RESEARCH

Evaluation of Lines from a Farmer Participatory Organic Wheat Breeding Program

M. H. Entz,* A. P. Kirk, M. Carkner, I. Vaisman, and S. L. Fox

ABSTRACT

Involving farmers directly in early-generation selection may contribute to the development of well-adapted organic wheat (*Triticum aestivum* L.) germplasm. This project involved a partnership between a professional breeder and farmers. Progeny from 19 spring wheat crosses were distributed to eight organic farmers (three populations per farmer) in southern Manitoba, Canada. Each farmer selected for three consecutive years, resulting in 23 unique advanced lines. The farmer-selected lines were compared with eight registered cultivars and one landrace cultivar in replicated field experiments at a total of three site years in 2014 and 2015. Although there was significant variation in agronomic performance of different farmer-selected lines, the farmer selections were generally taller, later maturing, more susceptible to lodging; farmer selections were higher yielding than the check cultivars at one site-year. When selecting from the same population, farmers produced distinctively different lines; differences were observed in disease response, days to maturity, height, lodging, and yield. The highest yielding wheats included farmer-selected lines, a heritage cultivar, and two modern checks, one bred for organic conditions and one with a unique insect resistance trait. This preliminary study shows the potential of farmers working together with a professional breeder to produce wheat germplasm for organic production. Results also confirm the value of certain conventional cultivars to organic production.

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Abbreviations: FHB, Fusarium head blight.

THE RECOGNITION that growing conditions are much different in organic compared with conventional grain systems (Entz et al., 2001; Wolfe et al., 2008) has prompted breeding programs aimed at developing cultivars specifically for organic production (Murphy et al., 2007; Wolfe et al., 2008; Lammerts van Bueren et al., 2011; Lammerts van Bueren and Myers, 2012). Selection in organic breeding programs has been focused on factors such as early season vigor, the ability to suppress and tolerate weed presence, and efficient N uptake from non-inorganic forms (e.g., manure and N-fixing cover crops). In their study of 35 different soft white winter wheat (*Triticum aestivum* L.) breeding lines, Murphy et al. (2007) found that direct selection within organic systems resulted in yields 5 to 31% higher than when the lines were selected in conventional systems. In Manitoba, Kirk et al. (2012) observed a 10% yield advantage and higher grain protein content in organically vs. conventionally selected lines from the same crosses, whereas Wiebe et al. (2017) observed higher kernel production efficiency in organically selected vs. conventionally bred commercial wheat cultivars. Reid et al. (2011) observed that lines which ranked first and second under conventional management ranked 53rd and 21st, respectively, under organic management. However, Kronberga et al. (2013), working in Latvia, found no advantage to direct selection in triticale (Triticale × *Triticosecale*).

Plant breeding by modern professional plant breeders has become increasingly isolated from plant breeding by farmers

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(Cleveland et al., 1994). An attempt to reverse this historical trend involves bringing farmers and professional plant breeders together in the process of developing new crop cultivars (Cleveland et al., 1994). Farmers can be involved in two different ways. A first approach, participatory cultivar selection, involves selecting new cultivars developed by the institutional system within farmers' fields (Carr et al., 2006). A second approach involves farmers making selections within segregating populations on their own farms. This practice is referred to as farmer participatory plant breeding (Murphy et al., 2005), and experiences show that farmers sometimes use selection criteria not normally used by breeders (Ceccarelli et al., 2001). Farmer selected populations are referred to as landraces (Mercer and Perales, 2010) or "folk varieties" (Cleveland et al., 1994). In Syria, decentralized, participatory selection by farmers was significantly more efficient in identifying the highest yielding entries in farmers' fields than any other selection strategy (Ceccarelli et al., 2001). Farmer-selected populations are not genetically homogenous, which may lead to greater yield stability in varying environments.

The scientific basis for farmer participatory selection is well established. Falconer (1952) pointed out that direct selection in the target environment is always the most efficient. This has been supported by more recent analyses (Murphy et al., 2005; Love and Spaner, 2007; Murphy et al., 2016). Using simulation models, Simmonds (1991) concluded that systematic selection in the target environment is required, not merely trials of potential cultivars after selection in a good environment. The environment for organic wheat production in Canada is now well defined (Entz et al., 2001; Knight et al., 2010).

Participatory plant breeding has often been used in smallholder production systems (Almekinders and Elings, 2001), but interest in industrialized countries has grown (Murphy et al., 2016). In 2014, there were 148 active farmer potato (*Solanum tuberosum* L.) breeders in the Netherlands; half of the commercial potato cultivars grown in that country are selected by farmers, and these cultivars cover 44% of arable potato acres (Almekinders et al., 2014). Farmer participatory breeding is also used in novel crops, such as quinoa (*Chenopodium quinoa* Willd.) (Murphy et al., 2016).

Farmer participatory wheat breeding for organic production has been conducted in the Pacific Northwest of the United States (Murphy et al., 2005; Dawson et al., 2008), in collaboration with long time farmer participation researcher Ceccarrelli (Stephen Jones, personal communication, 2010). "The results obtained so far (Ceccarelli et al., 2001; van Eeuwijk et al., 2001; Ceccarelli and Grando, 2007) indicate that it is possible to organize a plant breeding program in a way that addresses those plant characteristics that maximize yield and stability over time in a given physical environment" (Ceccarelli and Grando, 2007). An additional advantage of participatory crop improvement is conservation of crop diversity on farms (Cleveland et al., 1994; Love and Spaner, 2007).

The present study also presented a unique opportunity to observe how farmers making selections may shape the population differently. Given commonalities between organic farmers' preferences to specific traits such as weed competitiveness, resistance to diseases and insects, and yield (Mason and Spaner, 2006; Ghaouti and Link, 2009), and the relatively small geographical distribution of our participating farmers, we hypothesized that farmers and their associated selection environment will select similarly to one another within the same cross-progeny population. To our knowledge, such an analysis has not been previously conducted in Canadian wheat breeding.

MATERIALS AND METHODS

Creating Germplasm for Farmer Participatory Selection

Crosses for the study were made at the Agriculture and Agri-Food Canada Cereal Research Station in Winnipeg, MB, under the supervision of Dr. Stephen Fox. Crosses were made using growth cabinet grown parent plants. F_1 plants were grown in 15-seed, 2-m rows near Leeston, New Zealand, to produce 400 to 660 g of F_2 generation seed. With input from the plant breeder and coordinator, the participating farmers chose wheat populations based on the known characteristics of the parental lines. A total of 19 crosses were made (Table 1), resulting in 19 different populations for distribution to farmers.

The protocol for our participatory plant breeding followed that of Murphy et al. (2005). Each of the eight participating farmers received three populations in 2011 (Table 1). Each of the populations had 4000 seeds, the amount recommended by Murphy (Washington State University, personal communication, 2010). Plots were seeded on farm using a range of methods from a small grain seeder, a garden seeder, or by hand in 20-m^2 plots. An instruction manual was sent to each farmer, and each farmer received a visit from the program coordinator in the first and second year of the program (Kirk, 2014). The following check cultivars were sent to each farmer for planting in a 2-m row for comparison purposes: 5602HR, AC Barrie, AC Cadillac, Carberry, Harvest, McKenzie, Unity, and Waskada. Selections occurred throughout the growing season based on the farmer's preferences and included removing undesirable plants from the populations and identification of desirable plants. Final selections were made at harvest. At harvest, farmers selected ~300 spikes per population. The selected spikes were sent to the University of Manitoba for threshing and cleaning and returned to the farmers the following spring. This process was repeated for three consecutive years: 2011, 2012, and 2013. In 2013, the F_5 was harvested by the participating farmers. One participating farmer (GM) bulk harvested the plots each year and saved the largest seeds each year.

The Common Garden Experiment

To evaluate the field performance and quality of the farmer-selected populations, the F_5 farmer selections were seeded in

Table 1. Treatment name and pedigree (female parent/male parent) of crosses included in the study, initials of farmer selectors, and location of participating farms. Farmer-selected populations were selected under organic crop production as part of the participatory plant breeding project. Check cultivars were selected under conventional crop production.

Treatment†	Pedigree	Farmer	Latitude	Longitude
			° N	° W
BJ08	BW430/BW897	IG, SC		
BJ10	ACS 54608/Kane	SC, KB		
BJ11	ACS 54608/Waskada	SC, CG, KB	49.12326	98.55193
BJ03	HW341/Kane	HRE	50.16118	96.42452
BJ04	HW341/Vesper	KB	49.29534	98.02146
BJ05	HW341/Waskada	GM	49.30100	96.52076
BJ13	BW433/BW430	HRE		
BJ15	BW425/BW430	GM		
BJ18	Cardale/BW880	KS	51.10114	100.41377
BJ21	3X1-134*FA0067/Muchmore	HRE		
BJ22	3X1-134*FA0067/BW880	IG	49.45068	99.52128
BJ23	BD94B*D0371/BW880	IG		
BJ25	ND04/3-21/Carberry	SC	49.16113	100.59243
BJ26	ND04/3-21/Shaw	KS		
BJ27	SD3948/Unity	MW	50.04426	96.29263
BJ28	SD3948/BW880	MW		
BJ32	BD92A*D0621/BW410	KS		
BJ43	3X1-134*FA0067/Kane	GM		
PA00	Red Fife/5602 HR	KB		
Check cultivar			**Year of registration**	
AC Cadillac	Pacific*3/BW553		1996	
Glenn	ND2831/Steele-ND		2009	
AAC Brandon	Superb/CDC Osler//ND744		2013	
Carberry	Alsen/Superb		2009	
Unity	McKenzie*3//BW174*2/Clark		2007	
Vesper	A/HWA//*3ACBarrie/6/Vesper = Augusta/Hard White Alpha//3*AC Barrie/6/ BW150*2//Tp/Tm/3/2*Superb/4/94B35-112 R5C/5/Superb		2010	
AAC Tradition	98B25-AS6D01/ND744		2016	
PT245	Somerset/BW865		–	
Red Fife			~1845	

† The initials of the farmer that selected the population have been added to the population name. In some cases, more than one farmer received the same population.

a replicated field experiment at the University of Manitoba research farm near Carman, MB, in 2014. The 2014 study also allowed seed increase so that in 2015, seed for the farmer-selected F_6 populations were grown in the same production environment and could be evaluated in two additional replicated field experiments. Check cultivars were included in the study for comparison purposes (Table 1).

Site Descriptions and Experimental Design

In 2014, experiments were located at the University of Manitoba's Ian N. Morrison research farm in Carman (Hibsin fine sandy loam; Orthic Black Chernozem; Soil Classification Working Group, 1998). The 2015 experiments were located at Carman again, and on an organic farm near Brandon, MB (Oxbow clay loam; Orthic Black Chernozem; Soil Classification Working Group, 1998).

Soil samples were collected at each site prior to or shortly after seeding from two depths (0–15 cm, 15–60 cm) and were sent to Agvise laboratories in Norwood, ND, for analysis (Table 2). Weather data collected by Manitoba Agriculture, Food and Rural Initiatives (MAFRD 2015), Environment Canada's climate data online (Environment Canada, 2011a), and weather normals (Environment Canada, 2011b) are presented in Table 3. Data for 30-yr normals were based on values from the Graysville weather station (~14 km from Carman site).

All field experiments in 2014 and 2015 were replicated four times in a randomized complete block design. At all sites, experimental units were four rows, 4 m long with 15-cm row spacing. Border rows of fall rye (*Secale cereale* L.) were seeded between experimental unit blocks, and border plots of wheat were sown on either side of each trial to minimize edge effects. The land was prepared for seeding using cultivation to create a smooth uniform seedbed. Plots were seeded using a disk drill (Fabro Industries). Plots were seeded into moisture (~2.5–5 cm) at all sites with an approximate density of 350 viable kernels m^{-2} based on a standard germination test Seeding dates were 16 May 2014 and 11 May 2015 at Carman and 22 May 2015 at Brandon. Plots were harrowed with a Lely tine harrow at the three-leaf stage in Carman 2014 only. Inter-row cultivation was used in Brandon 2015 on 11 June using a hand-operated, double-blade wheel hoe. All experimental units were harvested at the harvest ripe stage (Zadoks et al., 1974; Zadoks Stages 92–93). In 2014 and 2015, prior to grain harvest, the ends of plots were trimmed and individual plot area measured. Plots were harvested using a

Table 2. Soil nutrient status, organic matter, pH, and crop history of experimental sites in 2014 and 2015.

Site	Depth	NO_3–N	SO_4	Olsen P	K	Organic matter	pH	Previous crop
	cm	kg ha^{-1}		mg kg^{-1}	kg ha^{-1}	%		
Carman 2014	0–15	64	25	29	341		5.1	Green manure
	15–60	111	94				6.4	
Carman 2015	0–15	18	11	11	258	4.8	5.5	Green manure
	15–60	67	27				6.5	
Brandon 2015	0–15	32	54	9	372	6.5	7.2	Green manure
	15–60	107	74					

Table 3. Mean monthly temperature and precipitation during the growing season (MAFRD, 2014, 2015) and long-term averages (Environment Canada, 2015) at each experimental site.

Research site	May	June	July	Aug.	Sept.	Growing season
			Air temperature			
			°C			
Carman 2014	11.3	16.6	18.2	18.7	13.1	15.6
Carman 2015	10.7	17.5	19.9	18.3	15.8	16.4
Long-term avg.	11.6	17.2	19.4	18.5	13.4	16.0
Brandon 2015	10.3	17.2	19.8	18.1	14.1	15.9
Long-term avg.	11.4	16.6	19.2	18.2	12.2	15.6
			Precipitation			
			mm			
Carman 2014	31	117	48	122	47	364
Carman 2015	99	75	109	47	42	373
Long-term avg.	70	96	79	74	49	368
Brandon 2015	45	34	52	50	33	214
Long-term avg.	52.1	79.6	68.2	65.5	41.6	307

Wintersteiger Nurserymaster Elite plot combine. Samples were dried on a forced-air drying bed (35°C for 48 h) before further cleaning. Grain samples were cleaned to remove chaff and weed seeds using a Carter Day dockage tester (Model 31624/W-3301). The dockage tester contained a No. 1 riddle, 9/64 tri double cut sieve, and an S-909 S1/2 164 R.086 sieve. Additional chaff was removed with a forced-air grain separator.

Data Collection

Plant population density was evaluated at the three-leaf stage and was measured on 2- or 3-m randomly selected wheat row lengths per plot. Early season vigor was visually rated from 1 to 5, with 5 as the most vigorous and 1 being the least. Visual rating took into account the general health and appearance of the plants. Leaf disease at anthesis (Zadoks Stage 65) was measured at Carman in 2014 and 2015 using the Horsfall–Barratt scale on 10 flag leaves per experimental unit. Leaf disease is represented by per cent foliage damage using the mean foliage percentage conversion (Horsfall and Barratt, 1945). Fusarium head blight (FHB, *Fusarium acuminatum* Ellis & Everh.) incidence and severity were measured 3 to 4 wk after anthesis (Zadoks Stage 85) at all sites. Aboveground weed biomass was measured at heading (Zadoks Stage 59) and at physiological maturity (Zadoks Stage 87) at Carman 2014. At Carman 2015, aboveground crop and weed biomass were collected at hard dough stage (Zadoks Stage 87). In all cases, plants were cut at ground level (0–2.5 cm). Material was dried at 70°C for 48 h after being collected. Dried biomass samples from each sampling were weighed to assess dry matter value. Aboveground biomass was not sampled at Brandon 2015. Crop height measurements were taken at maturity at all sites by measuring the distance from the soil to tip of spike (not including awns) in 10 plants within each experimental unit. Lodging measurements were taken at maturity on a 1-to-9 scale, with 1 representing upright rows and 9 representing plants lying flat on the ground. Plants were monitored every 3 d from hard dough (Zadoks Stage 87) to maturity.

After harvest, 250 seeds were counted to determine kernel mass using a seed counter (Old Mill Model 850-3, International Marketing and Design Company). The kernel number per unit of area was calculated by dividing the number of kernels per hectare by the kilograms of yield per hectare. Grain harvest index was calculated as grain yield per unit total aboveground biomass at maturity.

Data Analysis: ANOVA

Treatment differences were tested using the ANOVA for all measurements. Data sets were analyzed using the PROC Mixed procedure with SAS 9.4 (SAS Institute, 2013). Treatments were analyzed as a combined analysis for all sites and separately for each site when there was a site × treatment interaction. Wheat genotypes and check cultivars were considered as fixed effects, and replications and site-years were considered as random effects for all measurements. Assumptions of ANOVA were tested by using the PROC Univariate procedure. Appropriate data transformations were performed if the data were not normally distributed. Differences were considered significant at $P < 0.05$. To compare the farmer-selected populations with the conventionally selected checks, treatments were combined and analyzed as two groups: farmer-selected populations and modern conventionally selected checks (not including AAC Tradition and Red Fife). A second analysis was conducted where AAC Tradition, a modern organically selected cultivar, and Red Fife, a >100-yr-old cultivar popular with some Canadian organic farmers and bakers, were included among the check cultivars.

RESULTS AND DISCUSSION

Environmental Conditions

Average temperature during the growing season (May–September) at all sites ranged between 15.6 and 16.4°C (Table 3; MAFRD, 2014, 2015) and closely matched long-term averages (Environment Canada, 2015). At all sites, growing season precipitation ranged between 214 to 373 mm (Table 3; MAFRD, 2014, 2015). In general, precipitation at Carman 2014 followed long-term averages, except in August, and exceeded average precipitation by 48 mm. Similarly, Carman 2015 followed long-term precipitation averages but exceeded the average by 35 mm in July. Seasonal precipitation was below the average at Brandon 2015 in every month, 93 mm below average throughout the growing season (Environment Canada, 2015).

Agronomic Responses

Combined analysis across the three site-years resulted in significant site-year × genotype interactions for all parameters except plant population density (data not shown). Therefore, analysis was conducted on individual site-years.

The two sets of analyses, each with different check cultivars, produced similar results in most cases. That is, results tended to be similar whether Red Fife and AAC Tradition were included among the check cultivars or whether these two cultivars were left out. Because of this, comparisons in the present study involve farmer selections vs. all check cultivars.

Establishment and Growth

Average crop plant density ranged from 218 to 286 plants m^{-2}, close to the recommendation of 230 to 280 plant m^{-2} (MAFRI, 2013). The one significant effect was 26 plants m^{-2} more plants for farmer selections than check cultivars in 2014 (Table 4). Rapid emergence, increased early season leaf area, and early growth rate are connected with increased weed suppressive ability and lower yield losses in cereals (Huel and Hucl, 1996; Zerner et al., 2008; Andrew et al., 2015). The only difference between groups was at Carman in 2014, where vigor was significantly ($P < 0.05$) greater for check cultivars than farmer selections. Differences in vigor among the farmer-selected lines were observed in some cases. BJ25-SC and PA00-KB-AL had particularly low vigor at Carman in 2014.

Crop biomass at maturity ranged from 8030 to 13,319 kg ha^{-1} at Carman in 2014 and from 4358 to 8726 kg ha^{-1} are Carman in 2015 (Table 4). Weed biomass was negligible in 2014 but ranged between 646 and 1437 kg ha^{-1} in 2015. No significant differences in weed biomass between farmer selections and check cultivars were observed. In both years, crop biomass at maturity was greater for the farmer selections than the check cultivars ($P = 0.11$ in 2015, Table 4). This demonstrates that farmers appear to have selected for larger plants, and in 2015, greater crop biomass was correlated with less weed biomass ($r = -0.3199$, $P < 0.0002$).

Increased height is known to benefit organic production systems, including increased solar radiation capture in the face of weed competition (Mason et al., 2007; Zerner et al., 2008; Kokare et al., 2017). Plant heights ranged from 91 to 119 cm at Carman 2014, 81 to 110 cm at Carman 2015, and 59 to 78 cm at Brandon 2015. As a group, farmer-selected lines were an average 7 cm taller (9 cm if Red Fife excluded from comparison) than the conventional checks (Table 4). Therefore, farmers tended to select for taller wheat plants.

Lodging scores ranged from 1.2 to 4.2, averaged across all treatments and locations (Table 4). Farmer-selected lines lodged significantly more than check cultivars at Carman in 2014 and 2015; no differences were observed at the low-yielding Brandon site (Table 4). Lodging was significantly correlated with height at all sites ($r = 0.47$, $P < 0.001$; $r = 0.45$, $P < 0.001$; $r = 0.24$, $P < 0.0141$ for Carman 2014 and 2015 and Brandon 2015, respectively). Greater lodging can be connected to tallness, and many cereal breeders have reduced lodging potential by selecting for shorter cultivars and introducing dwarfing stem genes (Zhu et al., 2010; Benaragama et al., 2014). It was interesting to observe different behavior between two farmer-selected lines, BJ11A-CG and BJ25A-SC. These lines had lodging ratings of 5.3 and 4.5, respectively, at Carman 2014 with plant heights of 103 and 91 cm. However, at Carman in 2015, these two lines had much lower lodging scores (3.3 and 2.3, respectively), even though plants were slightly taller (Table 4). An explanation for less lodging with essentially the same height may be attributed to more weed growth at Carman 2015; the weeds may have kept the wheat from lodging, although no correlation between weed biomass and lodging was observed within site-years.

Days to maturity ranged from 93 to 104 d at Carman 2014 and 87 to 95 d during the warmer season at Carman 2015 (Table 4). Typically, spring wheat cultivars grown in Manitoba require between 95 and 105 d to mature (Seed Manitoba, 2017). As a group, farmer-selected lines matured 2.5 d later than the conventionally selected check cultivars in 2014 and 2.3 d later in 2015 (Table 4). Mason et al. (2007) reported that earlier-maturing cultivars have higher grain yield than later-maturing cultivars in organic systems and may avoid abiotic stress conditions of early and late frost, providing an adaptive advantage. Conventionally selected cultivars tend to have a broader adaptation target, and therefore avoidance of later maturity is given a higher priority.

Table 4. Growth parameters of 23 farmer-selected populations and nine check cultivars at three site-years of experiments in Manitoba.

Treatment name	Stand density			Early-season vigor			Wheat biomass		Weed biomass		Lodging			Plant height			Days to maturity	
	C14†	C15	B15	C14	C15	B15	C14	C15	C14	C15	C14	C15	B15	C14	C15	B15	C14	C15
	plant m^{-2}			1–5 scale			kg ha^{-1}				1–9 scale			cm			d	
BJ08-IG	285.2	272.3	288.5	2efghi‡	3.3bcd	2.5	12,196abcde	8,726a	11.5	1,110.3	3.7bcde	4ab	3.3abc	102def	107ab	73abcdef	98efghij	89fghijk
BJ08-CG	243.5	262.7	282.7	1.62ghi	2.8d	3	11,559bcdefgh	7,832abc	26.4	847	3.3cdef	2.5defg	2.3def	103de	101defgh	71abcdefg	103abc	94ab
BJ10-SC	259.8	246.7	321.8	2.12efgh	3cd	2.5	11,109bcdefgh	7,050abcdef	27.9	950.3	2.8efg	1.5gh	2.3def	92k	95jk	71abcdefg	100bcdefg	89fghijk
BJ10-KB	223.7	249	303.3	2.5cdef	3.3bcd	3	12,504abc	6,716abcdefg	16.4	1,134.5	2.8efg	3.3bcde	2.7cde	109b	106abc	76abc	101bcdef	92bcde
BJ11-SC	270.5	256.3	272.9	3.12abcd	3.3bcd	3.5	13,317a	5,934cdefgh	28.8	1,148	3.8bcd	4ab	3.3abc	103de	102cdefg	73abcdefg	104abc	93bcd
BJ11-CG	251.6	267.3	297.5	2.5cdef	3.5abc	3	10,612defghij	6,552bcdefg	41.6	881.8	5.3a	3.3bcde	2.7cde	103de	105abcd	75abcd	105a	95ab
BJ11-KB	236.1	240.3	282.5	2.25efgh	3.8ab	3	12,616abc	5,454efgh	22.2	928.8	3.3cdef	2.3efgh	2ef	103de	102cdef	71abcdefg	103abcd	94abc
BJ03-HRE	254.1	261	295.1	2fgh	3.5abc	2	10,680defghij	5,870cdefgh	18.4	1,005.7	3def	1.8fgh	1.7f	93jk	96ijk	75abcd	98efghij	90efghijk
BJ04-KB	265.5	236.5	258.2	2.5cdef	3.3bcd	3.5	11,715abcdefg	6,464bcdefg	14.7	1,085	2.8efg	2.3efgh	2.3def	100efg	103bcde	69cdefgh	99defghi	90efghi
BJ05-GM	215.5	275.5	333.8	3.25abc	3.3bcd	3	11,234bcdefgh	6,060bcdefgh	22.3	989.3	2.5fgh	1.8fgh	2ef	99fgh	100efghi	68efgh	100bcdefg	91defgh
BJ13-HRE	229.5	251.8	330.3	2.6bcdef	3.3bcd	3	11,167bcdefgh	7,292abcdef	13.9	707	4bc	3.8abc	3.7ab	104cd	106ab	78a	99cdefgh	91cdefg
BJ15-GM	198.3	217.3	325.4	3.25abc	3.7ab	3	10,956cdefghi	6,038cdefgh	26.3	752	3.3cdef	3.3bcde	3.7ab	103de	103bcde	70bcdefg	100cdefgh	91cdefg
BJ18-KS	251.6	273	341.8	2.1efgh	2.7d	3	11,173bcdefgh	7,288abcdef	14.6	810	4.5ab	2.3efgh	2.7cde	103de	105abcd	68defgh	100cdefgh	92bcde
BJ21-HRE	210.6	243.5	291.8	2.6bcdef	3cd	3	9,791hij	7,020abcdefg	16.4	1,200	1.8hij	1.8fgh	2.7cde	94ijk	99fghij	67fgh	99cdefgh	90efghijk
BJ22-IG	277.1	243.3	348.1	1.75fghi	3cd	3	12,275abcdef	6,726abcdefg	9.5	1,133	1.5hij	2.5defg	3.3abc	103def	100efghi	70cdefg	99cdefghij	92bcde
BJ23-IG	268.8	246.3	318.6	2.25cdefgh	3.3bcd	3	11,662abcdefgh	6,744abcdefg	17.4	1,267.5	3cdefg	2.3abc	3bcd	100efg	98ghijk	70cdefg	98defghijk	91cdefg
BJ25-SC	259	235.3	284.4	1.5hi	3.3bcd	3	9,329ijk	6,806abcdefg	20.7	845.7	4.5ab	1.3h	2.3def	91k	96ijk	75abcd	103abcd	90efghij
BJ26-KS	240.2	238	290.2	2fgh	3.3bcd	3.5	10,019ghij	6,492bcdefg	14.8	828.3	3.5cde	2.8cdef	4a	101efg	101defgh	75abcd	94jk	88hijk
BJ27-MW	258.2	240.3	312.3	2.7abcdef	3.3bcd	3	11,372bcdefgh	5,328fgh	22.3	646	3.3cdef	3.3bcde	4a	96hij	100efghi	75abcd	95ijk	89ghijk
BJ28-MW	245.1	236	318	2.7abcdef	3cd	3	12,342abcd	7,428abcde	16.1	741.5	1.8hij	2.3efgh	3.3abc	100efg	97hijk	73abcdef	98efghij	92bcdef
BJ32-KS	283.6	231.5	319.6	2.87abcde	3.7ab	3	10,610defghij	6,278bcdefgh	33.5	1,222	3.8bcd	3.5abcd	3.3abc	99fgh	102defg	70bcdefg	96hijk	92bcdef
BJ43-GM	181.9	223.5	337.7	3.5a	3.5abc	3	10,462efghij	6,584bcdefg	36.3	1,245.5	2.5fgh	2.5defg	2.3def	96hij	96ijk	70bcdefg	102abcde	89fghijk
PA00-KB	233.6	277.3	370.5	1.1i	3cd	2	11,130bcdefgh	7,556abcd	2.5	862.5	4.5ab	3.8abc	3.7ab	108bc	107a	75abcde	101abcdef	92bcdef
AC Cadillac	232.3	229	332.2	3.1abcd	3cd	3.5	9,798hij	7,360abcdef	29.3	944.8	4.5ab	3.3ab	4a	102de	99efghij	74abcde	96hijk	89fghijk
AAC Tradition	220.5	249.3	363.9	2.6bcdef	3.25bcd	3	10,716defghij	5,588defgh	15.2	1,411.3	1.3hij	1.7h	3bcd	93jk	91l	65ghi	98efghij	87jk
Red Fife	218.5	262.7	315.5	2.3defg	3cd	3	12,810ab	7,720abc	7.8	943	4.5ab	4.5a	3.7ab	119a	110a	78ab	104ab	96a
Glenn	235.2	255.5	354.9	2fgh	3cd	2.5	9,083k	6,652abcdefg	19.9	863.3	1.3ij	2fgh	2.7cde	91k	95k	65ghi	99defghi	89fghijk
AAC Brandon	237.7	231.3	277	3.2abc	3.3bcd	3	9,265ijk	6,956gh	45.2	1,437.3	2.5fgh	2.3efgh	2.3def	83l	82m	62hi	97ghijk	88hijk
Carberry	190.2	235.5	355.7	3.4ab	3.3bcd	3	8,030k	4,358h	47.3	1,244.3	1.8hij	1.8fgh	2.3def	81l	81m	67efgh	97fghij	88ijk
Unity	225.4	272	307.4	3.4defg	3cd	3	1,0641defghij	7,084abcdef	29.3	704.3	3.5cde	2.8cdef	2.7cde	98ghi	100efghi	68defgh	98efghij	87jk
Vesper	184.5	251	287.7	2.3efgh	3.3bcd	3	1,0634defghij	8,136ab	13.5	977.8	2ghi	2fgh	3bcd	93jk	95jk	69cdefgh	94jk	88hijk
PT245	248.1	250.3	273.2	2.3efgh	3.7ab	3	1,0212fghij	5,554defgh	29.8	1,061.8	1j	1.3h	1.7f	91k	83m	59i	93k	87k
Farmer selections	245.9a	248.8	309.2	2.4b	3.1	2.9	11,296.9a	3,353.1a	21.1	971.4	3.2a	2.7a	2.9	100a	101.1a	71.9a	99.7a	91.1a
All checks	220.1b	248.5	318.3	2.6a	3.1	2.9	10,132.1b	3,189.2b	26.4	1,065.2	2.5b	2.3b	2.8	91.3b	92.6b	67.2b	97.2b	88.7b
Contrast									**ANOVA**									
Selections vs. all checks	0.013	0.958	0.505	0.0532	0.6449	0.628	<0.0001	0.1161	0.072	0.2187	<0.0001	0.0130	0.5403	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Estimate	25.82	0.38	−9.00	−0.2374	0.0374	−0.05	1253.2	206.9	−10.5	−83.12	0.721	0.334	0.0837	8.79	8.46	4.697	3.48	2.34

† C14, Carman 2014; C15, Carman 2015; B15, Brandon 2015.

‡ Means within a column not sharing a lowercase letter differ significantly at the $P < 0.05$ level.

Diseases

The highest levels of leaf disease at anthesis were recorded at Carman 2015. Under these conditions, farmer selections had significantly greater leaf disease severity than check cultivars (25.6 vs. 21.9% leaf area infected, Table 5). Reasons for poor leaf disease selection by farmers may be related to leaving the selection until later in season or unfamiliarity with visual symptoms of leaf pathogens. Leaf disease was highest for Red Fife and one farmer selection (BJ08CG). It was interesting to observe that PA-00KB, the cross between Red Fife and a modern cultivar (5602HR), had significantly less leaf disease than Red Fife (Table 5).

For FHB, on the other hand, farmer selections had significantly less infection and severity than check cultivars at the wetter Carman 2015 site (Table 5). It is not surprising that farmers selected against Fusarium-infected spikes, as they have good knowledge about how to identify this pathogen. Another possible reason for less FHB in farmer selections is greater height. In a meta-analysis, Mao et al. (2010) confirmed negative associations of dwarfing genes and FHB resistance.

Yield and Yield Components

As a group, the farmer-selected lines yielded significantly higher than the check cultivars only at Carman in 2015

Table 5. Disease parameters of 23 farmer-selected populations and nine check cultivars at three site-years of experiments in Manitoba.

				Fusarium head blight			
	Flag leaf disease at anthesis			Incidence		Severity	
Treatment name	C14†	C15	B15	C15	B15	C15	B15
	Horsfall–Barratt scale			%			
BJ08-IG	7.5bcde‡	20.8efghijkl	14.9abcdef	25fghijk	26.6	25hij	26.6
BJ08-CG	4. cde	57.3ab	12.4abcdefgh	32.5efghij	6.6	32.5fghij	6.6
BJ10-SC	11.1bcd	10hijkl	16.8abc	42.5cdef	26.6	42.5cde	26.6
BJ10-KB	14b	26cdefgh	13.6abcdefg	16.3ijk	10	16.2ij	10
BJ11-SC	8.5bcde	30.5cdef	11.2bcdefghi	13.8jk	13.3	13.8j	13.3
BJ11-CG	6.5cde	31.5cde	10.6cdefghi	13.7jk	10	13.7j	10
BJ11-KB	4.5cde	25.2defghij	14.2abcdefg	26.3fghijk	0	26.5fghij	0
BJ03-HRE	5.6cde	22.5efghijkl	14.1abcdefg	32.5efghij	20	32.5cdef	20
BJ04-KB	3.6e	42.2bc	5.8hi	26.3fghijk	16.6	26.5fghij	16.6
BJ05-GM	8.3bcde	20.5efghijkl	10.6cdefghi	21.3ghijk	16.6	21.3fghij	16.6
BJ13-HRE	4.4cde	22.5cde	11.8abcdefgh	11.2k	20	11.3ghij	20
BJ15-GM	9. bcde	21.3efghijkl	9.2efghi	31.3efghij	16.6	31.3fghij	16.6
BJ18-KS	4de	31.5cde	9.5defghi	35defghi	6.6	35fghij	6.6
BJ21-HRE	7bcde	14.5fghijkl	16.8abc	28.7efghijk	30	28.7fghij	30
BJ22-IG	11.4bcde	33.2cde	8.7efghi	26.2fghijk	10	26.2defghij	10
BJ23-IG	5.3cde	31.5cde	13.2abcdefg	47.5cde	6.6	47.5cd	6.6
BJ25-SC	8.3bcde	6.3l	18.1ab	42.5cdef	13.3	42.5cdefgh	13.3
BJ26-KS	7.7bcde	8.3kl	9.7defghi	42.5cdef	26.6	42.5defghi	26.6
BJ27-MW	5.5cde	25defghij	13.5abcdefg	28.7efghijk	13.3	28.7cdefgh	13.3
BJ28-MW	10.4bcde	27.7cdefg	9.1efghi	27.5fghijk	33.3	27.5ij	33.3
BJ32-KS	5.3cde	23efghijk	12.6abcdefgh	37.5cdefgh	8.3	37.5fghij	8.3
BJ43-GM	5.6cde	8.7jkl	13.9abcdefg	27.5fghijk	30	27.5cdefg	30
PA00-KB	11.6bc	40cd	10.6cdefghi	18.8hijk	26.6	18.7fghij	26.6
AC Cadillac	7.2bcde	26cdefghi	16.3abcd	70ab	3.3	70ab	3.3
AAC Tradition	5.2cde	22.5efghijkl	7.6ghi	52.5bcd	10	52.5cde	10
Red Fife	25.3a	61.7a	4.4i	22.5ghijk	20	22.5fghij	20
Glenn	5.2cde	11.7ghijkl	8.8efghi	38.7cdefg	16.6	38.7defghij	16.6
AAC Brandon	9.6bcde	18efghijkl	12.5abcdefgh	26.3fghijk	6.6	26.3efghij	6.6
Carberry	6.6cde	8.7jkl	18.8a	33.8defghi	11.6	33.7cdefgh	11.6
Unity	7.6bcde	13.5fghijkl	10.9cdefghi	55bc	3.3	55bc	3.3
Vesper	8.6bcde	8kl	8.1fghi	43.7cdef	20	43.7efghij	20
PT245	7.4bcde	9.2ijkl	7.7ghi	75a	0	75a	0
Farmer selections	7.3	25.6a	12.2	28.5b	16.8	26.9b	14.5
All checks	9.2	21.9b	10.5	46.3a	10.1	44.4a	13.1
Contrast				**ANOVA**			
Farmer selections vs. all checks	0.0653	0.0165	0.0901	<0.0001	0.1006	<0.0001	0.6866
Estimate	–1.935	5.74	1.667	–17.91	6.698	–17.5	1.417

† C14, Carman 2014; C15, Carman 2015; B15, Brandon 2015.

‡ Means within a column not sharing a lowercase letter differ significantly at the $P < 0.05$ level.

(Table 6). A contributing factor to better yields for farmer selections may be related to lower weed biomass. At the Carman sites, weed biomass was negatively correlated with yield in 2014 ($r = -0.282$, $P < 0.0016$) and 2015 ($r = -0.1878$, $P < 0.0104$).

The top-yielding wheats were a combination of farmer selections (BJ27-MW, BJ08-CG, and BJ18-KS) and registered commercial cultivars (Vesper and AAC Tradition) plus the heritage cultivar, Red Fife (Table 6). Although these results show the potential of farmer selections (Murphy et al., 2016), they also demonstrate the value of registered cultivars in organic production. AAC Tradition was selected and tested under organic production conditions; therefore, its performance was not surprising. The highest yielding cultivar in the present study was Vesper, a conventionally bred cultivar with wheat midge (*Sitodiplosis mosellana*) resistance.

Yield components and assimilate partitioning differed between farmer selections and check cultivars. Seed mass was significantly lower for farmer selections than for check cultivars (Table 6). Kernel number per unit area of land, on the other hand, was greater for farmer selections (data not shown), indicating greater sink strength (Entz and Fowler, 1990). Wiebe et al. (2017) observed greater kernel production per unit area of land in organically selected lines compared with conventional check cultivars. As a

Table 6. Yield parameters of 23 farmer selected populations and 9 check cultivars at three site years of experiments in Manitoba.

	Yield			Seed mass			Harvest index
Treatment name	**C14†**	**C15**	**B15**	**C14**	**C15**	**B15**	**C14**
	kg ha^{-1}			g 1000 seeds^{-1}			
BJ08-IG	4658cdefghi‡	3256abc	810a	40.5efgh	35.5abc	31.3cdef	0.38ghijk
BJ08-CG	5095abcd	2808cdefgh	569cdefgh	41ef	34defg	30.7efg	0.45abcdefg
BJ10-SC	4750cdefgh	2622defghi	534efgh	37.9o	32klm	31.1def	0.43bcdefgh
BJ10-KB	4716cdefgh	2711defghi	594abcdefgh	40.2fghijk	33ghijkl	30.5efg	0.37hijk
BJ11-SC	4740cdefgh	2313i	590abcdefgh	39.9ghijkl	33.8efgh	30.7efg	0.35k
BJ11-CG	4788cdefg	2548defghi	559defgh	39.6hijkl	34.3defg	30.3efg	0.45abcdefg
BJ11-KB	5081abcd	2816abcdefg	715abcde	41.4cde	34.7bcd	30.8ef	0.40efghijk
BJ03-HRE	4457efghij	2514efghi	695abcdef	39.3kl	33fghijk	30.9def	0.42cdefghij
BJ04-KB	4311ghij	2862cdefg	451gh	41.1def	34.3cdef	30.9def	0.36jk
BJ05-GM	4184ij	2567defghi	698abcdef	39.7ghijkl	32.7hijkl	30.8def	0.37ijk
BJ13-HRE	4635defghi	2946abcde	802ab	42.2c	36.5a	32.5bc	0.41defghijk
BJ15-GM	4332fghij	2858bcdefg	565cdefgh	41.1def	33.5fghi	30.1fgh	0.39fghijk
BJ18-KS	5318ab	2696defghi	557defgh	40.7efg	34.5def	31.5cde	0.49abcde
BJ21-HRE	4856bcde	2572defghi	592abcdefgh	40.5efghi	33.7fgh	30.5efg	0.50abc
BJ22-IG	4983abcde	2650defghi	570cdefgh	40.7defgh	34.2def	30.3efg	0.40cdefghij
BJ23-IG	4928bcdef	2578defghi	612abcdefgh	39.1ijklmn	32.5ijklm	30.3efg	0.42abcdefg
BJ25-SC	4536efghi	2725defghi	580bcdefgh	38.3mno	31.5m	31.2cdef	0.49abcd
BJ26-KS	4622defghi	2699defghi	636abcdefgh	40.2fghijk	34.3cdef	30.8ef	0.47abcdefg
BJ27-MW	5102abcd	3018abcd	511efgh	40.4efghij	33.7defgh	30.2efg	0.44abcdefg
BJ28-MW	4834bcde	3359ab	630abcdefgh	39.7ghijkl	33.3fghij	31.1cdef	0.39fghijk
BJ32-KS	4027jk	2404ghi	638abcdefgh	37.6o	32jklm	28.1i	0.38hijk
BJ43-GM	4041jk	2559defghi	478fgh	39.1lm	32.7ghijkl	30.7ef	0.39ghijk
PA00-KB	4453efghij	2899abcdefg	651abcdefg	41.1def	34cdef	30.7efg	0.40fghik
AC Cadillac	4437efghij	2323hi	697abcdef	39.8ghijkl	32klm	19.3ghi	0.52ab
AAC Tradition	5567a	2878bcdefg	510efgh	46.1a	36.5a	33.5ab	0.40defghijk
Red Fife	5132abc	2988abcdef	793abc	43.9b	36.2ab	34.7a	0.46abcdefg
Glenn	4834bcde	2773cdefghi	482fgh	38no	32.5ijklm	28.3i	0.53a
AAC Brandon	4272hij	2415ghi	533efgh	40.3fghijk	32.7hijklm	30.2efg	0.46abcdefg
Carberry	3315l	2491fghi	590abcdefgh	39.5ijkl	33.7defgh	31.1def	0.42cdefghij
Unity	5108abcd	2659defghi	496efgh	39.4jkl	32jklm	28.7hi	0.47abcdefg
Vesper	5050bcd	3377a	770abcd	42.1cd	35bcde	32.3bcd	0.48abcdef
PT245	3591kl	1453j	460gh	40.5efghi	32lm	30.7efg	0.35k
Farmer selections	4661.6	2755.6a	611.5	40.05b	33.6	30.7a	0.42b
All checks	4589.9	2606.5b	592.4	41.04a	33.5	30.9b	0.46a
Contrast				**ANOVA**			
Farmer selections vs. all checks	0.2606	0.0333	0.5763	<0.0001	0.6911	0.1585	0.0068
Estimate	78.33	149.03	17.877	–0.97	0.0691	–0.2697	–0.0397

† C14, Carman 2014; C15, Carman 2015; B15, Brandon 2015.

‡ Means within a column not sharing a lowercase letter differ significantly at the $P < 0.05$ level.

group, farmer selections had significantly lower harvest index than check cultivars, indicating a lower efficiency in assimilate partitioning.

Farmer Selection Influence on Populations

Three populations (BJ10, BJ11, and BJ08) were distributed to more than one farmer. Our alternative hypothesis was that different farmers would select different phenotypes. The resulting lines were similar among farmer-selectors in terms of plant stand density, weed biomass, and harvest index. Differences between farmer-selectors were, however, observed for early-season vigor, disease pressure, height, days to maturity, lodging, yield, and seed mass (Table 7). At Carman 2014, BJ11-SC had greater early season vigor than BJ11-KB (Table 7). At Carman 2014, BJ11-SC had greater leaf disease than the line BJ11-CG or BJ11-KB. It was interesting that differences were not observed in Carman 2015, where leaf disease pressure was higher (Table 5). Additionally, FHB incidence and severity differences were observed between BJ10-SC and BJ10-KB at Carman 2014, but not in Carman 2015 or Brandon 2015.

For the population BJ10, farmer KB selected for significantly taller plants than farmer SC: 17 cm taller in 2014 and 11 cm in 2015 (Table 4 and 7). Similar differences were observed for population BJ25 (data not shown). Farmer KB had >20 yr of experience growing organic wheat, whereas SC was newer to organic production. BJ11-CG lodged more than BJ11-SC or BJ11-KB.

For both years at Carman, days to maturity for BJ08-IG was 5 d less ($P < 0.05$) than BJ08-CG (Table 4). The IG farm is located in a shorter-season growing area than the CG farm; this illustrates how genetically diverse populations can be tailored to the environment where they will be grown.

At the high-stress, low-yield site (Brandon 2015), BJ08-IG yielded 241 kg ha^{-1} higher than BJ08-CG (Table 4). Farmer IG hosted the Brandon study on their farm, which may have given the line "home-field advantage." Further research is required to determine this phenomenon.

Our hypothesis that farmers and their associated selection environments would select similar traits was rejected, but the alternative hypothesis was supported. Therefore, our study demonstrated that within a relatively small geographic region, individual farmers selected for different characteristics.

CONCLUSIONS

All participating farmer-selectors completed three consecutive years of selection on their organic grain farms. As farmer-selectors were given F_2 seed to start with, they had the best opportunity to modify the distribution of genotypes most suited to their farms. Although there was significant variation in agronomic performance among farmer selections, farmer-selected lines were generally

Table 7. Analysis of variance for significant agronomic parameters comparing three populations selected by four farmers at three site-years in 2014 and 2015.

	Early-season vigor	Leaf disease		Fusarium head blight Incidence	Fusarium head blight Severity	Crop biomass	Lodging			Height		Days to maturity		Yield		Seed mass
Contrasts	C14†	C14	C15	C15	C15	C14	C14	C15	B15	C14	C15	C14	C15	C15	B15	C15
BJ08-IG vs. BJ08-CG	0.395	0.778	**0.0006**‡	0.435	0.528	0.515	0.465	**0.0017**	**0.0471**	0.814	**0.0094**	**0.0059**	**0.0005**	0.106	**0.0394**	**0.0223**
BJ10-SC vs. BJ10-KB	0.384	0.677	**0.0078**	**0.0073**	**0.0021**	0.098	1	**0.0003**	0.502	**<0.0001**	**<0.0001**	0.701	**0.0339**	0.715	0.6	0.1505
BJ11-CG vs. BJ11-SC	0.148	**0.0013**	0.845	1	0.899	**0.019**	**0.0031**	0.109	0.182	0.721	0.112	0.233	0.284	0.289	0.788	0.5722
BJ11-CG vs. BJ11-KB	0.561	0.653	0.397	0.194	0.314	0.17	**0.0001**	**0.0338**	0.182	0.721	0.178	0.092	0.474	0.274	0.175	0.1505
BJ11-SC vs. BJ11-KB	**0.044**	**0.0003**	0.514	0.194	0.257	0.358	0.312	**0.0003**	**0.008**	1	0.805	0.616	0.720	**0.0329**	0.275	**0.046**
Estimates	C14	C14	C15	C15	C15	C14	C14	C15	B15	C14	C15	C14	C15	C15	B15	C15
BJ08-IG vs. BJ08-CG	0.396	2.369	−36.3	−7.5	−6.25	575.264	0.39	448.03	1	−0.445	5.37	−5.321	−5	438.7	240.68	1.43
BJ10-SC vs. BJ10-KB	0.375	3.145	16.16	−26.25	−31.25	1568.306	0	−167.25	0.333	16.875	10.6	0.75	3	74.8	60.196	0.895
BJ11-CG vs. BJ11-SC	−0.625	−1.992	1.2	0	1.25	−2103.74	1.5	309.8	−0.666	−0.625	3.2	1.75	1.5	226	−30.8	0.35
BJ11-CG vs. BJ11-KB	0.25	1.933	6.4	−12.5	−10	−1289.62	2	549.3	0.666	−0.625	2.7	2.5	1	−347.03	−156.7	−0.89
BJ11-SC vs. BJ11-KB	0.875	3.926	5.14	−12.5	−11.25	814.125	0.5	239.4	1.333	0	−0.5	0.75	−0.5	−573.03	−125.9	−1.24

† C14, Carman 2014; C15, Carman 2015; B15, Brandon 2015.

‡ Bold values indicate the significant *P* values.

taller, later maturing, and more susceptible to lodging than commercial check cultivars. Yields were either similar or greater for farmer selections compared with check cultivars, although significant variation among farmer selections was observed. Characteristics that the farmers selected for overlapped with those of scientists in some cases (Mason and Spaner, 2006; Zerner et al., 2008). Future studies to better understand selection criteria of individual farmers would be useful, especially if farmer and professional breeders work together in wheat like they do in potato (Almekinders et al., 2014). Two possibilities are to use farmer-developed lines in crosses, or to have professional breeders apply further selection to these lines.

When selecting from the same population, farmers produced unique lines that differed significantly in disease response, days to maturity, height, lodging, and yield. These preliminary observations suggest that years of organic farm experience and length of the growing season were factors in farmer selection decisions and prove that farmers can shape the population.

A limitation of the present study is that the actual breeding progress by individual farmers could not be determined. To carefully evaluate progress from farmer participatory breeding, farmer selections should be compared with unselected bulk population of the original populations.

Our study demonstrated it is possible to engage farmers in on-farm, participatory plant breeding in the Canadian context, and that high-yielding wheat lines may be produced by having farmers select early generation material in partnership with breeding programs. We also observed good performance of a number of check cultivars: a >100-yr-old cultivar, one cultivar bred specifically for organic production, and a conventionally bred cultivar with insect resistance. Therefore, in addition to involving farmers in early-generation selection, farmer participatory cultivar evaluation for organic production, as suggested by Carr et al. (2006), should also be considered.

Conflict of Interest

The authors declare that there is no conflict of interest.

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