methods of the AACC. 10th ed. Approved Methods 44-15A and 76–13. American Association of Cereal Chemists, St. Paul, MN.

Black, H.C., Hsieh, F.H., Tipples, K.H., and Irvine, G.N. 1980. GRL sifter for laboratory flour milling. Cereal Food World, **25**: 757–760.

DePauw, R.M., Knox, R.E., McCaig, T.N., Clarke, F.R., and Clarke, J.M. 2011. Carberry hard red spring wheat. Can. J. Plant Sci. **91**: 529–534. doi:10.4141/cjps10187.

Dexter, J.E., and Tipples, K.H. 1987. Wheat milling at the Grain Research Laboratory. Part 3. Effect of grading factors on wheat quality. Milling, **180**: 18–20.

Dupuis, B., and Fu, B.X. 2016. A new lean no time test baking method with improved discriminating power. J. Cereal Sci. **74**: 112–120. doi:10.1016/j.jcs.2017.01.017.

Fetch, T.G. 2005. Races of *Puccinia graminis* on wheat, barley, and oat in Canada, in 2002 and 2003. Can. J. Plant Pathol. **27**: 572–580. doi:10.1080/07060660509507258.

Fox, S.L., Humphreys, D.G., Brown, P.D., Townley-Smith, T.F., McCallum, B.D., Fetch, T.G., Gaudet, D.A., Menzies, J.G., Gilbert, J.A., and Noll, J.S. 2007. Kane hard red spring wheat. Can. J. Plant Sci. **87**: 889–894. doi:10.4141/CJPS06043.

Fox, S.L., McKenzie, R.I.H., Lamb, R.J., Wise, I.L., Smith, M.A.H., Humphreys, D.G., Brown, P.D., Townley-Smith, T.F., McCallum, B.D., Fetch, T.G., Menzies, J.G., Gilbert, J.A., Fernandez, M.R., Despins, T., Lukow, O., and Niziol, D. 2010. Unity hard red spring wheat. Can. J. Plant Sci. **90**: 71–78. doi:10.4141/CJPS09024.

Frohberg, R.C., Stack, R.W., Olson, T., Miller, J.D., and Mergoum, M. 2006. Registration of 'Alsen' wheat. Crop Sci. **46**: 2311–2312. doi:10.2135/cropsci2005.12.0501.

Gaudet, D.A., and Puchalski, B.L. 1989. Races of common bunt (*Tilletia caries* and *T. foetida*) in western Canada. Can. J. Plant Pathol. **11**: 415–418. doi:10.1080/07060668909501089.

Gaudet, D.A., Puchalski, B.J., Kozub, G.C., and Schaalje, G.B. 1993. Susceptibility and resistance in Canadian spring wheat cultivars to common bunt (*Tilletia tritici* and *T. laevis*). Can. J. Plant Sci. **73**: 1217–1224. doi:10.4141/cjps93-161.

Gilbert, J., and Woods, S. 2006. Strategies and considerations for multi-location FHB screening nurseries. Pages 93–102 in T. Ban, J.M. Lewis, and E.E. Phipps, eds. The Global Fusarium Initiative for International Collaboration: A Strategic Planning Workshop, 14–17 Mar. 2006. CIMMYT, El Batan, Mexico.

Graf, R.J., Hucl, P., Orshinsky, B.R., and Kartha, K.K. 2003. McKenzie hard red spring wheat. Can. J. Plant Sci. **83**: 565–569. doi:10.4141/P02-115.

Jin, Y., Szabo, L.J., Pretorius, Z.A., Singh, R.P., Ward, R., and Fetch, T., Jr. 2008. Detection of virulence to resistance gene Sr24 within race TTKS of *Puccinia graminis* f. sp. *tritici*. Plant Dis. **92**: 923–926. doi:10.1094/PDIS-92-6-0923.

McCallum, B.D., and Seto-Goh, P. 2006. Physiologic specialization of *Puccinia triticina*, the causal agent of wheat leaf rust, in Canada in 2004. Can. J. Plant Pathol. **28**: 566–576. doi:10.1080/07060660609507335.

Menzies, J.G., Knox, R.E., Nielsen, J., and Thomas, P.L. 2003. Virulence of Canadian isolates of *Ustilago tritici*: 1964–1998, and the use of the geometric rule in understanding host differential complexity. Can. J. Plant Pathol. **25**: 62–72. doi:10.1080/07060660309507050.

Mergoum, M., Frohberg, R.C., Stack, R.W., Olson, T., Friesen, T.L., and Rasmussen, J.B. 2006. Registration of 'Glenn' wheat. Crop Sci. **46**: 473–474. doi:10.2135/cropsci2005.0287.

Peterson, R.F., Campbell, A.B., and Hannah, A.E. 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res. **26**: 496–500. doi:10.1139/cjr48c-033.

PRCWRT. 2015. Prairie Recommending Committee for wheat, rye and triticale operating procedures. [Online]. Prairie Recommending Committee for Wheat, Rye and Triticale, Prairie Grain Development Committee, Lethbridge, AB. Available from http://pgdc.ca/pdfs/wrt/CFIA_ACIA%20-%20_7730947%20-%20v2F%20-%20VRO-2018-19-RC-OP-PRCWRT_Prairie%20wheat%20committees%20operating%20procedures_March%2022%202018.pdf.

Preston, K.R., Kilborn, R.H., and Black, H.C. 1982. The GRL pilot mill. II. Physical dough and baking properties of flour streams milled from Canadian red spring wheats. Can. Inst. Food Sci. Technol. J. **15**: 29–36. doi:10.1016/S0315-5463(82)72310-7.

Randhawa, H.S., Puchalski, B.J., Frick, M., Goyal, A., Despins, T., Graf, R.J., Laroche, A., and Gaudet, D.A. 2012. Stripe rust resistance among western Canadian spring wheat and triticale varieties. Can. J. Plant Sci. **92**: 713–722. doi:10.4141/cjps2011-252.