Comparison of Certified and Farm-Saved Seed on Yield and Quality Characteristics of Canola

G. W. Clayton,* S. Brandt, E. N. Johnson, J. T. O'Donovan, K. N. Harker, R. E. Blackshaw, E. G. Smith, H. R. Kutcher, C. Vera, and M. Hartman

Canola

ABSTRACT

Relatively high seed prices and low canola (*Brassica napus* L.) grain prices created a controversy over using farm-saved seed from hybrids. Agronomic implications of saving seed from a canola crop were investigated by planting certified seed and saved-seed of an open-pollinated and a hybrid canola cultivar at eight site-years in Saskatchewan and Alberta, Canada. In one series of experiments cultivars and seed rates were compared, while in another experiment seed treatments and use of sized seed were investigated. Results tend to agree with similar studies with other crops where agronomic performance was unaffected when farm-saved seed from open-pollinated crops was used, but declined when this practice was used with hybrid cultivars. Using farm-saved seed from hybrid canola (HY-FSS) compared with hybrid certified seed (HYC) reduced plant population density by 16 to 18% at the time of crop maturity and yield by an average of 12%, delayed maturity by 2 d, reduced seed oil content by 5 g kg^{-1}, and resulted in a small increase in incidence of green seed. Yield and quality loss associated with using HY-FSS could not be recovered by using increased seeding rates or by sizing and planting only large seed. The inability to use the most effective combined insecticide plus fungicide seed protectant treatments with farm-saved seed resulted in a 20% yield loss compared with treated certified hybrid seed. Our study demonstrates the production risks of growing HY-FSS on plant density, yield, maturity, and seed oil content.

Most of Canada's canola crop historically has been produced using certified seed, mainly because seed cost was a minor part of the cost of producing an open-pollinated (OP) canola crop. Seed costs changed dramatically with the introduction of hybrid (HY) cultivars because seed production costs are much higher than for OP cultivars. Canola hybrids give significant yield gains and are widely used on about 70% of the canola hectarage in western Canada (Chris Anderson, personal communication, 2009). However, canola grain prices can be quite volatile over time, whereas production costs continue to increase. Whenever costs increase or canola prices decrease, producers search for ways to reduce costs without incurring large decreases in yield. One strategy is to save and clean seed ("farm-saved seed" [FSS]) from a current crop to use for next year's planting, a practice that is common with cereal and pulse crops. Saving and cleaning seed of hybrid canola has raised production risk and quality concerns by the canola industry.

G.W. Clayton, R.E. Blackshaw, and E.G. Smith, Agriculture and Agri-Food Canada, Lethbridge Research Centre, Box 3000, Lethbridge, AB, Canada T1J 4B1; S. Brandt and E.N. Johnson, Agriculture and Agri-Food Canada, Scott Research Farm, Box 10, Scott, SK, Canada S0K 4A0; J.T. O'Donovan and K.N. Harker, Agriculture and Agri-Food Canada, Lacombe Research Centre, 6000 C & E Trail, Lacombe, AB, Canada T4L 1W1; H.R. Kutcher and C. Vera, Agriculture and Agri-Food Canada, Melfort Research Farm, Box 1240, Melfort, SK, Canada S0E 1A0; M. Hartman, Alberta Agriculture and Rural Development, 5030-50th St., Lacombe, AB, Canada T4L 1W8.
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*Corresponding author (george.clayton@agr.gc.ca).

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Seed of open-pollinated cultivars are produced by allowing natural pollination (self-pollination, cross-pollination by insects, wind, etc.) during the seed multiplication years. If the pedigreed seed was developed from pure, stable lines, and kept isolated from other varieties, then open-pollinated cultivars will undergo relatively little genetic change from one generation to the next. If seed quality is high, there is little risk that productivity of a crop grown from FSS of an OP cultivar (OP-FSS) would decline dramatically. The results from limited research on canola OP-FSS has ranged from no yield loss compared with certified seed (Carmody and Walton, 2003) to significant yield losses (Marcroft et al., 1999; McKay et al., 2003).

In contrast, hybrid seed is produced by collecting the first generation seed (F_1) after crossing two different parental lines. Useful hybrids are the product of two genetically dissimilar parents where the hybrid exhibits characteristics superior to either parent (termed heterosis or hybrid vigor). A crop grown from the first generation (F_1) of commercial hybrid seed is uniform because the parents were highly inbred and unwanted cross-pollination is restricted by various means. Subsequent generations (F_2, F_3, etc.) are nonuniform because they segregate, exhibiting various combinations of characteristics of their dissimilar ancestors. The degree to which FSS from hybrid (HY-FSS) differs from the hybrid certified seed (HYC) mainly depends on how much the parents of the hybrid differ from each other.

There are few published reports on the yield of HY-FSS (F_2) vs. HYC (F_1) in spring canola. Cervantes Martinez and Castillo Torres (2005) reported that F_2 seed of the hybrid 'Hyola 401' yielded 22% less than certified seed (F_1) in northeastern

Abbreviations: FSS, farm-saved seed; HY, hybrid; HYC, hybrid certified seed; HY-FSS, farm-saved seed from hybrid; OP, open-pollinated; OPC open-pollinated certified seed; OP-FSS, farm-saved seed from OP.

Mexico. McKay et al. (2003) reported large yield declines when using farm-saved hybrid canola seed compared with certified seed in North Dakota. In contrast, Starmer et al. (1998) found that hybrid canola (F_1) and the second-generation seed (F_2) had similar yield increases over the inbred mid-parent average in Northern Idaho. The use of HY-FSS from other crops has been shown to reduce yield compared with the use of HYC. Guillen-Portal et al. (2002) found the yield of FSS for hard red winter wheat (*Triticum aestivum* L.) in the Nebraska Panhandle was 22% lower than from the HYC. Kratochvil and Sammons (1990) found that for soft red winter wheat the F_2 seed yielded 8.3% less than the HYC. Lapinski and Stojalowski (1999) found a similar result for hybrid rye (*Secale cereale* L.). The yield reduction for seeding the F_2 HY rye was 14%. Valdivia-Bernal and Vidal-Martinez (1995) found that the use of F_2 compared with certified seed was not recommended for maize (*Zea mays* L.) in any of the four cultivars tested. Yield was reduced 45.3% on average in the Nayarit region of Mexico. Ochieng and Tanga (1995) found the same result for the use of F_2 seed in maize. They suggest that FSS should not be used in maize.

Not all studies have shown a yield advantage for certified seed over farm-saved seed. The benefits will be largely dependent on the purity of the variety, and maintaining a weed-free condition (Edwards and Krenzer, 2006). Proper seed production and seed-saving practice will also affect the yield difference (Reddy et al., 2000).

Seed size of HY canola is often larger than for OP, and there is evidence a canola crop grown from larger seed can be more productive (Kondra, 1977; Elliott and Rakow, 1999; Gusta et al., 2004; Elliott et al., 2007; Elliott et al., 2008). This has led to speculation that any advantage of HYC seed over HY-FSS canola crop could be at least partially offset by sizing the HY-FSS and planting only large seed. This option appeared attractive since sizing would not add greatly to the cost of FSS. Other speculation about using FSS centered on seed rates, and whether higher rates would be effective in recovering any lost yield potential; again, a practice that would only slightly increase cost with FSS.

With cultivars protected by plant breeders' rights, it is not legal to sell farm-saved seed to other producers for planting. Only the F_1 seed of hybrid canola cultivars are registered varieties, and thus technically the F_2 HY-FSS cannot be legally grown since it will have segregated and contain possibly unregistered parental lines. Seed treatment protocols can restrict which seed treatment products can be applied to FSS. Combined insecticide plus fungicide seed treatments registered for use on canola are unavailable for application on FSS, while some fungicide-only treatments are permitted. However, most commercial sources sell canola seed precoated with insecticidal and/or fungicidal seed treatments in North America, mainly to protect canola seedlings from flea beetle (*Phyllotreta* spp.) damage (Soroka et al., 2008).

We conducted a study to address the core issues of whether there is a yield or quality loss associated with using FSS from HY spring canola compared with using HYC seed and if that differed from FSS of an OP cultivar. We also investigated some of the associated issues to determine if any yield loss could be recovered by using FSS of relatively large size or by increasing the seeding rate. We included key seed treatment comparisons to address issues associated with being unable to use some of the more effective combined insecticide plus fungicide products. Agronomic results are reported here, and economic results are being reported in a companion paper.

MATERIALS AND METHODS

This study was conducted in the major canola-producing areas of Alberta and Saskatchewan in 2004 and 2005. Direct-seeded field experiments were conducted at Lacombe, AB (52°27′ N, 113°45′ W) and Scott, SK (52°21′ N, 108°50′ W) in 2004 and Lacombe, Scott, Beaverlodge, AB (55°13′ N, 119°24′ W), Lethbridge, AB (49°38′ N, 112°47′ W), Melfort, SK (52°79′ N, 104°30′ W), and Canora, SK (51°38′ N, 102°26′ W) in 2005. The soil characteristics of the study locations are summarized in Table 1. These locations, representing different soil types and moisture regimes in the major canola-growing area of Western Canada, provided a wide spectrum of conditions to evaluate the potential of FSS and certified seed on canola yield and quality.

Three experiments were conducted at each site-year. Experiments 1 and 2 included the variables genetic background (certified vs. farm-saved seed canola), seed rate (120 vs. 240 seeds m^{-2}), and variety (hybrid vs. open-pollinated). Experiments 1 and 2 were similar except that Experiment 2 was seeded with tame oat and herbicide application was delayed to increase weed pressure. Experiment 3 compared the genetic background (HYC vs. HY-FSS) of the hybrid only along with seed size (normal vs. large) and seed treatment. We combined three different seed lots for each seed source in an attempt to account for seed lot effects. Germination percentage and seed weight of each treatment is given in Table 2. A representative sample of seed from each seed lot was sent to a certified seed laboratory. The laboratory determined germination percentage using the *Methods and Procedures of Seed Testing* of the Canadian Food Inspection Agency (Canadian Food Inspection Agency, 2008).

Table 1. Site-year and soil characteristics at eight study sites.

Site-year	USDA soil description	Canadian† soil classification	Textural class	Sand	Silt	Clay	Organic matter	pH
				g kg^{-1}				
Lacombe 2004	Typic Haplustoll	Black Chernozem	loam	350	390	250	91	7.3
Lacombe 2005	Typic Haplustoll	Black Chernozem	loam	430	390	180	83	6.7
Scott 2004	Typic Borall	Dark Brown Chernozem	loam	310	420	270	40	6.0
Scott 2005	Typic Borall	Dark Brown Chernozem	loam	310	420	270	40	6.0
Beaverlodge 2005	Molic	Dark Gray Luvisol	clay loam	270	380	350	75	5.9
Lethbridge 2005	Cryoboralf	Dark Brown Chernozem	loam	370	360	270	34	7.8
Melfort 2005	Typic Haplustoll	Black Chernozem	silty clay loam	170	420	410	95	6.0
Canora 2005	Typic Haplustoll	Black Chernozem	loam	na	na	na		

† Canada Soil Survey Committee, Subcommittee on Soil Classification (1978).

Table 2. Germination percentage, seed weight before and after sizing of seed lots of hybrid, and open-pollinated canola used in farm-saved seed studies during 2004 and 2005.

Treatment	Germination		Seed size before sizing		Seed size after sizing	
	2004	2005	2004	2005	2004	2005
	%		g 1000^{-1}			
Hybrid certified	95	95	3.73	4.57	4.60	4.90
Hybrid farm-saved seed	97	93	3.06	4.06	3.95	4.71
Open-pollinated certified	98	98	3.03	3.65	na†	na
Open-pollinated farm-saved seed	95	91	3.47	3.71	na	na

† Seed size after sizing was only applicable to the hybrid certified and farm-saved seed, so na refers to not applicable.

All seed lots exceeded the minimum 90% germination required for Canada Certified No. 1 seed. Fertilizer N, P_2O_5, and K_2O was banded at the time of seeding according to soil test recommendations. Weed control was accomplished with recommended herbicides and surfactants at the recommended rates for the respective treatments. Seeding, swathing, and harvest dates for the three experiments are described in Table 3.

In Experiments 1 and 2, the experimental design was a 2 × 2 × 2 factorial arrangement of the three treatment variables randomized in complete blocks with four replications for all site-years. Treatments were HYC cultivar 'InVigor 2663', HY-FSS of 'InVigor 2663', certified OP seed (OPC) cultivar '46A76', and OP-FSS grown from the OP. Seeding rates were adjusted to seed 120 and 240 viable seeds m^{-2}. All seed lots were treated commercially with Helix (thiamethoxam (3-[(2-chloro-5-thiazolyl)methyl]tetrahydro-5-methyl-*N*-nitro-4*H*-1,3,5-oxadiazin-4-imine), difenoconazole (1-[2-[2-chloro-4-(4-chlorophenoxy)phenyl]-4-methyl-1,3-dioxolan-2-ylmethyl]-1*H*-1,2,4-triazole), metalaxyl-M (methyl *N*-(2,6-dimethylphenyl)-*N*-(methoxyacetyl)-D-alaninate) plus fludioxonil (4-(2,2-difluoro-1,3-benzodioxol-4-yl)-1*H*-pyrrole-3-carbonitrile)), a widely used canola fungicide/insecticide treatment. Canola was seeded during May at all site-years, but was reseeded at Melfort in June because of a mid-May frost that affected emerged plants (Table 3). Experiments 1 and 2 were seeded with hoe-type openers with row space of 30, 30, 25.4, and 24 cm at Lacombe, Beaverlodge, Scott, and Canora, respectively, and a double-disc press seeder with 23- and 18-cm row space at Lethbridge and Melfort, respectively. Seeding depth varied between sites but generally was between 13- and 20-mm, a depth well-suited for canola emergence. Plot size was 3.6 m by 15 m at Lacombe, Beaverlodge, and Melfort; 1.5 m by 5 m at Scott; and 2.5 m by 6 m at Lethbridge.

In Experiment 2, tame oat (*Avena sativa* L. 'AC Morgan') was planted at a rate of 100 seeds m^{-2} to increase the potential weed pressure on the crop. Otherwise, experimental treatments were similar in Experiments 1 and 2. Weeds were controlled in the HY canola 'In Vigor 2663' with a tank mixture of glufosinate ammonium (2-amino-4-(hydroxymethylphosphinyl)butanoic acid) plus clethodim ((*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) applied at 500 g a.i. ha^{-1} and 15 g a.i. ha^{-1} at 275 kPa in 100 L water ha^{-1} at the 2- to 3-leaf stage of canola in Experiment 1 and at the 6- to 7-leaf stage in Experiment 2. Weeds were controlled in the OP canola '46A76' with sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one)/ethametsulfuron (2-[[[[[4-ethoxy-6-(methylamino)-1,3,5-triazin-2-yl]amino] carbonyl]amino]sulfonyl]benzoic acid) mixture applied at 200 g a.i. ha^{-1} and 20 g a.i. ha^{-1} or imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid) plus imazethapry (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) at 200 g a.i. ha^{-1} plus Merge adjuvant at 0.5% v/v at 275 kPa in 100 L water ha^{-1} at the 2- to 3-leaf stage of canola in Experiment 1 and at the 6- to 7-leaf stage in Experiment 2. Delaying time of weed removal exerts significant weed pressure on crop plants that negatively affects seed yield (Harker et al., 2003), but the impact could differ by genetic background of the seed.

Experiment 3 evaluated three seed treatments, two seed sizes, and two seed origins at the eight site-years in 2004 and 2005. Experiment 3 was designed as a complete factorial with four replicates, but the treatments differed each year. Only HYC and HY-FSS were used in this experiment. In 2004, treatments included seed source, seed sizing, and seed treatment. The HYC and HY-FSS seeds were either as-is or sized, and then either untreated, treated with Helix, or treated with Foundation Lite (iprodione [3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide] plus thiram [tetramethylthioperoxydicarbonic diamide ([[$(CH_3)_2N$]$C(S)]_2S_2$)]). Helix provides insect and seedling disease protection, Foundation Lite provides only seedling disease protection. As previously indicated, Helix is not available to treat HY-FSS. Also, in practice it is unlikely the HYC seed would be sized. All treatment combinations were included to balance

Table 3. Planting date (PD), swathing date (SD), and harvest date (HD) of canola in Experiments 1, 2, and 3 for the study site-years.

Site-year	Experiment 1			Experiment 2			Experiment 3		
	PD	SD	HD	PD	SD	HD	PD	SD	HD
Lacombe 2004	18 May	16 Sept.	6 Oct.	18 May	16 Sept.	6 Oct.	26 May	–	1 Oct.
Lacombe 2005	11 May	12 Sept.	6 Oct.	11 May	13 Sept.	12 Oct.	11 May	13 Sept.	12 Oct.
Scott 2004	21 May	26 Aug.	13 Sept.	21 May	26 Aug.	13 Sept.	20 May	27 Aug.	14 Sept.
Scott 2005	16 May	–	30 Sept.	16 May	–	6 Oct.	16 May	–	30 Sept.
Beaverlodge 2005	13 May	9 Sept.	13 Oct.	13 May	9 Sept.	13 Oct.	13 May	9 Sept.	13 Oct.
Lethbridge 2005	26 May	01 Sept.	30 Sept.	26 May	1 Sept.	30 Sept.	26 May	1 Sept.	30 Sept.
Melfort 2005	13 June	12 Oct.	18 Oct.	13 June	12 Oct.	18 Oct.	30 May	19 Sept.	29 Sept.
Canora 2005	11 May	27 Aug.	29 Sept.	11 May	27 Aug.	29 Sept.	12 May	27 Aug.	29 Sept.

the experimental design. In 2005, the HYC seed was treated only with Helix, and the FSS treatments were: (i) untreated, (ii) treated with Foundation Lite, and (iii) treated with Helix. We used the same combined seed lots for each seed source as used in Experiments 1 and 2. Seed sizing over a 1.98-mm screen increased mean seed size of HYC by 23 and 7% in 2004 and 2005, while HY-FSS was increased by 30 and 16% for 2004 and 2005 (Table 2). In all cases the sized HY-FSS had a larger seed size than unsized HYC. Canola was seeded during May at all site-years in Experiment 3 (Table 3). Experiment 3 was seeded with hoe-type openers with row space of 30 cm, 25.4 cm, and 24 cm at Beaverlodge, Scott, and Canora, respectively, and a double-disc press seeder with 23-, 23-, and 18-cm row space at Lacombe, Lethbridge, and Melfort, respectively. Seeding depth and plot sizes were the same as described above for Experiments 1 and 2. Recommended herbicides were used for weed management in-crop at the 2- to 3-leaf growth stage.

Data were collected on plant density, percentage emergence, days to maturity, seed yield, seed weight, percentage green seed, and oil content. Canola plant density was determined approximately 3 wk after emergence by counting two 1-m length rows in two randomly chosen locations in each plot. The date when seed rows were visually distinguishable with cotyledons (GS 1) was defined as the date of emergence (Thomas, 2003). Canola plant density was also determined after harvest by counting two 1-m length rows in two randomly chosen locations in each plot. Maturity was defined as the time at which 10% of seeds in pods on the top one-third of the main stem, and 90% of seeds in pods on the bottom two-thirds of the main stem were tan, reddish-brown, brown, or black (Thomas 2003). At maturity, canola plants in each plot were cut approximately 10 to 15 cm above the soil surface in a 3.6-m by plot length (Lacombe, Beaverlodge, Melfort, Canora) or a 1.5-m-wide area by plot length (Lethbridge and Scott) and windrowed with a swather and harvested with a plot combine when dry. Canola was direct combined from the whole plot area at Scott in 2005. Seed weight and moisture content were recorded from each plot, the seed was cleaned and weighed, and the seed yield was reported on a 100 g kg^{-1} water basis. A harvested seed subsample of approximately 1000 g from each plot was used to determine dockage and 1000-seed wt. Green seed was determined by counting one 100-seed sample from each plot onto a piece of masking tape then crushing the seed with a roller and counting the number of distinctly green seeds. Oil concentration from a harvested cleaned subsample (125 g) was determined by near-infrared spectroscopy.

Statistical Analysis

The data were partitioned two ways for the statistical analysis. A combined analysis was performed for Experiment 1 and 2 data, with random restrictions associated with the effect of experiment (Experiment 1: early weed control and Experiment 2: late weed control) being considered. An analysis of Experiment 3 was conducted to determine the effect/interactions of seed background, seed sizing, and seed treatment.

The two analyses were separately conducted with the PROC MIXED procedure of SAS (Littel et al., 1996). The effect of replications and site (location × year combination) were considered random, and the effects of the seed background, canola variety, seeding rate, seed treatment, and/or seed sizing were considered fixed. Exploratory analysis revealed some variance heterogeneity among sites that affected the analysis results for green seed data (Experiment 1 and 2 data). This heterogeneity was modeled using the repeated statement within the PROC MIXED procedure. Model fit criteria (corrected Akaike's information criterion) were used to decide the worthiness of modeling unique residual variance estimates for the different combinations of sites. A combination of variance estimates and P values were used to determine the importance of the random site × treatment interaction.

For the combined analysis of data from Experiments 1 and 2, the lack of replication associated with the effect of experiment (weed removal) was recognized. Consequently, the effect of experiment, site, and experiment within site were considered invalid and not presented. Treatment effects were declared significant at $P < 0.05$ for all analyses.

The two analyses were separately conducted for Experiment 3 data with the PROC MIXED procedure of SAS (Littel et al., 1996). An analysis was conducted for Helix level of seed treatment with seed source and seed sizing as applied treatments. The other analysis was conducted for farm-saved (FSS) level of seed source with seed treatment and seed sizing as applied treatments. Exploratory analysis revealed some variance heterogeneity among sites for selected variables. This heterogeneity was modeled using the repeated statement within the PROC MIXED procedure. Model fit criteria (corrected Akaike's information criterion) were used to decide the worthiness of modeling unique residual variance estimates for the different combinations of sites. A combination of variance estimates and P values were used to determine the importance of the random site × treatment interaction.

RESULTS

The growing season weather conditions were near normal at Lacombe (2004), at Beaverlodge (2005), and at Canora (2005). At Lacombe in 2005, it was expected that harvest might be late, so plots were harvested earlier than desirable to minimize a potential green seed problem. In 2004, Scott had an early fall frost that impacted seed quality, particularly green seed count. Scott had some hail damage and excessive moisture conditions in 2005, resulting in high green seed count and delayed canola maturity. Melfort in 2005 had a mid-May frost and Experiments 1 and 2 were reseeded on 13 June, which delayed maturity and caused high green seed count for this location. At Lethbridge in 2005, excessive moisture in June and a minor hail event reduced the site yield.

Experiments 1 and 2: Variety × Genetic Background × Seed Rate

The ANOVA revealed that genetic background × variety interactions for all crop variables except for maturity and seed weight were significant (Table 4). In addition, the presence of tame oat to increase weed pressure in Experiment 2 had no effect on the treatments (Table 4). Canola emergence at 3 to 4 wk after seeding was similar for HYC, HY-FSS, and OPC (Table 5). Only OP-FSS had a significantly higher crop percent emergence compared with the others. Canola seedling emergence ranged from 65 to 75% (Table 5). Averaged across

Table 4. Combined ANOVA for Experiment 1 (early weed removal) and Experiment 2 (late weed removal).

Effect/contrast	Plant density† Emergence	Plant density† Maturity	Days to maturity	Seed yield	Green seed	Seed wt.	Oil conc.
	P value						
Genetic background (B)	0.042	0.882	0.153	<0.001	0.386	0.545	0.068
Variety (V)	0.321	0.015	<0.001	<0.001	0.015	<0.001	0.030
B × V	<0.001	<0.001	0.056	<0.001	0.003	0.415	0.030
HYC‡	0.215	<0.001	0.021	<0.001	0.007	0.317	0.006
HY-FSS	<0.001	<0.001	0.710	0.837	0.101	0.881	0.784
Seeding rate (R)	<0.001	<0.001	0.980	0.052	0.765	0.274	0.808
B × R	0.639	0.915	0.644	0.989	0.325	0.972	0.689
V × R	0.767	0.930	0.924	0.360	0.755	0.377	0.188
B × V × R	0.612	0.003	0.758	0.960	0.637	0.827	0.360
Experiment (E) × G	0.416	0.579	0.453	0.148	0.188	0.311	0.378
E × V	0.969	0.734	0.195	0.498	0.749	0.971	0.648
E × B × V	0.492	0.501	0.959	0.804	0.227	0.395	0.305
E × R	0.216	0.062	0.623	0.526	0.808	0.492	0.872
E × B × R	0.508	0.872	0.156	0.503	0.726	0.323	0.625
E × V × R	0.547	0.193	0.555	0.585	0.854	0.433	0.138
E × B × V × R	0.275	0.858	0.131	0.487	0.100	0.809	0.177
	variance estimate						
Site (S)	147*	45.4§	158§	0.938*	110§	0.133§	1767§
S × B × V × R	23**	2.8	2**	0.016**	<1	0.011**	4
	% total variance¶						
S	86	94	99	98	100	93	100
S × B × V × R	14	6	1	2	<1	7	<1
Site heterogeneity#	no	no	no	no	yes	no	no

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Percentage of seedlings or stubble counted relative to the corresponding seeding rate.

‡ A comparison of the effect of seed background for each variety; hybrid certified (HYC) and hybrid farm-saved seed (HY-FSS).

§ 0.10 ≥ *P* value ≥ 0.05.

¶ The variance for a given effect, divided by the sum of the variance estimate for the effects associated with location, and multiplied by 100.

Those response variables where model fit was improved by accounting for site heterogeneity within the residual variance.

the two densities, canola emergence was 122, 117, 115, and 132 plants m^{-2} for HYC, HY-FSS, OPC, and OP-FSS, respectively [LSD (0.05) = 9]. Canola plants were also counted at harvest, where a significant genetic background × variety × seeding rate interaction was detected (Table 4). Harvest plant density was 22% higher for HYC than for HY-FSS when seeded at 120 seeds m^{-2} and 9% higher when seeded at 240 seeds m^{-2} (Table 5). Whether greater HYC plant density was due to uniform herbicide tolerance, hybrid vigor, or a combination of the two factors, is not known. Plant density at harvest for OP-FSS at the 120-seed m^{-2} seeding rate was higher than plant density OPC (Table 5).

Canola yield was significantly affected by genetic background and variety, and the interaction of the two (Table 4). Canola yield of HYC was 12% higher than HY-FSS, whereas the OPC and the OP-FSS were similar in yield (Table 5). The HYC had 24% greater yield than the OPC. There may have been a marginal (3%) overall increase ($P = 0.052$) in yield at the higher seeding rate (Table 4). However, since the genetic background × variety × seeding rate interaction was not significant ($P = 0.960$), it is unlikely that increasing the seeding rate would compensate for yield reduction associated with HY-FSS. The maturity of HY-FSS was significantly delayed by 2 d compared with HYC; however, both varieties matured 2 to 5 d earlier than the OPC and OP-FSS (Tables 4 and 5). Both the HYC and HY-FSS had significantly higher seed weight than the OP (Table 5), whereas the genetic background did not affect the canola seed weight harvested (Table 5). The green seed content of HY-FSS was 9% higher than HYC, whereas there was no difference in green seed content between OPC and OP-FSS (Table 5). The HYC had less green seed than HY-FSS, OPC, or OP-FSS, likely due to the earlier maturity and possibly more uniform maturity. Seeding HYC produced similar oil concentration in the seed to the OPC and OP-FSS. However, seeding HY-FSS resulted

Table 5. Mean percent population density at emergence and at harvest, days to maturity, yield, green seed, seed weight and seed oil content of seed background and variety mean responses for Experiment 1 and 2 data averaged over eight site-years.

Variety/seed background	Plant density Emergence	Plant density Maturity 120	Plant density Maturity 240	Days to maturity	Yield	Green seed	Seed weight	Oil content
	%†			DAS	t ha^{-1}	%	mg	g kg^{-1}
InVigor 2663								
Certified	70.0	68.3	53.0	111	2.82	6.06	3.70	446
Farm-saved	67.0	55.7	48.3	113	2.51	6.62	3.63	441
46A76								
Certified	65.2	58.7	51.4	116	2.27	6.86	3.25	446
Farm-saved	75.2	72.0	56.2	115	2.29	6.54	3.28	446
LSD (0.05)	4.8	5.1		1	0.12	0.42	0.10	3

† Percentage of seedlings or stubble counted relative to the corresponding seeding rate.

Table 6. Analysis of variance, source of variation and contrasts of evaluated canola agronomic characteristics for Experiment 3 data averaged over eight site-years in 2004 and 2005.

Effect/contrast	Plant density: Emergence	Plant density: Maturity†	Days to maturity	Yield	Green seed	Seed wt.	Oil content‡
	P value						
Genetic background (B)	0.781	0.005	0.001	<0.001	<0.001	<0.001	<0.001
Seed treatment (T)	<0.001	0.004	0.703	0.037	0.585	0.014	0.189
B × T	0.225	0.077		0.375	0.369	0.632	0.868
Certified§	0.002	0.009		0.594	0.972	0.417	0.632
Farm-saved	0.006	0.193	0.703	0.003	0.097	0.005	0.254
Seed sizing (Z)	0.377	0.575	0.539	0.091	0.719	0.161	0.175
B × Z	0.991	0.313	0.496	0.870	0.833	0.062	0.404
Certified	0.609	0.381		0.282	0.735	0.053	0.704
Farm-saved	0.389	0.611	0.917	0.124	0.890	0.662	0.124
T × Z	0.230	0.152	0.912	0.201	0.502	0.534	0.672
B × T × Z	0.738	0.126		0.123	0.732	0.606	0.066
Certified	0.008	0.011	0.270	0.300	0.920	0.337	0.289
Farm-saved	0.029	0.575	0.964	0.015	0.363	0.044	0.276
	variance estimate						
Site (S)	400*	54	345	1.04*	136**	0.221**	
S × B × T × Z	23	66.7**	2**	0.02*	12**	0	
	% total variance#						
S	95	45	99	98	92	100	
S × B × T × Z	5	55	1	2	8	0	
Site heterogeneity	no	no	no	no	no	no	no

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† Data were not collected for all levels of seed treatment for certified seed.

‡ Variance estimates were not available because data was collected at only one site.

§ A comparison of the effect of T, Z, or T × Z for each level of seed background.

The variance for a given effect, divided by the sum of the variance estimate for the effects associated with location, and multiplied by 100.

in a 1% reduction in oil concentration compared with seeding HYC, OPC, and OP-FSS (Table 5).

Experiment 3: Seed Size and Seed Treatment by Genetic Background

Genetic background had a significant effect on plant density at maturity, days to maturity, yield, the proportion of green seed, seed weight, and oil concentration (Table 6). When compared with HY-FSS, HYC increased plant density by 26% at maturity, yield by 17%, seed weight by 5%, oil concentration by 1.4%; while green seed was reduced by 52% averaged over seed size (Table 7). Seed treatment had a significant effect on plant density at emergence and maturity, and both yield and seed weight (Table 6). Unprotected contrast *F* tests indicated that Helix-treated HYC seed resulted in seedling emergence greater than seed treated with Foundation Lite, which was greater than the untreated check (Table 7). In contrast, only Helix-treated HY-FSS resulted in seedling emergence higher than the untreated check. At maturity, HYC plant density was significantly higher with seed treatments than the untreated check, whereas plants surviving to maturity were similar for treated and untreated HY-FSS (Table 7). The higher response to seed treatments of the HYC compared with HY-FSS for plant density is interesting and deserves further study.

Seed treatment did not affect seed yield or seed weight of HYC (Table 7). In contrast, Helix-treated HY-FSS resulted in significantly higher yield and seed weight than the seed treated with Foundation Lite and the untreated check. However, even the improved yield and increased seed weight of Helix-treated HY-FSS remained significantly lower than any Helix-treated HYC (Table 7).

Table 7. Mean responses of plant population, maturity, yield, green seed, seed weight and oil concentration of seed background averaged over seed size and seed treatments for Experiment 3† averaged over eight site-years in Alberta and Saskatchewan, Canada in 2004 and 2005.

Variable/seed background	Check	Foundation light	Helix	LSD (0.05)‡	Means
Emergence plant density	no. m^{-2}				
Certified	58	68	79	10	68
Farm-saved	64	63	74	7	67
Stubble plant density	no. m^{-2}				
Certified	50	68	79	16	66
Farm-saved	50	48	56	9	52
Seeding to maturity§	DAS				
Certified			113	2	
Farm-saved	117	117	117	2	117
Yield	t ha^{-1}				
Certified	3.26	3.35	3.38	0.21	3.33
Farm-saved	2.78	2.76	2.98	0.14	2.84
Green seed	%				
Certified	6.5	6.7	7.2	5.3	6.8
Farm-saved	15.3	13.2	11.1	3.8	13.2
Seed wt. (mg)	mg				
Certified	3.59	3.63	3.67	0.11	3.63
Farm-saved	3.43	3.44	3.55	0.08	3.47
Oil	g kg^{-1}				
Certified	429	427	427	4	428
Farm-saved	423	420	421	4	422

† See ANOVA table to determine those seed background means different from each other.

‡ LSD (0.05) to compare seed treatment means for each level of seed background.

§ Data were not collected for all levels of seed treatment for certified seed.

Seed sizing did not have a significant effect on plant density at emergence or maturity, days to maturity, yield, the proportion of green seed, seed weight, or oil concentration (Table 6). The seed background × seed treatment × seed size interaction was not significant for plant density at emergence or maturity, yield, green seed, seed weight, and oil concentration (Table 6). However, unprotected contrast *F* tests indicated that seed treatment increased plant density of HYC compared with the untreated check when seed was unsized (Table 8). When seed was sized, the larger seeded Helix-treated HYC significantly increased the number of plants surviving at harvest compared with the untreated check. Seed treatment had no effect on plant density of HY-FSS whether the seed was sized or unsized, and plant density of HY-FSS was similar to that of untreated HYC seed. Averaged over seed size, Helix-treated HYC plant density was 40% higher than HY-FSS plant density (Table 8). Seed treatment resulted in an increased yield of HYC unsized seed compared with the untreated check, whereas increasing the seed size of HYC resulted in similar yield of the check and the seed treatments. Seed treatment had no impact on yield of unsized HY-FSS; however, Helix-treated HY-FSS significantly improved yield compared with seed treated with Foundation Lite or untreated when the seed was sized. Consequently, Helix-treated HYC yielded 16 and 11% greater than Helix-treated HY-FSS when unsized and sized, respectively (Table 8). The seed weight of HYC was unaffected by seed size or seed treatment, whereas Helix-treated HY-FSS resulted in a significantly higher seed weight from planting both sized and unsized seed (Table 8).

Table 8. Mean responses of plant population, yield, and seed weight of seed background, seed size and seed treatments for Experiment 3† averaged over eight site-years in Alberta and Saskatchewan, Canada, in 2004 and 2005.

Variable/seed background/seed sizing	Check	Foundation light	Helix	LSD (0.05)†
		no. m^{-2}		
Stubble plant density				
Certified				
Unsized	57	78	72	22
Sized	44	59	85	22
Farm-saved				
Unsized	50	46	55	13
Sized	50	50	57	13
Yield		t ha^{-1}		
Certified				
Unsized	3.05	3.38	3.41	0.30
Sized	3.48	3.32	3.36	0.29
Farm-saved				
Unsized	2.74	2.72	2.93	0.19
Sized	2.81	2.81	3.04	0.19
Seed wt.		mg		
Certified				
Unsized	3.51	3.58	3.66	0.16
Sized	3.67	3.69	3.69	0.16
Farm-saved				
Unsized	3.42	3.46	3.56	0.11
Sized	3.43	3.42	3.55	0.11

† LSD (0.05) to compare seed treatment means for each level of seed background/seed sizing.

DISCUSSION

Most of Canada's canola crop is produced using certified seed. Hybrid canola is quickly replacing open-pollinated varieties in Canada, mainly because of the higher yield realized by producers. With rising input costs, some producers are tempted to save and replant seed (farm-saved seed) either due to financial constraints or lack of knowledge of seeding FSS. To the best of our knowledge, there is no documented information on the use of canola HY-FSS in western Canada. Consequently, we asked the questions, "Is there a reduction in yield potential of the F2 generation seed from high-yielding hybrid canola compared with the actual hybrid?" and "Is the relationship of second-generation seed similar for hybrid and non-hybrid cultivars?" In our experiments, plant density shortly after emergence did not differ between HY-FSS and HYC. However, plant losses during the growing season were much higher for HY-FSS than for HYC, resulting in lower densities at harvest. It is probable that up to 15% of the HY-FSS plants died because they lacked resistance to glufosinate due to segregration in the F_2 generation. The better competitive ability of hybrids (Harker et al., 2003; Zand and Beckie, 2002) could not improve harvest plant counts with certified seed, particularly at higher seeding rates, despite the much higher hybrid vigor than farm-saved seed. Other studies have shown a reduction of percent emergence and a higher percentage of abnormal seedlings from farm-saved seed compared with the hybrid seed in Guar bean (*Cyamopsis tetragonolobus* L.) (Arora et al., 1998), winter rye (Lapinski and Stojalowski, 1999), and hard red winter wheat (Edwards and Krenzer, Jr., 2006). Seeding rate affected the proportion of established plants, similar to results from North Dakota (Hanson et al., 2008) but contrary to results reported by Harker et al. (2003). Nevertheless, in all cases, canola plant density was adequate for healthy canola stands both at emergence and at harvest for all experiments.

In our study, no difference in yield and quality occurred between OPC and OP-FSS. This agrees with other similar studies where OP-FSS performed as well as OPC, provided seed quality was high (Carmody and Walton, 2003). The HYC had 24% greater yield than the OPC, a result consistent with other studies (Harker et al., 2003; Hanson et al., 2008). In most cases, canola yield was 13.5 to 16% higher with HYC compared with HY-FSS, which is comparable with that reported in Mexico (Cervantes Martinez and Castillo Torres, 2005). Other studies showed yield reductions of up to 50% with maize, 12% with winter wheat, and 15 to 20% with winter rye from farm-saved seed compared with the pure hybrid seed (Ochieng and Tanga, 1995; Guillen-Portal et al., 2002; Lapinski and Stojalowski, 1999). A popular perception in the farm community was that increased seed rates or using large seed could improve yield of HY-FSS to be similar to HYC. In our study, the yield advantage of HYC could not be recovered by seeding HY-FSS at higher seed rates, nor could it be recovered using only large HY-FSS seed. The use of farm-saved seed is complicated because combined insecticide plus fungicide treatments can only be obtained with certified seed in most locations. Our results indicate that Helix-treated HYC yielded 24% higher than untreated HY-FSS. This suggests that yield can be adversely affected when such products are not used with FSS. Crop quality, as indicated by a reduction in green seed and increased oil content, was also higher for the crop grown with HYC compared with HY-FSS. These results would suggest that the yield and quality losses were primarily due to genetic differences such as hybrid vigor between HYC and HY-FSS, and not due to differences in seed quality. The delayed maturity of the HY-FSS possibly contributed to the higher green seed content and thus poorer quality.

CONCLUSION

Results of this study conducted in the major canola growing area of western Canada indicated that HYC yielded 13.5% higher than HY-FSS, averaged over three experiments and eight site-years. This relationship did not occur for the OPC and OP-FSS. The perception of preserving similar yield of HYC when growing HY-FSS, by either increasing seeding rate or using larger seed, failed to occur in our trials, likely due to the genetic differences between the generations of hybrid seed. Further exacerbating the problem is the inability to apply seed treatments on farm-saved seed, where untreated HY-FSS yielded 20% less than Helix-treated HYC. Growing HY-FSS resulted in higher plant mortality throughout the growing season than growing HYC; however, the final plant densities at maturity were not likely the cause of the HY-FSS yield decline. The inherent risk in growing HY-FSS on plant density, yield, maturity, seed weight, and seed oil content shown in this study increases farmer production risk. There is good agronomic value from certified hybrid canola seed and growing farm-saved seed from hybrids should not be recommended.

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