Sustainable Agriculture Research; Vol. 7, No. 3; 2018
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Evaluation of Selected Advanced Spring Wheat Germplasm Lines In Eastern Canada

Shuhui Xu[1, 2], Junjie Yu[1, 2], Yanhong Chen[2], Mirko Tabori[2], Xuelian Wang[2], Brent McCallum[3],George Fedak[2], Barbara Blackwell[2], Allen Xue[2], Zefeng Yang[1] & Shahrokh Khanizadeh[2]

[1]Jiangsu Provincial Key Laboratory of Crop Genetics and Physiology/Co-Innovation Center for Modern Production Technology of Grain Crops, Key Laboratory of Plant Functional Genomics of the Ministry of Education, Yangzhou University, Yangzhou, China

[2]Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, Ottawa, Canada

[3]Morden Research and Development Center, Agriculture and Agri-Food Canada, Morden, Canada

Correspondence: Shahrokh Khanizadeh, Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, Ottawa, Canada. E-mail: Shahrokh.khanizadeh@outlook.com

Received: September 19, 2018 Accepted: October 4, 2018 Online Published: May 25, 2018

doi:10.5539/sar.v7n3p63 URL: https://doi.org/10.5539/sar.v7n3p63

Abstract

Twenty-three selected advanced spring wheat (*Triticum aestivum* L.) lines from Ottawa Research and Development Centre (ORDC) were compared with four known cultivars for agronomic performance at eight sites in 2016 (Ottawa CEF-C1, Ottawa CEF-C2, St. Isidore, Harrington, Palmerston, Princeville, Kincardine, Beloeil) in Eastern Canada, and for fusarium head blight (FHB). The reaction of these lines to six races of LR was determined in a growth cabinet and the LR susceptible cultivar 'Morocco' was included as the control for disease development in these trials. The majority of the selected lines showed no significant differences compared to four check cultivars, however ECSW05 and ECSW48, showed higher yield, moderate resistance to FHB and resistance to most of the tested LR races. Lines ECSW05 and ECSW48 will be advanced to grower's trials in eastern Canada in 2018 and may be used as sources of resistance to LR for future cultivar development in Eastern Canada.

Keywords: spring wheat, *Triticum aestivum*, fusarium head blight, *Fusarium graminearum*, leaf rust, *Puccinia triticina*

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the worldwide staple foods in human life. It accounts for almost one-third of global grain production. Given that the world's population continues to grow and that wheat is one of the main crops cultivated in Canada. Wheat breeding programs aim to produce new high-yielding, high-quality cultivars with effective resistance to diseases, especially fusarium head blight (FHB) and leaf rust (LR), which occur annually and can lead to substantial yield losses.

Grain yield is one of the most important characteristics to wheat growers and many breeding programs aim to increase wheat yield in Canada (DePauw et al. 2011). Hucl and Baker (1987) found there is a correlation between crop grain yield and biological yield in those later-heading cultivars which had more kernels per spikelet, more total spikelets, and had higher grain yield. In addition, though some cultivars have significantly fewer spikelets per square meter, yet due to their heavier kernels, the crop yield still had increased 25%. (Hucl & Baker, 1987). They also found kernel weight had a correlation to grain yield by affecting test weight (Hucl & Baker, 1988). As we know, test weight represent the average weight of a cereal as measured in pounds per bushel, which is important to yield and flour extraction rate for wheat. The optimal industry standard for test weight is considered to be 55 to 60 lb/bushel (Darby, 2015). Also breeders have attempted to produce high-yielding wheat cultivars by using spring wheat hybrids, for which mean yields were found to be better than those of all controls (McKenzie & Grant, 1974). In addition, grain protein is also an important predictor of wheat yield and the optimal content is reported to be 12% to 14% as an industry standard (Darby, 2015). Bell and Anderson (1984) have studied superior performance of wheat protein in wheat cultivars and found some cultivars had the highest protein digestibility and superior protein rating. However, Löffler and Busch (1982).reported grain yield has a negatively correlation to grain protein which makes it important to find a way to maintain the protein concentration while improving the yield

Apart from plant yield and other plant quality traits, resistance to fusarium head blight, caused by *Fusarium graminearum* Schwabe, is a key concern. This worldwide wheat disease occurs annually in Canada, causing yield losses by damaging wheat kernels. Every year, scientists use many methods to examine the wheat genome in hopes of identifying the gene segment that confers FHB resistance (Buerstmayr, Ban & Anderson, 2009). Unfortunately, there have been no explicit results yet, but some correlation between plant height and FHB severity has been reported (Moidu et al., 2015). In addition, *F. graminearum*, leads to high concentrations of deoxynivalenol (DON) in wheat kernels, a mycotoxin known to be harmful to humans (Xue, 2012). There is currently no single way to control FHB, but the use of resistant cultivars with appropriate fungicide application and suitable farming practices can help to overcome outbreaks (Gilbert & Tekauz, 2000). Leaf rust, caused by *Puccinia triticina* Eriks., is another worldwide disease that occurs in Canada and can easily be widely disseminated over large geographic areas by winds. In a warm, high-humidity environment, the uredinia erupt easily and release spores that infect wheat, making it difficult to prevent the disease from spreading (Kolmer, 2013). Annual virulence survey have been conducted on the wheat leaf rust pathogen, *Puccinia triticina* Eriks., in Canada since 1931 and revealing a diverse and constantly evolving population (McCallum et al. 2016a), such as in 2010 in which 41 different virulence phenotypes were found (McCallum et al. 2016b).

The objective of the present study was to evaluate the agronomic performance and susceptibility of selected spring wheat lines to FHB and LR in order to identify the best performers to be evaluated in grower trials.

2. Materials and Methods

2.1 Field Evaluation

Twenty-three hard red spring wheat germplasm lines, namely Eastern Cereal and Oilseed Research Centre advanced lines (ECAD) (ECO410.1.15, ECO410.1.7, 12NQW-300, 12NQW-303, 12NQW-734, 12NQW-754, 13NQW-73, 13NQW-454, 13NQW-979, 12CRF12-29, 12CRF14-94, 13Bou-64, 12BW0491, 13BW0426, BH33-47-4, ECSW05, ECSW43, ECSW48, ECSW49, ECSW16, ECSW72, ECSW69, and ECSW70) were evaluated in 2016 at eight sites in eastern Canada (St. Isidore, Ontario, 45°23′ N, 74°54′W; Palmerston, Ontario, 43°50′N, 80°50′W; Kincardine, Ontario, 44°10′N, 81°38′W; Princeville, Quebec, 46°10′N, 71°52′W; Harrington, Prince Edward Island, 46°21′N, 63°10′W; and Beloeil, Quebec, 45°34′ N, 73°11′ W) and two fields at the Ottawa Research and Development Centre (ORDC) Central Experimental Farm (CEF-C1 45°22′N, 75°43′W; and CEF-C2, 45°23′N, 75°43′W) and compared to four known varieties (AC Scotia, AC Carberry, Norwell and Sable) (Table 1). A randomized complete block design was used at all sites with three replicates. Depending on the location, the seeding date varied from April 20 to May 20, and the grain was harvested from late August to early September. Yield, test weight, height, protein content, thousand-kernel weight, days to head and FHB were measured at each site. DON analysis was conducted on 1gm representable samples using the in-house enzyme-linked-immunosorbent-assay (ELISA) procedure as described by Sinha et al. (1995).

Table 1. Pedigree of selected lines

Variety	Pedigree
ECO410.1.15	BA83-EC-23/3/ECO145.8.3.B (BW307/2*HOFFMAN HRF)
ECO410.1.7	BA83-EC-23/3/ECO145.8.3.B (BW307/2*HOFFMAN HRF)
12NQW-300	ERA52 / SWS403
12NQW-303	FL94R9 / SWS 416005
12NQW-734	FL94R9 / SWS 416005
12NQW-754	Sadash / FL54R1
13NQW-73	FL62R1 / TP-108
13NQW-454	06GG-294 / 06FL-94 (F7AB-143F8)
13NQW-979	06GG-294 / 06FL-94 (F7AB-143F8)
12CRF14-29	F5 PL223.C2C F6 / BA83-EC8 / F4 PL249.N1 F5 / BD76A*F0763
12CRF14-94	Glenn / 03TAB86A1 (5V55a1) / HD-22 (GS-0-EM0134) / 03TAB86A1 (5V55a1)
13Bou-64	F4 PL259.B1 F5 / BD76A*F0763
12BW0491	BW450/BD31-7-B-B-PNB-13-N
13BW0426	BW430/BD31-7-B-B-PNB-13-N
BH33-47-4	K2619=HF15*A0084/K2627&2628
ECSW05	AW 625/FL62R1/ZM24049/EC0017.8
ECSW43	AW 625/FL62R1/HOFFM/FL62R1
ECSW48	AW 625/FL62R1/HOFFM/FL62R1
ECSW49	AW 625/FL62R1/HOFFM/FL62R1
ECSW16	AW 625/FL62R1/AW 620/FL62R1
ECSW72	HOFFM/EC0017.8/AW 625/FL62R1
ECSW69	HOFFM/EC0017.8/AW 625/FL62R1
ECSW70	HOFFM/EC0017.8/AW 625/FL62R1
SCOTIA	AC Helena//Quantum/AC Walton
CARBERRY	Alsen/Superb
NORWELL	Max/PT742//Blue
SABLE	TG3S/B58664HCH

2.2 LR Growth Cabinet Evaluation

A randomized complete block design with four replicates was used to evaluate the susceptibility of the 23 lines against six common races of *P. triticina* (77-2 TJBJ, 06-1-1 TDBG, 12-3 MBDS, 74-2 MBGJ, Race 1 BBBD, 128-1 MBRJ) provided by Dr. McCallum (Morden Research and Development Centre, 101 Rte 100, #100, Morden, MB, R6M 1Y5), In addition to the four checks (AC Scotia, AC Carberry, Norwell and Sable), a known LR susceptible cultivar 'Morocco' was included as the control for disease development in these trials.

The urediniospores of *P. triticina,* used as inoculum, were stored in a freezer at −20 °C until use. The experiments were carried out in a growth chamber at a temperature ranging from 16 to 18 ℃ and 16 hour photoperiod. All test cultivar seeds were sown in 48-cell trays filled with normal soil and placed in a greenhouse. The plants were inoculated with the *P. triticina* isolates at the two-leaf stage. The inoculum was prepared immediately prior to use by suspending urediospores in a solution of Bayol oil provided by Ottawa Research and Development Centre and then place in the water bath at 45 ℃ for 15 min to revive them. The mixed solution was sprayed with an atomizer (0.5 atm), and the inoculated plants were covered with a black plastic bag for 24 h to create appropriate humidity and encourage the urediospores to infect the plants. The growth chamber was maintained at 50% humidity during the disease development period (12–15 days) and watered every 2 days. Data were collected by rating the infection types described by McCallum et al. (2016)

2.3 Statistical Analysis

Analysis of variance was performed on the data sets using the SAS software program (version 9.1, SAS Institute Inc., Cary, NC), and the least significant difference (LSD) test was used to compare the means when the differences were significant.

3. Results

Generally, results from Table 2 show that all advanced lines performed as well as or better than the check varieties. Line AC Scotia had the highest yield (4091 kg/ha), and line ECSW16 (3306 kg/ha) had the lowest yield but did not show a significant difference. Line ECSW43 had the longest days to head (60 d), which is significantly longer than lines AC Carberry, Norwell and Sable (50, 52 and 52 d, respectively) but not different from AC Scotia (56 d). Line 13NQW-979 had the highest test weight among all lines. Additionally, line ECSW16 (75.1 kg/hl) had the lowest test weight among all lines, but its test weight was not different from that of AC Scotia (75.2 kg/hl). Line ECSW72 had the highest thousand-kernel weight (39.9 g), followed by line ECSW69 (39.7 g), and it performed significantly better than AC Carberry, Norwell and Sable (32.9, 34.5 and 34.9 g, respectively) but not differently from AC Scotia (38.6 g). Line ECSW72 performed the best and had the highest mean value for plant height (101.5 cm), which was not different from that of AC Scotia (94.7 cm) but was significantly higher than those of AC Carberry, Norwell and Sable (72.9, 82.5 and 70.5 cm, respectively).

Table 2. Grain yield, days to head, test weight, thousand-kernel weight, plant height and protein of 27 spring wheat lines tested at eight sites in eastern Canada in 2016

Variety	Grain yield (kg/ha)	Rank	Days to Head	TSTWT (kg/hl)	TKW (g)	Height (cm)	PROT (%)
ECO410.1.15	3505	16	51	75.7	35.9	78.7	15.7
ECO410.1.7	3847	4	51	76.3	36.6	83.5	14.7
12NQW-300	3753	6	53	76.5	34.4	86.8	14.4
12NQW-303	3524	14	56	76.8	36.5	88.3	15.1
12NQW-734	3457	20	55	76.1	32.2l	86.9	14.6
12NQW-754	3756	5	53	77.7	37.1	89.9	13.4
13NQW-73	3502	17	55	78.0	31.3	[illegible].6	15.7
13NQW-454	3392	23	52	78.7	30.9l	81.1	14.7
13NQW-979	3478	19	52	79.1	31.1	81.3	14.7
12CRF14-29	3542	13	52	77.0	36.1	[illegible].4	14.7
12CRF14-94	3440	21	52	77.0	33.9	[illegible].7	14.9
13Bou-64	3595	12	54	76.2	34.2	[illegible].4	14.4
12BW0491	3360	24	52	76.5	34.9	[illegible].5	15.1
13BW0426	3490	18	51	76.2	36.3	[illegible].0	14.9
BH33-47-4	3342	25	52	75.9	33.5	82.4	15.6
ECSW05	3924	3	57	76.5	37.6	95.9	15.0
ECSW43	3635	10	60	75.4	37.7	98.7	14.0
ECSW48	3963	2	55	77.0	37.0	88.3	13.6
ECSW49	3401	22	59	75.6	36.0	95.6	14.5
ECSW16	3306	27	58	75.1	34.9	97.4	14.3
ECSW72	3630	11	58	76.6	39.7	101.5	14.1
ECSW69	3688	8	57	77.0	39.9	99.5	13.9
ECSW70	3511	15	55	76.8	37.8	93.8	13.8
SCOTIA	4091	1	56	75.2	38.6	94.7	14.2
CARBERRY	3320	26	50	76.7	32.9	72.9	15.3
NORWELL	3665	9	52	77.1	34.5	82.5	15.6
SABLE	3696	7	52	76.4	34.9i	70.5	15.6
LSD 0.05	**1324**		**7.07**	**3.52**	**3.34**	**16.22**	**1.74**

Abbreviations: TSTWT: test weight; TKW: thousand-kernel weight; PROT %: protein percent;
LSD: least significant difference at the 0.05 level.

When comparing yield parameter between the sites in Table 3, mean value in Beloeil location was found to be the highest (5880.8 kg/ha), which was significantly higher than the recorded for the CEF-C1, CEF-C2, St. Isidore, Princeville, Palmerston and Kincardine sites (2692.0, 2287.5, 3735.5, 4612.2, 2301.8 and 2133.6 kg/ha, respectively). However, CEF-C2, Palmerston and Kincardine did not differ significantly. With respect to the test weight, CEF-C2 had lowest mean value (73.2 kg/hl) and was significantly lower than that for the Beloeil site (80.7 kg/hl) but not significantly different from the mean values for the CEF-C1 and St. Isidore sites (73.3 and 73.6 kg/hl, respectively). As thousand-kernel weight parameter was compared among the seven sites, the highest mean value (39.5 g) is in Beloeil, which was significantly higher than the mean values for the CEF-C1, CEF-C2, St. Isidore and Princeville sites (34.9, 32.1, 35.4 and 32.7 g, respectively). Comparing the days-to-head parameter, CEF-C2 had lowest mean value (45.6 d), which was significantly lower than that for the CEF-C2, St. Isidore, Palmerston, Kincardine and Beloeil sites (45.6, 50.9, 57.8, 56.2 and 58.4 d, respectively), and none of the sites differed significantly from the mean values. With regard to the plant height parameter, Princeville had the highest mean value (112.4 cm), which was significantly higher than the mean values recorded for the CEF-C1, CEF-C2, St. Isidore, Palmerston, Kincardine and Beloeil sites (69.9, 67.3, 74.9, 102.4, 91.4 and 89.2 cm, respectively). Additionally, the value for the CEF-C1 site did not significantly differ from CEF-C2 and St. Isidore sites, but CEF-C2 and St. Isidore were significantly different. Comparing the protein content parameter among the seven sites, the St. Isidore location had the second highest mean value (15.9%), which was significantly lower than the mean value for CEF-C1 (16.3%) and significantly higher than the mean values for the Princeville and Beloeil sites (12.5% and 15.6%, respectively) but not significantly differ from the mean value at the CEF-C2 site (15.8%).

Table 3. Grain yield, test weight, thousand-kernel weight, days to head, plant height, and protein of 27 spring wheat lines tested at seven sites in eastern Canada in 2016

Site	Grain Yield (kg/ha)	Rank	TSTWT (kg/ha)	TKW (g)	Days to Head (d)	Height (cm)	PROT (%)
CEF-C1	2692.0	4	73.3	34.9	49.0	69.9	16.3
CEF-C2	2287.5	6	73.2	32.1	45.6	67.3	15.8
St. Isidore	3735.5	3	73.6	35.4	50.9	74.9	15.9
Princeville	4612.2	2	77.4	32.7	-	112.4	12.5
Palmerston	2301.8	5	-	-	57.8	102.4	-
Kincardine	2133.6	7	-	-	56.2	91.4	-
Beloeil	5880.8	1	80.7	39.5	58.4	89.2	15.6
LSD	310.5		0.7	1.1	0.4	6.6	0.2

Abbreviation: TSTWT: test weight; TKW: thousand-kernel weight; PROT: protein percent; CEF-C1, CEF-C2: Ottawa Development and Research Centre Central Experimental Farm, Ottawa, Ontario; St. Isidore: Ontario; Princeville: Quebec; Palmerston: Ontario; Kincardine: Ontario; Beloeil: Quebec; '-': attribute not measured at that location; LSD: least significant difference at the 0.05 level.

The overall results for susceptibility to FHB and LR were presented in Table 4. In terms of mean values for FHB index, line ECSW69 shows an exceptional FHB resistance (7.8%), and lines ECSW05, ECSW16, ECSW48, ECSW49 and ECSW70 (10.7%, 13.3%, 10.0%, 13.3% and 11.7%, respectively) performed significantly better than AC Carberry, Norwell and Sable (50.0%, 38.3% and 76.7%). As for DON evaluation, the average of DON content among all the tested lines is ranged from 1.4 to 24.0 μg g^{-1}, and lines that performed the best were 13NQW-979, ECSW48 and ECSW49 (1.5, 1.4 and 1.7 ppm, respectively), their performance being significantly better than Norwell and Sable (8.7 and 24.0 ppm, respectively) but not different from AC Scotia and AC Carberry (4.7 and 5.5 ppm, respectively).

Table 4. Average test results for fusarium head blight and leaf rust for selected wheat lines or cultivars

Variety	INC(%)	SEV(%)	FHBi(%)	DON ppm	Leaf Rust Races					
					128-1MBRJ	12-3 MBDS	74-2MGBJ	Race 1	06-1-1TDBG	77-2 TJBJ
ECO410.1.15	100	30.0	30.0	8.2	2-3	2	2-3	2-3	2-3	3-4
ECO410.1.7	100	30.0	30.0	4.9	2-3	3-4	3-4	2-3	3-4	3-4
12NQW-300	100	18.3	18.3	7.9	1-2	3-4	2	1	2-3	4
12NQW-303	100	16.7	16.7	4.1	3-4	4	3-4	1-2	3-4	4
12NQW-734	100	18.3	18.3	4.7	2-3	3-4	3-4	1-2	4	4
12NQW-754	100	16.7	16.7	5.0	2-3	3-4	3-4	3-4	2-3	4
13NQW-73	100	18.3	18.3	6.3	1	1	3-4	0	3-4	3-4
13NQW-454	100	18.3	18.3	4.3	0	1-2	4	2	0	2-3
13NQW-979	100	21.7	21.7	1.5	0-1	2	0	0	1-2	2-3
12CRF14-29	100	15.0	15.0	3.7	0-1	1-2	2-3	0	2	3-4
12CRF14-94	100	21.7	21.7	4.2	1-2	2-3	4	1	4	3-4
13Bou-64	100	20.0	20.0	13.7	0	2	1-2	0	2	2-3
12BW0491	100	15.0	15.0	4.0	0-1	0	1-2	1	2	3-4
13BW0426	100	23.3	23.3	6.6	0-1	0	3-4	1-2	3-4	3-4
BH33-47-4	100	18.3	18.3	3.1	0	0	2-3	1	3	2-3
ECSW05	90	11.7	10.7	4.3	1-2	2-3	3-4	1-2	2	3-4
ECSW43	100	15.0	15.0	3.2	2	2-3	2-3	1-2	3-4	3-4
ECSW48	83	11.7	10.0	1.4	1-2	1-2	2	1-2	1-2	4
ECSW49	100	13.3	13.3	1.7	2-3	1-2	3-4	1-2	3-4	3-4
ECSW16	100	13.3	13.3	3.4	1-2	1-2	4	1	2-3	3-4
ECSW72	100	15.0	15.0	6.4	2-3	3-4	3-4	0	2-3	3-4
ECSW69	67	11.7	7.8	2.0	3-4	4	2-3	1	3-4	3-4
ECSW70	87	13.3	11.7	3.3	2-3	2-3	3-4	2-3	2-3	3-4
SCOTIA	93	15.0	14.1	4.7	2-3	4	3-4	1-2	4	4
CARBERRY	100	50.0	50.0	5.5	1	0	1-2	1	4	4
NORWELL	100	38.3	38.3	8.7	2-3	2-3	3-4	1	3-4	4
SABLE	100	76.7	76.7	24.0	1	2-3	4	1	3	4
Morocco	-	-	-	-	4	3-4	3-4	3-4	3-4	3-4
LSD	7.77	5.89	6.04	5.44	-	-	-	-	-	-

Abbreviation: INC: incidence; SEV: severity; FHBi: fusarium head blight index = incidence × severity ×100%; DON: deoxynivalenol; leaf rust grade: 1 – small uredinia with necrosis; 2: small- to medium-sized uredinia with chlorosis that were considered a virulent; 3: medium-sized uredinia without chlorosis or necrosis; 4: large uredinia without chlorosis or necrosis; LSD: least significant difference at the 0.05 level.

The tested lines were most susceptible to leaf rust race 77-2 TJBJ, followed by 74-2 MGBJ, 06-1-1 TDBG, 12-3 MBDS, 128-1MBRJ and Race 1. Several lines, including 13NQW-979, 13Bou-64 and BH33-47-4, exhibited moderate resistance to the six tested rust races in the growth cabinet environment. Other lines, including 12BW0491 and ECSW48, had better resistance to races 74-2 MGBJ, 06-1-1 TDBG, 12-3 MBDS, 128-1MBRJ and Race 1, but lower resistance to race 77-2 TJBJ. Line 13NQW-454 showed higher resistance to 77-2 TJBJ, 12-3 MBDS, Race 1, 128-1MBRJ and 06-1-1 TDBG, however it has a lower resistance to race 74-2 MGBJ. Line ECSW05 showed higher resistance to 06-1-1 TDBG, 12-3 MBDS, 128-1MBRJ and Race 1, but has lower resistance to races 77-2 TJBJ and 74-2 MGBJ.

The correlations between yield, test weight, thousand-kernel weight, days to head, plant height, protein and FHB was shown in Table 5. The result shows that plant test weight, thousand-kernel weight and height have significant negative correlation with both FHB index and protein percent. In addition, yield does not have significant correlation with DON, but had a significant negative correlation with FHBi.

Table 5. Correlation between grain yield, test weight, thousand-kernel weight, days to head, plant height, protein and fusarium head blight

	FHBi	DON	HGT	Grain Yield	TSTWT	TKW	PROTEIN
DON	0.65*						
HGT	-0.46*	-0.41*					
Grain Yield	-0.29*	-0.16	0.74*				
TSTWT	-0.22*	-0.24*	0.55*	0.50*			
TKW	-0.38*	-0.22*	0.61*	0.64*	0.24*		
PROT	0.46*	0.33*	-0.57*	-0.58*	-0.52*	-0.50*	
Days to Head	-0.46*	-0.31*	0.47*	0.20	0.03	0.34*	-0.29*

Note. FHBi: fusarium head blight index = incidence × severity×100%; DON: deoxynivalenol; HGT: height; TSTWT: test weight; TKW: thousand-kernel weight; PROTEIN: protein percent; *: means significant.

4. Discussion

This study was carried out at eight test sites to evaluate the performance of 23 selected advanced wheat lines for yield, test weight, thousand-kernel weight, heading date, height and protein. However, due to the extreme outliers in some sites which represent the average values for ECAD lines among the test sites in Table 3, it can be highly possible that this effected the values shown in Table 2. For example, the high yield and days-to-head values for the Beloeil sites in Table 3 could explain the high per-line yield and days-to-head estimates shown in Table 2. Taking this situation into consideration, the values of yield and days-to-head for the ECAD lines would possibly be much lower than their estimated value shown in Table 2.

This FHB resistance experiment demonstrated that the ECAD lines showed moderate resistance to fusarium spores and performed very well compared to the checks. A negative correlation was observed between plant height and FHB morbidity which is similar to a previous study reported by Moidu et al. (2015). In addition, race 77-2 TJBJ showed the highest damage to wheat leaves among all LR races in the LR inoculation test, similar to what was reported by Chen et al. (2015).

Based on the overall results, several tested lines not only showed their improvement in agronomic performance but also outperformed the selected commercially available cultivars. The observed scores of FHB ranged from immunity to high susceptibility with LR scores ranging from nearly immune (0) to very susceptible (4). Lines ECSW05 and ECSW48 not only had reasonable yields but also showed moderate resistance to FHB and were resistant to the tested LR races, which suggests that they should be evaluated further at sites across the country to test their response to FHB and LR under different environmental conditions. In addition, the climatic factor also needs to be considered since FHB and LR can be affected by the environment. Therefore, for more precise knowledge of test lines field performance under different environmental conditions the test lines will be evaluated further in the coming years.

Acknowledgments

The authors would like to acknowledge support received from the China Scholarship Council and the funding in part through Growing Forward 2 (GF2), a federal-provincial-territorial initiative with the Canadian Field Crops Research Alliance.

References

Bell, J. M., & Anderson, D. M. (1984). Protein quality evaluations of selected cultivars of wheat, measured by chemical scores and mouse bioassays. *Canadian Journal of Animal Science, 64*(1), 127-137. http://dx.doi.org/10.4141/cjas84-016

Buerstmayr, H., Ban, T., & Anderson, A. J. (2009). QTL mapping and marker-assisted selection for *Fusarium* head blight resistance in wheat: a review. *Plant Breeding, 128*(1), 1-26. http://dx.doi.org/10.1111/j.1439-0523.2008.01550.x

Chen, D., Hu, X. S, Wang, X., Deschiffart, I., Sparry, H., Xue, A. G., … Khanizadeh, S. (2015). Agronomic performance and susceptibility of selected spring wheat lines to fusarium head blight and leaf rust in Eastern Canada. *Journal of Food, Agriculture and Environment, 13*(3 & 4), 86-89.

Darby, H. (2015). *Heirloom Spring Wheat Seeding Rate Trial*, University of Vermont Extension. Retrieved from http://www.uvm.edu/extension/cropsoil/wp-content/uploads/2014-Heirloom-SWSR.pdf

DePauw, R. M., Knox, R. E., McCaig, T. N., Clarke, F. R., & Clarke, J. M. (2011). Carberry hard red spring wheat. *Canadian Journal of Plant Science, 91*, 529-534. http://dx.doi.org/10.4141/cjps10187

Gilbert, J., & Tekauz, A. (2000). Review: Recent developments in research on fusarium head blight of wheat in Canada. *Canadian Journal of Plant Pathology, 22*(1), 1-8. http://dx.doi.org/10.1080/07060660009501155

Hucl, P., & Baker, R. J. (1987). A study of ancestral and modern Canadian spring wheats. *Canadian Journal of Plant Science, 67*(1), 87-97. http://dx.doi.org/10.4141/cjps87-010

Hucl, P., & Baker, R. J. (1988). An evaluation of common spring wheat germplasm for tillering. *Canadian Journal of Plant Science, 68*(4), 1119-1123. http://dx.doi.org/10.4141/cjps88-133

Kolmer, J. (2013). Leaf rust of wheat: Pathogen biology, variation and host resistance. *Forests, 4*(1), 70-84. https://doi.org/10.3390/f4010070

Löffler, C. M., & Busch, R. H. (1982). Selection for grain protein, grain yield, and nitrogen partitioning efficiency in hard red spring wheat. *Crop Science, 22*(3), 591-595. http://dx.doi.org/10.2135/cropsci1982.0011183X002200030038x

McCallum, B. D., Hiebert, C. W., Cloutier, S., Bakkeren, G., Rosa, S. B., Humphreys, D. G., … Wang, X. (2016a). A review of wheat leaf rust research and the development of resistant cultivars in Canada. *Canadian Journal of Plant Pathology, 38*(1), 1-18. https://doi.org/10.1080/07060661.2016.1145598

McCallum, B. D., Seto-Goh, P., & Xue, A. (2016b). Physiologic specialization of *Puccinia triticina*, the causal agent of wheat leaf rust, in Canada in 2010. *Canadian Journal of Plant Pathology, 38*, 440-447. http://dx.doi.org/10.1080/07060661.2016.1261047

McKenzie, H., & Grant, M. N. (1974). Evaluation for yield potential of spring wheat strains from four spring × winter crosses. *Canadian Journal of Plant Science, 54*(1), 45-46. http://dx.doi.org/10.4141/cjps74-008

Moidu, H., Brownlee, J., Wang, X., Deschiffart, I., Langille, L., Voldeng, H., & Khanizadeh, S. (2015). Effect of plant height on Fusarium Head Blight in spring wheat. *Journal of Plant Studies, 4*(2), 105-109. http://dx.doi.org/10.5539/jps.v4n2p105

Sinha, R. C., Savard, M .E., & Lau, R. (1995). Production of monoclonal antibodies for the specific detection of deoxynivalenol and 15-acetyl-deoxynivalenol by ELISA. *J. Agric. Food Chem., 43*(6), 1740-1744. http://dx.doi.org/10.1021/jf00054a061

Xue, A. G., Chi, D. T., Zhang, S,-Z., & Li, Z.-F. (2012). Wheat production and wheat rust management in Canada. *Journal of Northeast Agricultural University, 19*, 1-14. https://dx.doi.org/10.1016/S1006-8104(12)60032-4