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CULTIVAR DESCRIPTION

AAC Icefield hard white winter wheat

R.J. Graf, B.L. Beres, H.S. Randhawa, D.A. Gaudet, and A. Laroche

Abstract: AAC Icefield is the first hard white winter wheat (*Triticum aestivum* L.) cultivar registered in western Canada. It was selected from a population of F_1-derived doubled-haploids of the cross McClintock/83W020007. Registration testing occurred from 2013 to 2017. These data, collected over 53 site–years, showed that AAC Icefield yielded significantly more grain than CDC Buteo, was similar in yield to Flourish, Moats, and CDC Falcon, and was significantly lower yielding than AAC Elevate and Sunrise. AAC Icefield expressed fair survival, intermediate maturity, short straw, and very good lodging resistance. Test weight and kernel weight were within the range of the checks. Ratings based on the prevalent disease races in western Canada were summarized as resistant to stem rust, moderately resistant to leaf and stripe rust, intermediate in resistance to *Fusarium* head blight, and susceptible to common bunt. The grain yield, agronomic characteristics, and disease resistance attributes of AAC Icefield provide good adaptation for all areas of western Canada. Despite lower grain protein concentration than Canada Western Red Winter wheat cultivars, AAC Icefield showed exceptional gluten strength per unit of protein. AAC Icefield is well-suited to a wide range of end-uses including white and whole-grain pan bread, French and flat breads, Asian steamed bread, and noodles. Currently designated in the Canada Western Experimental wheat class to facilitate test marketing, a decision on permanent class placement for AAC Icefield will be made by the Canadian Grain Commission following the assessment of market interest.

Key words: Triticum aestivum L., wheat (winter), cultivar description, hard white, Asian steamed bread, whole-grain bread, noodles.

Résumé : AAC Icefield est le premier cultivar de blé dur blanc d'hiver (*Triticum aestivum* L.) homologué dans l'Ouest canadien. La variété vient d'une population d'hybrides à double haploïdie dérivée de la F_1 du croisement McClintock/83W020007. Les essais d'homologation se sont déroulés de 2013 à 2017. Les données recueillies à plus de 53 sites-années indiquent qu'AAC Icefield produit sensiblement plus de grains que CDC Buteo, autant que Flourish, Moats et CDC Falcon, et nettement moins qu'AAC Elevate et Sunrise. AAC Icefield survit passablement bien à l'hiver, a une précocité moyenne et se caractérise par une paille robuste ainsi qu'une très bonne résistance à la verse. Son poids spécifique et le poids de son grain se situent dans la plage des témoins. Les résultats relatifs aux maladies qui prévalent dans l'Ouest canadien peuvent se résumer comme suit : résistance à la rouille de la tige, résistance modérée à la rouille des feuilles et à la rouille jaune, résistance intermédiaire à la brûlure fusarienne de l'épi et sensibilité à la carie. Le rendement grainier, les paramètres agronomiques et la résistance à la maladie d'AAC Icefield en garantissent une bonne acclimatation aux diverses régions de l'Ouest canadien. Malgré un grain à teneur plus faible en protéines que les autres cultivars « Blé rouge d'hiver de l'Ouest canadien », AAC Icefield fournit un gluten d'une fermeté exceptionnelle par unité de protéine. AAC Icefield se prête bien à une vaste gamme d'utilisations, y compris la production de pain moulé blanc ou à grains entiers, de pain baguette et de pain plat, ainsi que de pain à la vapeur asiatique et de nouilles. La variété a été admise dans la catégorie « grade expérimental de l'Ouest canadien » afin de faciliter les essais de marketing. La Commission canadienne des grains déterminera la classe définitive d'AAC Icefield après évaluation de l'intérêt commercial que suscite la variété. [Traduit par la Rédaction]

Mots-clés : Triticum aestivum L., blé (d'hiver), description de cultivar, blé dur blanc, pain à la vapeur asiatique, pain de grain entier, nouilles.

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Introduction

AAC Icefield is the first hard white winter wheat (*Triticum aestivum* L.) cultivar registered for production in western Canada. It was developed by the Agriculture and Agri-Food Canada (AAFC) Lethbridge Research and Development Centre (LeRDC) in Lethbridge, AB, Canada. Tested as LF1706W and W530, interim registration No. I-422 was granted by the Variety Registration Office, Plant Production Division, Canadian Food Inspection Agency on 30 Nov. 2016. Full registration No. 8533 was granted on 4 May 2018. Plant Breeders' Rights application No. 15-8743 has been accepted for filing. During the period of interim registration and for a time after full registration, the Canadian Grain Commission (CGC) designated AAC Icefield in the Canada Western Experimental (CW EXPRMTL) wheat class to facilitate test marketing. A decision on permanent class placement will be made following an assessment of market interest.

In 2010, the Alberta Winter Wheat Producers' Commission, Canadian International Grains Institute (CIGI), and AAFC met in Lethbridge to discuss strategies to increase the farm-gate value of western Canadian winter wheat. Among the suggestions was the pursuit of milling markets for Asian steamed breads, as the flour is of high value and Canada Western Red Winter (CWRW) is a medium-protein wheat that produces high yields of bright white, low ash flour with functionality suitable for this type of product. It was also proposed that hard white wheat cultivars with CWRW milling properties could have a competitive advantage. These deliberations prompted a small increase of LF1706W, which had been dropped from internal testing in 2006 due to the absence of an appropriate market class. The creation of the Canada Western General Purpose (CWGP) wheat class in 2008, later renamed Canada Western Special Purpose (CWSP), and subsequent end-use product analyses by CIGI, encouraged assessment for possible registration.

Pedigree and Breeding Methods

Early generation development and characterization

AAC Icefield is an F_1-derived doubled-haploid (DH) cultivar that originates from the cross McClintock/83W020007 made in 2000 at LeRDC. McClintock is a CWRW wheat cultivar developed by the University of Manitoba, Winnipeg, MB, that has VT2222/Norstar parentage (Brûlé-Babel 2003). 83W020007 was an experimental hard white winter wheat line developed by the Field Crop Development Centre, Alberta Agriculture and Forestry, Lacombe, AB, that was tested as W349 in the Western Winter Wheat Cooperative (WWWC) registration trials in 1999 and 2000. It originated from a cross between a winter wheat composite selection, 78W005002, and Norstar, and also appears in the parentage of Pintail, a winter feed wheat cultivar (Salmon et al. 2015).

In 2001 and 2002, 285 DH lines were produced from 28 ovary donor plants using maize hybridization techniques (Fedak et al. 1997; Knox et al. 2000). Eighteen lines were recovered from the F_1 plant from which AAC Icefield was derived. Initial evaluation of 219 DH genotypes occurred in 2 m observation rows with 46 cm spacing under irrigation near Lethbridge in 2003. Selection and harvest of 19 lines was based on winter survival, early spring vigour, plant type, height, lodging resistance, and seed colour. These lines were also screened for test weight, grain protein concentration, and sodium dodecyl sulphate sedimentation volume during the winter of 2003/2004, and assessed for stem rust (*Puccinia graminis* Pers.: Pers. f. sp. *tritici* Eriks. & E. Henn.) and leaf rust (*P. triticina* Eriks.) resistance in an artificially inoculated nursery on the University of Manitoba campus in Winnipeg in 2004. Based on rust reactions similar to McClintock, one line was advanced to an irrigated, single-replicate preliminary trial at Lethbridge in 2005. Favourable agronomic performance, stem and leaf rust resistance, and end-use quality prompted replicated testing across western Canada in 2006 and 2009. Nurseries to assess the reactions to stem and leaf rust, stripe rust (*Puccinia striiformis* Westend.), common bunt [*Tilletia tritici* (Bjerk.) G. Wint. in Rabenh. and *Tilletia laevis* Kühn in Rabenh.], and winter survival were also conducted. Following 11 site–years of preregistration testing, LF1706W entered the WWWC registration trials as W530 in the fall of 2012 and was evaluated for 5 yr.

Assessment for production and processing

During the 5 yr (2013–2017) that AAC Icefield was evaluated in the WWWC registration trials, several check cultivars changed but the final assessment for full registration was relative to six checks present for the full duration of testing, including the CWRW checks CDC Buteo (Fowler 2010), Flourish (Graf et al. 2012), Moats (Fowler 2012*a*), and AAC Elevate (Graf et al. 2015), and the CWSP checks CDC Falcon (Fowler 1999) and Sunrise (Fowler 2012*b*). The WWWC registration trial was randomized as a partially balanced lattice with three replicates and grown at 14–15 locations per year. The trial was 36 entries (6 × 6) in all years except 2015, when it was a 42 entry (6 × 7) test. Testing in Alberta [Beaverlodge, Lacombe, Lethbridge "dry land", Lethbridge "evergreen" (dry land + foliar fungicide), Lethbridge "irrigated", Olds, Warner], Saskatchewan (Indian Head, Kamsack, Melfort, Saskatoon, Swift Current), and Manitoba (Brandon, Carman, Portage la Prairie, Winnipeg) was accomplished through the collaborative efforts of AAFC, Alberta Agriculture and Forestry, the University of Manitoba, and Canterra Seeds Ltd. Analyses of variance were conducted using a combined mixed effects model where environments (years × locations) were considered random and genotypes considered fixed. The least significant difference (LSD) test was used to identify differences from the check cultivars.

During registration testing, reactions to the major winter wheat diseases of economic importance in both the eastern and western prairies were assessed by AAFC, the University of Manitoba, and the agronomic trial collaborators. Supplementary checks were added as required to aid in making accurate assessments. The adult plant reactions to stem and leaf rust were determined in artificially inoculated field nurseries conducted by the University of Manitoba in Winnipeg using race composites supplied by the AAFC Cereal Research Centre, and reported using the modified Cobb scale (Peterson et al. 1948). The stem rust races used for one or more years included MCCFR (P0001), QTHJT (P0005), RHTSK (P0002), RKQSR (P0003), RTHJT (P0007), TMRTK (P0006), and TPMKR (P0004) (Fetch et al. 2015, 2018). The leaf rust races were a representative mixture collected in western Canada during the previous field season (McCallum et al. 2013, 2016). Seedling reactions to individual races of stem and leaf rust prevalent in Canada were also determined under controlled-environment conditions. The races of stem rust were the same as those used in the field nurseries, whereas the leaf rust races used for one or more years included MBDS (12-3), MBRJ (128-1), MGBJ (74-2), TDBG (06-1-1), TJBJ (77-2), and TDBG (11-180-1). Stripe rust and common bunt reactions were rated in nurseries at LeRDC. Both natural infection and artificial inoculation using spores collected in the previous year were used to promote localized stripe rust epiphytotics (Puchalski and Gaudet 2011). Common bunt resistance was estimated by inoculating seed with a race composite that included L1, L16, T1, T6, T13, and T19 (Hoffman and Metzger 1976; Gaudet and Puchalski 1989) prior to planting into cool soil at two locations in October. *Fusarium* head blight (FHB) response was determined in a three-replicate, mist-irrigated field nursery conducted by the University of Manitoba in Carman. Each line was spray-inoculated at 50% anthesis and 3–4 d later with a 50 000 macroconidia mL^{-1} suspension of *Fusarium graminearum* Schwabe that included equal quantities of two 3-acetyldeoxynivalenol (3-ADON) and two 15-ADON producing chemotypes. Symptoms were typically well developed 18–21 d after anthesis and rated using a visual index (% incidence × % severity/100) (Gilbert and Woods 2006; Cuthbert et al. 2007). A 50 g grain sample from each inoculated row was used to determine the percentage of *Fusarium*-damaged kernels (FDK) and deoxynivalenol (DON) content using enzyme-linked immunosorbent assays (Sinha et al. 1995; Sinha and Savard 1996). The reactions to powdery mildew [*Blumeria graminis* (DC.) Speer] and unspecified leaf spots, which may have included tan spot [*Pyrenophora tritici-repentis* (Died.) Drechs.], leaf blotch complex [*Zymoseptoria tritici* (Desm.) Quaed. & Crous, and *Stagonospora nodorum* (Berk.) Castell. & Germano], and physiological leaf spot were recorded at agronomic test sites expressing differential symptoms.

In 2013 and 2015–2017, end-use quality analyses were conducted at the Grain Research Laboratory (GRL), CGC, Winnipeg, MB, following the protocols of the American Association of Cereal Chemists (2000). Following CGC determination of grain grade and protein concentration for the CWRW check cultivars at the agronomic test locations with statistically acceptable grain yield data, a common site blending formula for the checks and all experimental lines was provided so as to produce composite samples where the mean protein concentration of the checks was approximately 12.5%. Quality analyses of the checks and experimental lines were not conducted in 2014 due to severe preharvest sprouting and insufficient quantities of grain from acceptable sites to create sufficiently large composite samples of reliable quality. In addition to the quality evaluations described above, CIGI also analysed grain samples of AAC Icefield produced under nine environments (three locations in southern Alberta in 2012, 2015, and 2016) for potential in white and whole-grain pan bread, Asian steamed bread, and white-salted noodles.

Performance

Grain yield and agronomics

The agronomic characteristics of AAC Icefield were established based on 53 site–years of data collected across the Canadian prairies over 5 yr (2013–2017) relative to six winter wheat check cultivars present in the trials over the full duration of testing.

The overall mean grain yield of AAC Icefield across western Canada was 99.2% of the CWRW check mean (not significant) and 95.7% of the CWSP check mean ($p \leq 0.05$) (Table 1). Relative to specific checks, AAC Icefield produced significantly more grain ($p \leq 0.05$) than CDC Buteo (103.6%), was similar in yield to Flourish (102.1%), Moats (102.3%), and CDC Falcon (99.5%), and was significantly lower yielding than AAC Elevate (96.7%) and Sunrise (92.1%). AAC Icefield had yields similar to the CWRW check means in all regions and prairie provinces, indicating good adaptation to all environments (Table 1).

AAC Icefield exhibited winter survival similar to several of the check cultivars and is best described as possessing fair survival under western Canadian conditions (Table 2). Heading date for AAC Icefield was equal to AAC Elevate and later than the remaining checks ($p \leq 0.05$); maturity was later than all of the checks except Sunrise. AAC Icefield was similar in height to Flourish, 5 cm taller than CDC Falcon, 4 cm shorter than AAC Elevate, and 9–11 cm shorter than CDC Buteo, Moats, and Sunrise. Lodging resistance was superior to CDC Buteo, Moats, and Sunrise, similar to Flourish and CDC Falcon, but inferior to AAC Elevate. The test weight of AAC Icefield was within the range of the checks, higher than Flourish, AAC Elevate, CDC Falcon, and Sunrise, but lower than CDC Buteo and Moats. Kernel weight was lower than the CWRW checks but similar to

Table 1. Mean grain yield of AAC Icefield and various check cultivars (t ha^{-1} and percent of checks[a]), Western Canadian Winter Wheat Cooperative registration trials (2013–2017).

Cultivar	2013	2014	2015	2016	2017	Grand mean t ha^{-1}	Grand mean % Ck[a]	Alberta t ha^{-1}	Alberta % Ck	Saskatchewan t ha^{-1}	Saskatchewan % Ck	Manitoba t ha^{-1}	Manitoba % Ck	Zone 1[b] t ha^{-1}	Zone 1[b] % Ck	Zone 2 t ha^{-1}	Zone 2 % Ck	Zone 3 t ha^{-1}	Zone 3 % Ck	Zone 4 t ha^{-1}	Zone 4 % Ck
CWRW checks																					
CDC Buteo	5.42	5.61	4.31	4.85	4.79	4.93	95	4.80	92	4.59	96	5.64	99	4.60	91	5.02	94	4.35	96	5.28	97
Flourish	5.82	5.76	4.50	5.10	5.05	5.19	99	5.30	102	4.63	96	5.59	98	5.18	103	5.24	98	4.33	96	5.34	98
Moats	5.64	5.72	4.77	4.99	5.19	5.22	100	5.19	99	4.73	98	5.85	103	4.85	96	5.47	103	4.45	99	5.53	102
AAC Elevate	5.93	5.48	4.51	5.49	5.15	5.28	101	5.36	103	4.90	102	5.56	97	5.26	104	5.43	102	4.67	104	5.33	98
CWRW check mean	5.70	5.64	4.52	5.11	5.05	5.15	99	5.16	99	4.71	98	5.66	99	4.97	99	5.29	99	4.45	99	5.37	99
CWSP checks																					
CDC Falcon	5.42	5.65	4.44	5.18	5.24	5.14	98	5.20	100	4.63	96	5.59	98	5.00	99	5.30	100	4.47	99	5.28	97
Sunrise	6.21	6.37	4.78	5.43	5.33	5.55	106	5.46	105	5.34	111	5.97	105	5.37	106	5.45	103	4.80	106	5.91	108
CWSP check mean	5.82	6.01	4.61	5.31	5.29	5.34	102	5.33	102	4.99	104	5.78	101	5.19	103	5.38	101	4.64	103	5.59	103
AAC Icefield	5.90	5.44	4.23	5.17	5.01	5.11	98	5.14	99	4.56	95	5.67	100	4.96	98	5.19	98	4.27	95	5.35	98
LSD ($p \leq 0.05$)	0.52	0.28	0.41	0.43	0.28	0.17		0.23		0.31		0.37		0.30		0.34		0.35		0.29	
No. of tests	11	7	12	11	12	53		27		14		12		17		12		4		20	

Note: All means are weighted by the number of tests. LSD, least significant difference includes variation from the genotype × environment interaction.

[a]% Ck, percent of checks based on the mean of all (CWRW and CWSP) checks.

[b]Zone 1, Southern Alberta sites (Lethbridge "dry land", Lethbridge "irrigated", Lethbridge "evergreen", Warner); Zone 2, Parkland sites (Beaverlodge, Lacombe, Melfort, Olds); Zone 3, Semi-arid prairie site (Swift Current); Zone 4, Eastern prairie rust-hazard sites (Brandon, Carman, Indian Head, Kamsack, Portage la Prairie, Saskatoon, Winnipeg).

Table 2. Mean agronomic and seed characteristics of AAC Icefield and various check cultivars, Western Canadian Winter Wheat Cooperative registration trials (2013–2017).

Cultivar	Winter survival (%)	Heading[a] (d)	Maturity[a] (d)	Height (cm)	Lodging[b] (1–9)	Test weight (kg hL^{-1})	Kernel weight (mg)	Grain protein (%)	Grain protein yield (kg ha^{-1})
CDC Buteo	86	167	213	90	4.2	80.6	32.7	12.1	594
Flourish	87	166	210	80	2.6	78.5	34.8	12.4	645
Moats	85	167	213	91	3.7	79.9	32.4	12.4	654
AAC Elevate	88	168	213	84	2.5	78.2	36.6	11.7	621
CDC Falcon	85	167	211	75	3.0	78.5	30.0	11.8	612
Sunrise	85	167	214	89	3.7	76.3	31.5	11.0	611
AAC Icefield	83	168	214	80	3.0	79.0	31.2	11.3	581
LSD ($p \leq 0.05$)	3.2	0.4	0.7	1.2	0.40	0.41	0.59	0.57	20.4
No. of tests	24	46	44	51	31	50	50	50	50

Note: LSD, least significant difference includes variation from the genotype × environment interaction.

[a]Days to heading and maturity expressed as day of the year.

[b]Lodging scale: 1 = all plants vertical, 9 = all plants horizontal.

[c]Grain protein concentration determined using whole-grain near-infrared spectroscopy analysis.

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Table 3. Disease reactions of AAC Icefield and various check cultivars, Western Canadian Winter Wheat Cooperative registration trials (2013–2017).

	Year	CDC Buteo	Flourish	Moats	AAC Elevate	CDC Falcon	Sunrise	AAC Icefield
Stem rust	2013	40 MS/20 S	20 MR	5 R	10 I	20 MR	5 R-MR	tr MR
	2014	10 I	20 MR	tr R	tr R	10 R-MR	5 MR	tr MS
	2015	50 I	30 MR	tr R	20 MR	30 MR	20 MR	5 R-MR
	2016	40 MS-60 S	30 I	10 R	25 I	40 MS	5 R	tr R
	2017	20 MS	5 MR	5 R	tr R	5 MR	tr R	tr R
Leaf rust	2013	5 I	5 I	tr R-MR	10 I	tr R-MR	10 I	tr R-MR
	2014	tr MR-5 MS	tr R-MR	tr R	15 MS-S	10 I	5–50 MS	tr I
	2015	10 MR	tr R	tr R-MR	5 R-MR	5 R-MR	5 MR	5 MR
	2016	20 MR	15 I	5 R-MR	25 MS	25 I	15 I	15 I
	2017	10 I	10 I	tr R-MR	20 S	15 I	60 MS	10 I
Stripe rust	2013	13 I	2 R	0 VR	13 MR	4 R	10 MR	0 VR
	2014	70 S	40 MS	0 R	25 I	40 MS	0 R	5 R
	2015	60 S	20 I	2 R	70 S	20 I	10 R-MR	10 R-MR
	2016	75 VS	60 S	3 R	50 S	65 S	20 MR-I	10 R-MR
	2017	70 S	20 I	1 R	70 S	50 S	5 R	10 R
Common bunt	2013	—	—	—	—	—	—	—
	2014	29 MS	8 R	24 I	22 I	29 MS	45 VS	26 I-MS
	2015	30 MS	17 MR	18 MR	19 MR-I	28 I-MS	35 S	26 I-MS
	2016	35 VS	10 MR	16 I	3 R	31 VS	50 VS	14 MR-I
	2017	44 S	15 I	31 MS	8 MR	33 MS	49 S	40 S
Leaf spots[a,b]	2013	4.1	2.8	2.2	2.6	3.6	2.0	1.9
	2014	2.2	3.2	2.8	2.0	3.0	2.2	2.3
	2015	4.8	4.6	4.1	5.2	5.7	3.4	4.0
	2016	3.2	2.3	2.6	2.9	3.4	2.7	2.8
	2017	2.0	1.8	2.0	1.3	1.5	1.8	1.8
	Mean	3.3	3.0	2.7	2.8	3.4	2.4	2.6
Powdery mildew[b]	2013	4.0	2.7	3.0	3.3	3.7	3.0	5.3
	2014	3.0	2.8	2.3	2.5	2.0	2.2	2.2
	2015	3.0	4.2	2.7	3.2	2.5	2.3	2.2
	2016	3.7	3.7	2.0	4.3	4.3	3.0	3.3
	2017	2.7	2.2	2.9	2.0	2.5	2.2	3.1
	Mean	3.3	3.1	2.6	3.1	3.0	2.5	3.2

Note: Percent infection and type of reaction: tr, trace; VR, very resistant; R, resistant; MR, moderately resistant; I, intermediate; MS, moderately susceptible; S, susceptible; VS, very susceptible.
[a]Specific leaf spotting pathogens were not determined.
[b]Rated using a 1–9 scale: 1 = disease free, 9 = very severe symptoms.

Sunrise and higher than CDC Falcon. The grain protein concentration of AAC Icefield was significantly lower than CDC Buteo, Flourish, and Moats, numerically lower than AAC Elevate and CDC Falcon, and numerically higher than Sunrise. Grain protein yield per hectare was lower than all of the checks except CDC Buteo.

Disease and pest resistance

Five years of disease ratings for AAC Icefield were summarized by the Prairie Recommending Committee for Wheat, Rye, and Triticale (PRCWRT) Disease Evaluation Team as resistant to stem rust, moderately resistant to leaf and stripe rust, intermediate in resistance to FHB, and susceptible to common bunt (Tables 3 and 4). AAC Icefield had a mean leaf spot rating similar to Moats and was similar to most of the checks for powdery mildew resistance. The disease resistance characteristics of AAC Icefield should facilitate relatively disease-free production provided that appropriate fungicides are used in areas prone to common bunt infection (Gaudet et al. 2013) and best practices are used when environmental conditions favourable for FHB infection occur (Ye et al. 2017).

End-use quality

Four years of end-use quality analysis at the CGC, GRL showed that AAC Icefield had lower grain and protein concentration than the CWRW checks but was comparable in milling performance, had stronger rheological properties, and was similar or better in baking performance. Farinograph absorption was lower than the CWRW checks. The noodle colour attributes for AAC Icefield were superior to the CWRW checks at 2 and

Table 4. *Fusarium* head blight (FHB) reaction of AAC Icefield, check cultivars, and supplementary checks, Western Canadian Winter Wheat Cooperative registration trials (2013–2017).[a]

	Visual rating[b] (index and response)				DON (mg kg^{-1})				ISD index[c]				FDK (%)[d]			
	2013	2015	2016	2017	2013	2016	2017	Mean	2013	2016	2017	Mean	2013	2016	2017	Mean
CDC Buteo	31 I	28 MR	2 MR	15 MR	40	18	22	27	26	19	29 I	21	27	6	14	16
Flourish	79 S	87 S	34 S	38 S	53	57	28	46	35	58	41 I	45	41	38	18	32
Moats	48 MS	42 I	5 MR	17 MR	30	17	16	21	21	20	27 MR	23	20	5	8	11
AAC Elevate	23 MR	47 I	14 I	19 MR	27	24	16	22	18	29	26 MR	24	20	17	12	16
CDC Falcon	49 MS	78 MS	7 I	16 MR	42	20	6	23	28	22	26 MR	25	29	10	9	16
Sunrise	31 I	27 MR	4 MR	13 MR	25	17	10	17	17	18	22 MR	19	13	10	6	10
AAC Icefield	43 MS	63 MS	7 I	18 MR	28	21	15	21	20	23	26 MR	23	16	12	6	11
Supplementary checks[e]																
DH00W32C*17	12 R	4 R	1 R	3 R	4	7	4	5	16	8	9 R	11	2	4	4	3
FHB148	16 MR	19 MR	2 R	2 R	11	10	6	9	23	11	8 R	14	5	6	8	6
DH01W43I*18	34 I	19 MR	5 MR	9 MR	18	14	8	13	35	17	17 R	23	14	6	17	12
Freedom	34 I	34 I	9 I	15 I	24	18	23	22	38	22	28 I	29	14	9	4	9
Caledonia	63 S	79 S	30 S	56 S	43	46	49	46	57	50	59 MS	55	33	30	14	26
Hanover	68 S	92 S	30 S	61 S	49	51	58	53	62	53	66 S	60	40	33	31	35

Note: DON, deoxynivalenol content. Disease response category: R, resistant; MR, moderately resistant; I, intermediate; MS, moderately susceptible; S, susceptible.
[a]2014 data were unavailable due to winterkill of the nursery.
[b]Visual rating index = % incidence × % severity/100.
[c]ISD, incidence–severity–DON index = [(% incidence × 0.2) + (% severity × 0.2) + (DON × 0.6)]
[d]FDK, *Fusarium*-damaged kernels = damaged kernel weight/total weight × 100.
[e]Supplementary checks were chosen to differentiate resistance levels based on long-term data collection.

Table 5. Mean end-use quality characteristics of AAC Icefield and the CWRW wheat check cultivars, Western Canadian Winter Wheat Cooperative registration trials (2013, 2015–2017).

	CDC Buteo	Flourish	Moats	AAC Elevate	CWRW mean	AAC Icefield	SD[a]
Wheat and flour characteristics							
Wheat protein (13.5% mb)	12.2	12.4	12.5	11.8	12.2	11.5	0.1
Flour protein (%)	11.4	11.6	11.8	10.9	11.4	10.3	0.1
Hagberg falling number (s)	376	384	414	396	393	349	15
Amylograph peak viscosity (BU)	351	535	586	489	490	471	5
Milling performance							
Clean wheat flour yield (14.0% mb)	76.5	76.1	75.4	76.2	76.0	76.6	0.3
Flour yield (0.5% ash)	82.1	81.1	79.9	81.6	81.2	82.8	0.3
Protein loss on milling (%)	0.9	0.8	0.8	1.0	0.9	1.1	0.1
Flour ash (%)	0.35	0.37	0.39	0.36	0.37	0.34	0.01
Starch damage (%)	6.5	6.1	7.3	6.8	6.7	6.3	0.1
Dough parameters							
Farinograph							
Absorption (%)	58.3	58.4	58.6	56.7	58.0	54.9	0.2
Dough development time (min)	5.88	6.19	6.56	4.75	5.84	3.25	0.4
Stability (min)	8.0	9.5	10.6	8.5	9.2	12.3	1.4
Extensograph							
Area (cm^2)	88	120	110	82	100	116	4
R_{max} (BU)	413	516	523	434	471	698	20
Length (mm)	172	188	172	155	172	139	6
Baking parameters							
Remix-to-peak method (2013, 2015)							
Absorption (%)	57	58	58	55	57	54	0.0
Peak time (min)	2.1	1.7	2.2	1.9	2.0	2.8	0.1
Mixing energy ($W\ h\ kg^{-1}$)	3.7	3.7	4.0	3.0	3.6	5.8	0.3
Loaf volume (cm^3)	820	893	920	803	859	795	14
Loaf volume unit flour protein^{-1}	71.6	76.0	76.6	72.3	74.1	77.6	NA
Lean-no-time method (2016–2017)							
Absorption (%)	65	65	65	63	64	63	0.0
Peak time (min)	3.1	3.3	3.9	3.3	3.6	5.1	0.1
Mixing energy ($Wh\ kg^{-1}$)	7.9	8.9	9.9	8.9	9.4	12.8	0.8
Loaf volume (cm^3)	793	798	758	790	788	845	15
Loaf top ratio	0.60	0.61	0.59	0.67	0.63	0.73	0.04
Noodle colour (Minolta)							
Water dough (2 h)							
L^*	81.46	81.13	80.98	80.67	81.06	81.94	NA
a^*	2.11	2.56	2.35	2.42	2.36	1.87	NA
b^*	22.48	23.57	21.64	21.78	22.37	25.17	NA
Yellow alkaline noodle							
L^* (2 h)	78.47	78.42	77.78	78.31	78.25	80.91	NA
a^* (2 h)	−0.33	−0.36	−0.53	−0.10	−0.33	−0.68	NA
b^* (2 h)	26.82	28.07	28.14	26.65	27.42	30.41	NA
L^* (24 h)	72.73	73.04	72.06	72.53	72.59	76.61	NA
a^* (24 h)	0.42	0.50	0.19	0.72	0.46	−0.07	NA
b^* (24 h)	27.24	27.96	28.01	26.75	27.49	31.03	NA
White-salted noodle							
L^* (2 h)	80.29	80.39	80.92	80.81	80.60	81.90	NA
a^* (2 h)	2.36	2.53	2.44	2.60	2.48	1.97	NA
b^* (2 h)	21.38	23.15	21.64	22.09	22.06	25.28	NA
L^* (24 h)	76.38	76.15	75.75	75.69	75.99	78.09	NA
a^* (24 h)	2.83	3.13	3.18	3.12	3.07	2.46	NA
b^* (24 h)	21.75	23.48	21.95	22.27	22.36	25.75	NA

Note: American Association of Cereal Chemists (AACC) methods were followed by the CGC and GRL on a composite of several locations per year. NA, not available.

[a]SD, standard deviation of repeated testing of Allis–Chalmers mill check samples and standard bake flour samples with replicate tests performed over an extended period of time each year. Values provided by the CGC and GRL.

Table 6. Steamed bread quality of AAC Icefield, Canadian International Grains Institute.

	Lethbridge composite 2012	Lethbridge irrigated 2015	Lethbridge dry land 2015	Warner 2015	Lethbridge dry land 2016	Lethbridge evergreen 2016	Warner 2016	Mean
Wheat characteristics (13.5% mb)								
Wheat protein	10.9	12.0	11.0	13.5	11.6	8.8	13.2	11.6
Hagberg falling number (s)	483	441	367	537	518	398	573	474
Ash content (%)	1.17	—	—	—	0.95	1.10	1.15	1.09
Particle size Index (%)	52	51	48	49	50	57	46	50
Flour characteristics (14.0% mb)								
Flour yield (0.5% ash)	85.3	84.2	89.1	86.3	88.8	84.6	83.8	86.0
Flour protein (%)	10.2	10.3	9.3	12.0	10.6	7.7	12.3	10.3
Protein loss on milling (%)	0.7	1.7	1.7	1.6	1.0	1.1	0.9	1.2
Wet gluten (%)	27.0	27.2	22.9	31.3	24.3	16.2	31.9	25.8
Ash content (%)	0.38	—	—	—	0.29	0.32	0.33	0.33
Minolta colour								
L^*	87.6	87.2	87.8	87.8	87.3	87.6	87.0	87.5
a^*	−1.24	−0.81	−0.92	−0.79	−0.74	−1.19	−0.83	−0.93
b^*	13.9	15.9	14.8	15.0	13.2	13.8	15.3	14.6
Starch damage (UCD)	15.8	18.8	20.8	17.4	17.5	16.9	18.6	18.0
Amylograph peak viscosity (BU)	921	—	—	—	863	700	1052	884
Pasting profile (Rapid Visco-Analyzer)								
Peak viscosity (RVU)	238	—	—	—	226	215	247	232
Hot paste viscosity (RVU)	126	—	—	—	142	123	147	135
Breakdown (RVU)	101	—	—	—	85	92	100	95
Final viscosity (RVU)	253	—	—	—	259	226	253	248
Setback (RVU)	117	—	—	—	117	103	105	111
Pasting time (min)	5.56	—	—	—	5.93	5.93	6.13	5.89
Steamed bread quality								
Specific volume ($cm^3\ g^{-1}$)	1.89	3.50	3.04	3.64	3.28	3.26	3.19	3.11
Spread (diameter $height^{-1}$)	1.90	1.74	1.69	1.57	1.64	1.81	1.75	1.73
Exterior Colour (Minolta)								
L^*	94.1	91.1	92.0	93.8	91.5	91.3	90.9	92.1
a^*	−1.67	−1.94	−2.04	−1.82	−1.93	−1.82	−1.98	−1.89
b^*	18.0	18.9	18.3	18.2	18.2	18.1	18.2	18.3

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Table 7. Quality of AAC Icefield compared with CWRW and CWHWS harvest composite samples in white and whole-grain pan bread, Canadian International Grains Institute.

	CWRW composite 2013		CWHWS composite 2013	AAC Icefield 2012	
	SG Flour	WG Flour	SG Flour	SG Flour	WG Flour
Flour characteristics (14% mb)					
Protein (%)	11.2	12.1	12.3	10.2	11.1
Protein loss on milling (%)	0.9	—	0.8	0.7	—
Wet gluten (%)	27.6	—	32.8	27.0	26.4
Ash content (%)	0.41	1.42	0.39	0.38	1.18
Minolta colour					
*L**	86.1	—	86.5	87.6	77.4
*a**	−0.49	—	−0.69	−1.24	2.17
*b**	12.3	—	12.9	13.9	14.9
Starch damage (UCD)	17.4	14.4	18.9	15.8	14.7
Amylograph peak viscosity (BU)	1005	—	990	921	535
Dough parameters					
Farinograph					
Absorption (%)	52.6	64.9	61.3	52.3	62.4
Dough development time (min)	2.8	6.7	8.2	7.0	5.2
Stability (min)	27.8	11.2	24.3	18.0	5.0
Mixing tolerance index (BU)	14	21	9	22	35
Alveograph					
P (height × 1.1) (mm)	61	—	115	140	—
L (mm)	112	—	103	95	—
P/L	0.55	—	1.12	1.47	—
W (×10^4) (J)	261	—	451	475	—
Extensograph (45/135 min)					
Area (cm^2)	172/158	—	151/158	172/181	—
R_{max} (BU)	578/614	—	626/704	763/986	—
Length (mm)	228/203	—	197/182	188/157	—
Test baking (lean-no-time method)					
Absorption (%)	53.6	67.9	62.3	53.3	65.4
Peak time (min)	7.1	10.0	5.3	7.9	9.7
Power (W)	130.8	84.2	143.2	117.1	83.8
Loaf volume (cm^3)	907	727	881	951	734
Specific volume ($cm^3\ g^{-1}$)	6.6	5.2	6.4	6.8	5.3
Bread score					
External (0–40)	37	32	39	39	34
Internal (0–60)	58	53	57	60	60
Total (0–100)	95	85	96	99	94
Crumb colour (Minolta)					
*L**	82.8	63.6	83.4	83.8	70.6
*a**	—	6.55	—	—	4.34
*b**	—	13.0	—	—	17.0
Pilot baking (lean-no-time method)					
Absorption (%)	54	65	63	54	63
Peak time (min)	8.1	11.7	6.8	8.4	11.4
Loaf volume (cm^3)	3897	3210	3681	3919	3279
Specific volume ($cm^3\ g^{-1}$)	7.1	5.7	6.7	7.1	5.8
Bread score					
External (0–40)	40	34	38	37	34
Internal (0–60)	57	57	56	61	60
Total (0–100)	97	91	94	98	94
Crumb colour (Minolta)					
*L**	82.6	65.7	82.3	83.8	71.7
*a**	—	6.05	—	—	3.77
*b**	—	13.3	—	–	16.8

Note: Straight grade flour was used in white pan bread testing. SG, straight grade; WG, whole grain. Test baking is of a laboratory scale. Pilot baking simulates a commercial bakery setting.

24 h, with the exception that the excellent b^* values (yellow/blue coordinates) for yellow alkaline noodles corresponded to poor b^* ratings for white-salted noodles (Table 5).

Independent testing at CIGI evaluated the potential of AAC Icefield flour for Asian steamed breads based on samples grown over several years and locations in southern Alberta (Table 6). It was concluded that AAC Icefield produced steamed breads with excellent exterior appearance (smooth surface, white skin, symmetrical appearance) and acceptable textural attributes. The performance of AAC Icefield in white and whole-grain pan breads was also evaluated relative to composite samples of commercially grown CWRW and Canada Western Hard White Spring (CWHWS) wheat (Table 7). Straight grade flour was used to compare performance in white pan bread and despite the protein concentration of AAC Icefield being 1.0 units lower than the CWRW composite and 2.1 units lower than the CWHWS composite, the loaf volume, bread score, and crumb colour were better for AAC Icefield. A comparison of AAC Icefield with the CWRW composite in whole-grain pan bread showed similar advantages.

Other Characteristics

Seedling: Coleoptile green, no pigmentation.

Plant: Juvenile growth habit intermediate, leaves medium-green; tillering capacity medium-high, growth habit at tillering semi-erect to intermediate; flag leaf medium to dark green, slightly waxy, medium long, medium wide, low frequency of recurved leaves, upright; flag leaf sheath glabrous, medium-strong waxiness; auricle anthocyanin colouration strong, margins glabrous; culm neck straight, hollow, glabrous, strong waxiness, light-yellow at maturity.

Spike: Awned, tapering, medium dense, medium length, medium waxiness, light-yellow, inclined to nodding at maturity; awns white to light-yellow, slightly spreading; glumes medium to long, narrow to medium, glabrous, white to yellow; glume shoulders wanting to oblique, very narrow to narrow; glume beak short, acuminate; rachis margins strongly pubescent; resistant to shattering.

Kernel: White, texture medium hard, medium size.

Maintenance and Distribution of Pedigreed Seed

Breeder Seed development of AAC Icefield was initiated in the fall of 2014 by planting 168 random spikes, collected from rogued seed increase plots, on irrigated land under isolation in Lethbridge. In 2015, seed was harvested from 150 rows, where elimination of 18 rows was based on minor differences in plant appearance. Following examination of seed harvested from each row to ensure that it was of uniform colour and appearance, the AAFC Seed Increase Unit at Indian Head, SK, planted 105 prebreeder seed lines in the fall of 2015. During the winter of 2015/2016, a subsample from each line was treated with a sodium hydroxide solution to confirm that all were white-seeded and free from red-seeded contaminants (DePauw and McCaig 1988). All appeared to be pure and white-seeded. In 2016, 13 additional lines were eliminated based on height variability. The remaining 92 breeder lines were inspected, harvested individually, examined for seed uniformity and appearance, bulked, and then conditioned to produce 1857 kg of Breeder Seed, which became available in the fall of 2016. Breeder Seed will be maintained by the AAFC Seed Increase Unit at Indian Head. Other pedigreed seed classes (Select, Foundation, Registered, and Certified) will be derived from the initial lot of Breeder Seed, with multiplication and distribution managed by FP Genetics, 426 McDonald Street, Regina, SK S4N 6E1, Canada. Tel.: 1-877-791-1045; fax: 1-877-791-1046; www.fpgenetics.ca.

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