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Spring Wheat Breeding: Evaluation of Selected Adapted Spring Wheat Germplasm in Eastern Canada

Shahrokh Khanizadeh[1], Harvey Voldeng[1], Xuelian Wang[1], Allen Xue[1], Mirko Tabori[1], Hana Moidu[1], Richard Martin[2], Allan Cummiskey[2], Mark Etienne[3], Ellen Sparry[4] & Jean Goulet[5]

[1] Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, K.W. Neatby Building, 960 Carling Ave, Ottawa, Ontario, K1A 0C6, Canada

[2] Crops and Livestock Research Centre, Agriculture and Agri-Food Canada, 440 University Ave, Charlottetown, Prince Edward Island, C1A 4N6, Canada

[3] Dow AgroSciences rental field in Kincardine, Ontario, N0M 1A0, Canada

[4] C&M Seeds, 6180 5th Line, Palmerston, Ontario, N0G 2P0, Canada

[5] Centre de Recherche Semican, 1290 Route 116 Ouest, Princeville, Quebec, G6L 4K7, Canada

Correspondence: Shahrokh Khanizadeh, Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, K.W. Neatby Building, 960 Carling Ave, Ottawa, Ontario, K1A 0C6, Canada. E-mail: Shahrokh.Khanizadeh@AGR.GC.CA, http://khanizadeh.info

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Abstract

Twenty-five hard red spring wheat (*Triticum aestivum*) lines, including three known cultivars used as checks, were grown in seven locations across Eastern Canada. The objective of this multi-location experiment was to evaluate selected Eastern Cereal and Oilseed Research Centre advanced lines (ECAD lines) from the Spring Wheat Breeding Program in order to identify the best lines for performance and grower trials. The lines from this trial performed very well compared to the check varieties, especially at the Ontario locations. Overall, the ECAD lines were on a par with or superior to the checks in terms of several attributes, including yield, protein content, and Fusarium head blight resistance.

Keywords: Triticum aestivum, breeding, cultivar description, AC Carberry, AC Scotia, AC Sable

1. Introduction

Wheat (*Triticum aestivum*) breeding programs across Canada aim to produce high-yielding varieties (McCaig and DePauw 1995) with improved resistance to diseases, especially *Fusarium* head blight (FHB) (Gilbert & Tekauz 2000; McCaig & DePauw, 1995), early maturity (Thomas & Graf, 2014), and high protein content (Wang et al., 2002). Through these programs, crop losses have been greatly reduced and grain quality has been increased (Thomas and Graf 2014). Of particular interest to Canadian wheat growers are cultivars that have a short growing season, produce high yields, and are resistant to FHB (Preston et al. 1991; McCaig & DePauw 1995). Common attributes of interest to commercial mills are grain protein, falling number, test weight, and deoxynivalenol (DON) values (Darby, 2015).

Fusarium head blight resistance is currently of great importance for wheat production in Canada. Epidemics of FHB in 1980 in Eastern Canada and in 1993 in Manitoba sparked interest in developing FHB-resistant cultivars and FHB management strategies (Gilbert & Tekauz, 2000). There is currently no single control method for FHB; the best approach involves the use of a cultivar of intermediate resistance in combination with fungicide applications, and suitable farming practices (Gilbert & Tekauz, 2000). More than 0.25% *Fusarium*-damaged kernels by weight can downgrade wheat to the point of significant economic loss (Fernandez et al., 2005). In a spring wheat analysis conducted by Darby (2015), 13 out of 19 tested varieties had FHB symptoms, indicating that the disease is a severe problem. The risk of FHB is increased by warm and humid weather, short plant height, conservation tillage, and wheat–maize rotations (Gilbert & Tekauz, 2000). Practices that reduce FHB risk consist of shredding maize residues to decrease DON values, performing conventional tillage, and using fungicides such as tebuconazole (Gilbert & Tekauz, 2000). Despite such practices, FHB is difficult to manage, because shorter plants are more susceptible, and more than half of the world's wheat cultivars contain two major dwarfing genes that are gibberellic-acid-insensitive (Gilbert & Tekauz, 2000). Furthermore, FHB thrives in warm, humid climates, and climate change may create environmental conditions that are favorable for the disease (Gilbert & Tekauz, 2000).

Grain yield is very important to wheat growers, and thus many studies on how to increase yield have been published. The optimal test weight is considered to be 56 to 60 lb/bushel (Darby, 2015), and newly registered wheat cultivars often have increased yields relative to check varieties with which they are compared. In previous studies, two examples of this are 'Snowbird', which gave higher yields than all check varieties except 'McKenzie' (Humphreys et al., 2007) and 'Carberry', which yielded 9.6% more than all checks (DePauw et al., 2011). Wheat breeders attempting to produce high-yielding cultivars can adopt an approach that involves using hybrids of spring wheat and winter wheat: the mean yields of spring/winter hybrids were found to surpass those of all controls (McKenzie & Grant, 1974). A study conducted by Hucl and Baker (1987) found that crop grain yield was correlated with biological yield and that cultivars with a later heading date produced more spikelets and more kernels per spike and also had increased yield. The same study found that some cultivars produced significantly fewer spikes per square meter, but the kernels were heavier, resulting in a net 25% increase in crop yield (Hucl & Baker 1987). Another study on yield reported that grain yield was not associated with tillering capacity or mortality but was instead associated with kernel weight (Hucl & Baker, 1988). That study concluded that grain yield showed no association with tiller density or tiller mortality (Hucl & Baker, 1988). Biomass production can be modeled by the new DNDC-CSW crop model, which was found to be acceptable for describing crop growth processes (Kröbel et al., 2011).

In addition to FHB resistance and high yield, grain protein is an important attribute of newly registered spring wheat cultivars. Industry standards for protein content are 12% to 14% (Darby 2015). In a study that used mouse bioassays to evaluate the protein quality and digestibility of wheat, it was found that barley protein is superior to wheat protein and that lysine is the first-limiting amino acid in wheat (Bell & Anderson 1984). That study also found certain wheat cultivars with superior performance: 'Neepawa' had the highest protein digestibility and 'Twin' had a superior protein rating (Bell & Anderson, 1984). Nevertheless, in another study, grain yield and grain protein concentration were found to be negatively correlated (Löffler & Busch, 1982).

The objective of this multi-location experiment was to evaluate selected Eastern Cereal and Oilseed Research Centre advanced lines (ECAD lines) from the Spring Wheat Breeding Program at seven different locations across Eastern Canada in order to identify the best lines for performance and grower trials.

2. Materials and Methods

A total of 25 selected hard red spring wheat germplasm lines, including three known cultivars, were chosen from three populations, namely, eight lines from Ontario (ECO406.1-8, ECO427.1-19, ECO439.1-20, ECO441.1-32, ECO446.1-29, ECO448.1-38, EC0330-9, and AW775), eleven lines from Quebec (11NQW-28, 11NQW-112, 11NQW-161, 11NQW-294, 11NQW-372, 11NQW-624, 11NQW-697, 11NQW-842, 11NQW-956, 10NQW-228, and FL62R1), and three lines were selected from the western breeding program (11BS2210, 11BS2288, and 11BW0292), along with three known cultivars to be used as "checks" for comparison purposes ('AC Scotia', 'AC Carberry', and 'Sable'), in seven locations in Eastern Canada (Table 1). Two of the field experiment sites were located in Ottawa, Ontario, at the Eastern Cereal and Oilseed Research Centre: the Central Experimental Farm Advisory Council field (CEF9C) (45° 23′ N, 75° 43′ W) and the Central Experimental Farm no-till field (CEFNT) (45° 22′ N, 75° 43′ W). With regard to the rest of the fields, one was located in Kincardine, Ontario (44° 10′ N, 81° 38′ W), one in Palmerston, Ontario (43° 50′ N, 80° 50′ W), one in St. Isidore, Ontario (45° 23′ N, 74° 54′ W), one in Princeville, Quebec (46° 10′ N, 71° 52′ W), and one in Harrington, Prince Edward Island (46° 21′ N, 63° 10′ W). The 25 wheat lines were arranged or planted in plots (5 × 1.5 m) of six rows spaced 20 cm apart. Depending on the lines, most of the plots were seeded by the beginning of May and harvested in late August or early September. A completely randomized block design with three replicates was used in all locations. Yield, days to head, test weight, thousand-kernel weight, height, protein content (%), lodging, mildew, FHB, DON, and Fusarium-damaged kernels were evaluated at each site.

Table 1. Pedigree of selected lines

Variety	Pedigree
ECO406.1-8	00H04*J3/3/ECO159.13.5.B(BW307/2*HOFFMAN HRF)
ECO427.1-19	BD57-4 (3BS,Lr21)/3/ECO159.13.5.B(BW307/2*HOFFMAN HRF)
ECO439.1-20	NORWELL/AC-06FL-1
ECO441.1-32	AC06FL-75-B/NORWELL
ECO446.1-29	W984-8767(AC BRIO/AC BARRIE)/2/AC06FL-87
ECO448.1-38	BD57-4 (3BS,Lr21)/BAICHUN
11NQW-28	6N-564 / FL62.R1
11NQW-112	F4 PL162.A1 F5 / McKenzie
11NQW-161	FL62R1 / BC21B-83-18 // F5 PL223.C2C F6 / BA83-EC8
11NQW-294	BA83-EC8 / FL62R1 // 03TAB86A1 (4W149.1C) / AC Barrie
11NQW-372	BW297a / NyuBay
11NQW-624	F4 PL259.B1 F5 / FL62R1
11NQW-697	05SFV-106.A2 / 06FL-75.A // GS-1-EM0168 / 06FL-1
11NQW-842	AC Cadillac / F5 PL223.C2C F6
11NQW-956	06FL62A / 06FL-1 // Cadillac / FL62 R1
11BS2210	BG51A-47-7-4
11BS2288	BG51B-40-9-10
11BW0292	BF31A-5-8
10NQW-228	AC Cadillac/FL62R1
AW775	AW622/BD57-4
EC0330-9	AC03W-104(QG22.24/Alsen/2/Blomidon/Alsen)/3/AC Barrie
AC Scotia	AC Helena//Quantum/AC Walton
AC Carberry	Alsen/Superb
FL62R1	QG22.24/Alsen/2/Blomidon/Alsen
Sable	TG3S/B58664HCH

3. Statistical Analysis

Analyses of data obtained from the 25 wheat lines as well as all data obtained from the seven locations in Eastern Canada were analyzed using the MIXED procedure of SAS 9.3 (SAS Institute, Cary, NC, USA) after the homogeneity of the experimental error was examined, and the means were compared using least significant differences (0.05) when the differences were significant.

4. Results

No interaction between line and location, indicating that the relative performance of the lines was similar.

In general, all the advanced lines performed as well as or better than the check varieties (Table 2). The check line FL62R1 had the second lowest mean FHB index. In terms of yield, all varieties except 11NQW-372 (2707 kg/ha) performed better than 'AC Carberry' (2972 kg/ha), and 'AC Scotia' had the best yield (4096 kg/ha). For days to head, line EC0330-9 had the best performance (54 d), equaling that of 'AC Carberry'. For test weight, all lines performed better than 'AC Scotia' (75.3 kg/hl). For thousand-kernel weight, ECO446.1-29, ECO446.1-38, and ECO446.1-19 (40.0, 39.8, and 39.6 g, respectively) had the highest weights, even better than 'Sable' and 'AC Carberry' (34.8 and 34.1 g, respectively). For plant height, all the lines performed better than 'AC Carberry' and 'Sable' (74.5 and 83.7 cm, respectively), with ECO446.1-29 being the tallest (105.4 cm). For protein content, all lines performed better than 'AC Scotia' (12.4%), with ECO446.1-32 having the highest protein content (15.1%). For lodging, all lines performed better than 'AC Scotia' (4.9), with ECO446.1-32 being the line with the best performance (0.5). Of all the lines, ECO439.1-20 had the lowest mildew value (0.1), which was better than the values for ‘AC Scotia’, ‘Sable’, and ‘AC Carberry’ (1.6, 2.1, and 3.3, respectively). For mean FHB index, line 11NQW-294 showed exceptional FHB resistance (6.8%), and lines 11NQW-112 and 11NQW-956 (7.6% and 8.4%, respectively) performed much better than ‘AC Scotia’, ‘Sable’, and ‘AC Carberry’ (10.3%, 21.4%, and 28.4%) did. For DON values, the lines that performed best were 11NQW-956 and 11NQW-624 (6.5 and 7.5 ppm, respectively), achieving lower values than ‘Sable’, ‘AC Carberry’, and ‘AC Scotia’ (7.8, 14.0, and 15.3 ppm, respectively). For Fusarium-damaged kernels, line 11NQW-294 (4.4) performed the best, better than ‘Sable’, ‘AC Scotia’ and ‘AC Carberry’ (7.5, 8.0, and 8.5, respectively) did (Table 2).

Table 2. Average attributes of 25 spring wheat lines tested at seven locations in Eastern Canada in 2014

Variety	Yield (kg/ha)	Rank	Days to head	TSTWT (kg/hl)	TKW (g)	Height (cm)	PROT (%)	LODG (0–9)	Mildew (0–9)	Natural FHB (%)	FHB Index (%)	DON (ppm)	FDK (0-9)
EC0406.1-8	3134	16	56	77.0	37.5	98.0	14.3	1.5	3.4	17.6	21.9	19.8	8.2
EC0427.1-19	3382	5	57	76.6	39.6	98.1	13.6	2.0	4.0	16.9	19.3	18.4	8.0
EC0439.1-20	3199	12	59	76.5	37.4	92.8	14.5	0.8	0.1	8.4	22.0	18.3	7.3
EC0441.1-32	3162	14	59	77.3	37.3	86.5	15.1	0.5	2.1	10.6	15.9	15.8	7.5
EC0446.1-29	3191	13	59	76.7	40.0	105.4	14.2	3.2	1.3	14.5	11.1	9.6	7.5
EC0448.1-38	3322	8	58	77.5	39.8	99.4	14.1	2.2	0.3	23.1	16.9	12.2	7.5
11NQW-28	3145	15	59	77.1	35.4	100.2	13.7	2.9	1.1	13.3	9.5	9.7	6.4
11NQW-112	3378	6	59	78.2	33.7	101.2	14.2	2.4	1.8	3.8	7.6	8.7	6.3
11NQW-161	3105	18	55	78.1	33.3	87.1	14.7	1.7	4.1	7.9	18.8	8.3	7.8
11NQW-294	3323	7	61	78.0	31.4	96.0	14.9	1.0	2.3	4.7	6.8	10.3	4.4
11NQW-372	2707	25	55	77.3	30.0	92.4	14.4	3.0	3.4	12.2	12.0	13.1	8.8
11NQW-624	3013	22	63	76.4	33.8	101.0	14.5	2.7	1.4	6.1	4.2	7.5	5.8
11NQW-697	3212	10	62	76.0	34.9	102.1	13.8	1.5	0.8	5.3	11.3	11.4	8.8
11NQW-842	3095	19	58	77.9	36.1	95.7	14.2	2.7	1.9	4.8	9.5	9.1	7.3
11NQW-956	3050	20	60	78.8	37.3	103.2	14.2	2.7	2.9	7.6	8.4	6.5	7.4
11BS2210	3045	21	57	76.7	35.0	94.0	14.9	1.3	4.1	9.1	14.0	13.4	8.0
11BS2288	3217	9	55	78.5	37.1	91.5	14.1	0.9	3.3	11.9	22.0	23.7	8.8
11BW0292	2992	23	58	76.8	33.3	92.5	13.6	2.5	3.6	9.3	14.1	15.4	8.5
10NQW-228	3212	11	59	76.6	35.7	101.7	14.3	4.7	0.9	8.1	12.8	10.1	6.8
AW775	3873	2	55	76.5	38.7	96.4	12.7	1.7	1.7	18.6	23.4	13.4	8.3
EC0330-9	3126	17	54	76.0	35.5	90.2	14.3	1.8	0.3	13.7	29.3	19.4	7.8
AC Scotia	4096	1	59	75.3	42.7	106.8	12.4	4.9	1.6	9.4	10.3	15.3	8.0
AC Carberry	2972	24	54	77.3	34.1	74.5	14.5	0.3	3.3	7.9	28.4	14.0	8.5
FL62R1	3625	4	61	78.1	33.6	100.0	14.1	4.0	2.0	1.8	4.5	10.5	4.0
Sable	3631	3	57	78.1	34.8	83.7	14.0	1.1	2.1	33.6	21.4	7.8	7.5
LSD (p = 0.05)	1431.8		22.6	2.8	3.5	16.6	2.0	1.9	3.2	2.0	3.8	2.6	<0.001

Legend: TSTWT – test weight; TKW – thousand-kernel weight; PROT – protein content; LODG – lodging; FHB – *Fusarium* head blight; DON – deoxynivalenol; FDK – *Fusarium*-damaged kernels; LSD – least significant difference at the 0.05 level.

When the yield parameter was compared among the seven locations (Table 3), the CEFNT location was found to have the highest mean value (4222 kg/ha), which was significantly higher than the mean values recorded for the Kincardine, Princeville, St. Isidore, and Harrington locations (3833, 3427, 1892, and 1020 kg/ha, respectively) but did not differ significantly from the mean values for the Palmerston and CEF9C locations (4206 and 4128 kg/ha, respectively). Comparing the days to head parameter, the CEF9C location had the lowest mean value (47), which was significantly lower than the mean values for the Harrington locations (60) but did not differ significantly from the mean values for the Kincardine, CEFNT, St. Isidore, and Palmerston locations (48, 49, 49, and 49, respectively). In terms of the test weight parameter, the Harrington location had the highest mean value

(94.0 kg/hl), which was significantly higher than the mean values at the Princeville, CEFNT, CEF9C, St. Isidore, and Palmerston locations (78.9, 77.9, 77.5, 77.5, and 76.9 kg/hl, respectively). When the thousand-kernel weight parameter was compared among the seven locations, the Palmerston location had the highest mean value (40.0 g), which was significantly higher than the mean values for the CEF9C, CEFNT, Harrington, St. Isidore, and Princeville locations (37.6, 36.9, 34.5, 34.0, and 33.0 g, respectively). With regard to the plant height parameter, the Palmerston location had the highest mean value (117.9 cm), which was significantly higher than the mean values recorded for the Princeville, CEF9C, CEFNT, Kincardine, St. Isidore, and Harrington locations (105.4, 101.1, 99.2, 89.2, 84.8, and 73.3 cm, respectively). Comparing the protein content parameter among the seven locations, the Princeville location had the highest mean value (14.9%), which was significantly higher than the mean values for the CEF9C, St. Isidore, and CEFNT locations (14.6%, 14.1%, and 12.3%, respectively) but did not differ significantly from the mean value at the Palmerston location (14.7%).

Table 3. Average attributes per location of 25 spring wheat lines tested at seven locations in Eastern Canada in 2014

Locations	Yield (kg/ha)	Rank	Days to head	TSTWT (kg/hl)	TKW (g)	Height (cm)	PROT (%)	LODG (0–9)	Mildew (0–9)	Natural FHB (%)
CEF9C	4128a	2	47c	77.5ab	37.6b	101.1c	14.6b	1.72	-	-
CEFNT	4222a	1	49c	77.9ab	36.9b	99.2c	12.3d	-	-	-
St. Isidore	1892d	6	49c	77.5ab	34.0cd	84.8d	14.1c	-	-	-
Harrington	1020e	7	60b	74.1c	34.5c	73.3e	-	-	0.7	-
Palmerston	4206a	3	49c	76.9b	40.0a	117.9a	14.7ab	3.3	2.0	17.8
Kincardine	3833b	4	48c	-	-	89.2d	-	2.3	-	10.5
Princeville	3427c	5	-	78.9a	33.0d	105.4b	14.9a	1.1	3.8	5.4
LSD (p = 0.05)	159		2.6	1.8	1.0	2.6	0.6	-	-	-

Legend: TSTWT – test weight; TKW – thousand-kernel weight; PROT – protein content; LODG – lodging; FHB – *Fusarium* head blight; DON – deoxynivalenol; FDK – *Fusarium*-damaged kernels; CEF9C – Central Experimental Farm field, CEFNT – Central Experimental Farm field with no-till, both located at the Government of Canada research center in Ottawa, Ontario; St. Isidore – Government of Canada Rental field in St. Isidore, Ontario; Harrington – field located at the Government of Canada research center in Harrington, Prince Edward Island; Palmerston – field located at the C&M Seeds company's research facility in Palmerston, Ontario; Kincardine – field located at the Dow AgroSciences research facility in Kincardine, Ontario; Princeville – field located at the Semican company's research facility in Princeville, Quebec; " - " – attribute not measured at that location.

LSD – least significant difference at the 0.05 level.

5. Discussion

A In the current study, the ECAD lines generally performed best among all the tested lines based on the data analysis results for the different attributes. This is probably due to the pedigree of the lines, considering, for example, that 'Norwell' has performed well in terms of most of the attributes described (Canadian Food Inspection Agency, 2015). The lines at the research station in Quebec also have a resistant pedigree thanks to varieties such as 'Cadillac', which has been shown to be resistant to mildew disease and which performs better in drier and cooler environments. As well, FL62R1, which is in the pedigree of some of the varieties, has been shown to be resistant to FHB, which prefers wet and humid environments; the best performance for FL62R1 is obtained in cooler and drier environments.

The results obtained for the average attributes per location for the 25 spring wheat lines (Table 3) clearly demonstrate that some sites contain extreme outliers for certain attributes. These extreme highs and lows can alter the values given in Table 2, which represent the average values for each ECAD line across the seven locations tested. For example, the very low yield and protein content values for the Harrington location could explain the lower per-line yield and protein content estimates shown in Table 2. If these outliers are taken into account, the yield and protein content values for the ECAD lines would likely be much higher than the respective estimates in Table 2, whereas the values for days to head, test weight, and height are likely lower than their respective estimates in Table 2 are. Considering this, the ECAD varieties performed very well when compared to the check varieties.

Given the range of conditions to which the ECAD lines were exposed at the seven different locations, they performed quite well, especially at the CEF9C, CEFNT, Palmerston, and Kincardine locations.

The ECAD lines trial performed very well compared to the checks in this experiment, especially at the locations in Ontario. Further experimentation is required to evaluate whether the extreme outliers obtained for the St. Isidore, Harrington, and Princeville locations are the result of seasonal variations or whether those locations are not suitable growing sites for the ECAD lines.

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