Final Project Report

for the

SASKATCHEWAN CANOLA DEVELOPMENT COMMISSION (SASKCANOLA)

PROJECT TITLE: EFFECTS OF GENETIC SCLEROTINIA TOLERANCE AND FOLIAR FUNGICIDE APPLICATIONS ON THE INCIDENCE AND SEVERITY OF SCLEROTINIA STEM ROT INFECTION IN ARGENTINE CANOLA (CARP-SCDC-2013-16)

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Abstract / Executive Summary:

A three-year field study was conducted at five locations in Saskatchewan and Manitoba to evaluate the relative effectiveness of genetic tolerance and foliar fungicide applications to reduce sclerotinia stem rot infection in Argentine canola (*Brassica napus*). A secondary objective was to determine if, and under what conditions, foliar fungicide applications might be required when growing a cultivar with genetic tolerance to this disease. All locations were within the Black soil zone and/or irrigated and were selected to have moderate to high levels of disease pressure. While overall environmental conditions, subsequent disease pressure and canola yields varied across location-years, actual disease incidence was generally quite low and treatment effects were fairly subtle. Under the conditions encountered, disease levels were frequently lower for the tolerant hybrid 45S54 relative to 45H29 which is susceptible to sclerotinia. Interactions between hybrid and fungicide treatments for sclerotinia incidence and severity were such that fungicides reduced disease in the susceptible but not the tolerant hybrid where disease levels were low regardless of fungicide treatment. Not necessarily unexpectedly considering that disease incidence was less than 5% on average and only exceeded 10% in 1/14 cases, fungicide effects on seed yield were small and, in most individual cases, not significant. Averaged across locations and hybrids, there was a slight but significant yield increase with fungicide; however, the economic returns associated with the applications would at best be marginal depending on grain and fungicide costs. While the interaction was not significant, there was limited evidence that the yield response was slightly larger and more consistent with the susceptible versus the tolerant hybrid. There was no benefit to dual applications over single applications, regardless of application timing or location and, under this low disease pressure, were no measurable benefits to applying fungicides with a tolerant hybrid. While our results showed that genetic tolerance was effective for reducing disease and reducing the need for fungicide applications, the susceptible hybrid frequently yielded higher under the low disease pressure that was encountered. The greatest challenge for managing sclerotinia in canola continues to be accurately predicting whether yield responses to costly fungicide applications are likely. Genetic tolerance is an exciting advancement that has potential to reduce dependence on fungicides and provide adequate protection under low to moderate disease pressure. However, to be widely adopted and utilized to its full potential, sclerotinia tolerance should be incorporated into broader range of hybrids and, given the sporadic and unpredictable nature of this disease, yields must remain competitive with susceptible hybrids.

Background / Introduction:

Sclerotinia stem rot causes significant yield loss for canola in western Canada each year; however, the degree to which this disease affects individual fields varies dramatically depending on specific environmental and weather conditions. For example, in 2011 a total of 241 canola fields were surveyed (Dokken-Bouchard et. al. 2012) and it was found that 81% of the crops surveyed were affected by sclerotinia; however, the actual percent incidence ranged from 0-91% and averaged 9.4%. In 2012, sclerotinia stem rot was observed in 91% of fields surveyed with incidence ranging from 0-95% but a provincial average of 19.0% (Miller et al. 2013). In 2013, sclerotinia pressure was substantially lower with the disease occurring in 60% of fields surveyed, mean incidence ranging from 1-8% among regions and 5% province-wide average (Miller et al. 2014). Moderate pressure was again encountered in 2014 with disease detected in 80% of the fields surveyed and a provincial average of 14% incidence (Dokken-Bouchard et al. 2015). With respect to seed yield, a crude rule of thumb is that approximately 0.5% of yield may be lost for every 1% of infected plants; however, the actual impacts of sclerotinia incidence on yield often vary (Del Rio et al. 2007). At low levels of disease (i.e. 5% or lower), sclerotinia incidence does not generally impact canola yields due to the plant's ability to compensate provided that severity is not too high (Del Rio et al. 2007; Kutcher and Malhi 2010).

Past research aiming to reduce the impacts of sclerotinia on canola in western Canada has looked at many factors with varying levels of success. With the adoption of reduced- and no-tillage systems, many growers have expressed concerns over higher residue levels leading to increased disease and have considered burning and/or tillage as potential solutions. However, Kutcher and Malhi (2010) showed burning could actually increase sclerotinia incidence while tillage had no effect, therefore concluding that neither of these practices were effective or desirable methods for managing sclerotinia. Similar research conducted at Melfort also concluded that tillage did not impact sclerotinia and, furthermore, showed that crop rotation was also ineffective for reducing sclerotinia or response to fungicide applications (Kutcher et al. 2011). With respect to nitrogen fertility and landscape position, it is intuitive that higher N rates would produce a denser canopy and greater chance of sclerotinia infection and that lower slope positions would retain more moisture resulting in a better environment for disease. However, while this can sometimes be the case, actual results vary dramatically with environmental conditions and strong healthy crops are also better able to defend against disease (Kutcher et al. 2005). Under low to moderate disease pressure, Brandt et al. (2007) observed a stronger yield response to fungicide at low seeding rates which, while somewhat counter intuitive, was possibly due to the extended flowering period allowing more time for infection to spread and negatively affect the crop. They (Brandt et al. 2007) also detected slightly higher sclerotinia levels with hybrid versus open-pollinated canola (possibly due to a denser canopy) and, as expected, lower disease levels when foliar fungicide was applied. Difficulties managing this disease using basic agronomic practices may be largely due to the fact that the pathogen is extremely widespread but, for the disease to develop, specific combinations of soil (pathogen), weather and crop conditions must be met.

Foliar fungicides have proven to be the most consistent and effective method of controlling sclerotinia stem rot in canola. While throughout much of the Prairies, annual fungicide applications to canola are unlikely to be economical over the long-term (i.e. Kutcher et al. 2005; Brandt et al. 2007; Kutcher et al. 2011), the benefits can substantial with proper timing and heavy disease pressure. For example in 2012 at Indian Head, where disease pressure was severe, fungicide applications resulted in average yield increases up to 30% in small plot trials; however, field-scale trials completed at the same location over the past six seasons, have rarely shown economic benefits (Chris Holzapfel, unpublished data). Considerable resources have been directed towards developing practical methods to assess sclerotinia risk in canola in order to help producers determine when and where fungicides applications are likely to be beneficial (McLaren et al. 2004). Petal tests to assess the level of inoculum present in specific fields have shown reasonably strong correlations with sclerotinia infection; however, results are affected by the timing of the petal collection and still largely dependent on weather (Turkington and Morrall 1993; McLaren et al. 2004). While the traditional 3-5 day turnaround for petal test results has been somewhat impractical for producers, recent advancements in DNA testing may dramatically reduce the turnaround time while increasing the reliability of such tests (Ziesman et al. 2013). Another tool that is under development/evaluation and may provide early warnings of sclerotinia development are pre-inoculated sclerotia depots which are placed directly in the field and monitored for the period leading up to flowering (Buchwaldt et al. 2015). Risk assessment tables and weather-based risk models (i.e. Canola Council 2009) can also help producers make better informed decisions as to whether or not to spray but, similar to petal tests, the reliability of such approaches continue to be hampered by our inability to accurately predict upcoming weather patterns on a site-specific basis (McLaren et al. 2004).

While variation in the susceptibility of individual cultivars has been documented (Bradley and Khot 2006), commercial cultivars that are considered tolerant to sclerotinia stem rot have only relatively recently been introduced (Falak et al. 2011). Under severe disease pressure, tolerant cultivars have exhibited at least a 50% reduction in sclerotinia relative to susceptible controls (Falak et el. 2011). It is important to note that sclerotinia tolerant canola hybrids can still be affected by the pathogen responsible for this disease; however, the expectation is that tolerant hybrids will exhibit fewer symptoms and reduced yield loss relative to susceptible hybrids under the same conditions. If reliable, genetic sclerotinia tolerance could provide a first line of defense that might appeal both to growers in regions where high disease pressure has made annual fungicide applications commonplace and those in regions where sclerotinia is more variable and difficult to predict. Because sclerotinia infection is not eliminated in tolerant cultivars, conditions may exist where foliar fungicide applications are still recommended. Furthermore, combining tolerant hybrids with fungicide applications may reduce the potential for the pathogen to overcome individual control measures – experience has shown that relying heavily on any single technology is often risky and unsustainable. This project was initiated to enhance our current understanding of the benefits and limitations that might be expected with both genetic tolerance and foliar fungicide applications.

Objectives:

The specific objectives of this study are:

1) To evaluate the relative effectiveness of genetic tolerance and foliar fungicides to reduce sclerotinia stem rot infection in canola under field conditions.
2) To determine if, and under what conditions, foliar fungicide applications may still be required when growing a hybrid with genetic tolerance to sclerotinia.

Materials & Methods:

Field trials were initiated in 2013 at three locations in Saskatchewan and two in Manitoba. Two of the locations had access to irrigation and all of the locations were considered to at least have a moderate risk for sclerotinia in canola based on their climates. The locations were Indian Head, SK (50°33'N 103°39'W), Melfort, SK (52°50' N 104°35'), Melita MB (49°17' N 101°00'), Outlook, SK (51°28' N 107°03') and

Brandon, MB (49°52' N 99°58'). The plots at Outlook and Brandon received frequent, light irrigation through flowering to create conditions more favourable for disease development at these locations. Canola at Indian Head, Melfort and Melita did not receive supplemental irrigation. Plot size ranged from approximately 15-25 m^2 depending on the specific seeding and spraying equipment at each location, and alleyways between the plots were kept mowed over the growing season in the majority of cases.

The treatments were a factorial combination of two canola hybrids and four fungicide treatments for a total eight treatments. The hybrids were: 1) 45H29 RR (susceptible) and 2) 45S54 RR (tolerant) and the foliar fungicide treatments were: 1) untreated check, 2) fungicide applied at 20% bloom, 3) fungicide applied at 50% bloom and 4) fungicide applied at both crop stages. The treatments were arranged in a Randomized Complete Block Design (RCBD) with four replicates.

Canola Hybrid	*Foliar Fungicide Treatment*
1) 45H29 (susceptible)	1) Check (no fungicide)
2) 45S53 (tolerant)	2) Early (246 g Boscalid ha^{-1} at 20% bloom stage)
	3) Late (246 g Boscalid ha^{-1} at 50% bloom stage)
	4) Dual (full rate of fungicide at both stages)

Both hybrids were glyphosate tolerant (Roundup Ready®) and the target seeding rates were 125-150 viable seeds m^{-2}. Seed from the same source was used at all locations with a relatively high rate recommended to promote dense crop canopies conducive to disease development. Tillage systems and seeding equipment varied across locations (Tables 1-3). Row spacing ranged from 20-30 cm and nitrogen (N) fertilizer was either side-banded or broadcast and incorporated prior to seeding (Outlook). In 2014, two sites (Brandon and Outlook) had to be reseeded due to poor initial establishment – no fertilizer was applied during the second seeding operation. Fertilizer sources were granular urea, monoammonium phosphate, potassium chloride and ammonium sulphate and the rates varied with site but were intended to be non-limiting and balanced. Canola was swathed, pushed or straight-combined depending on the specific field equipment available at each location. Weed control was achieved with tillage and/or pre-emergent herbicide applications combined with either one or two in-crop applications of glyphosate. Additional agronomic details along with dates of field operations and data collection activities for each year are provided in Tables 1-3.

The data collected from each plot included spring plant density (to assess overall stand density and variability), mean disease incidence (% MDI), mean disease severity (0-5 MDS), seed yield, seed weight and percent green seed. Mean plant densities were determined by counting two separate 1 meter sections of crop row per plot approximately 4 weeks after planting and converting the mean values to plants m^{-2}. At the sites where sclerotinia was observed in 2013 and all sites in 2014-15, a total of 100 plants per plot were rated on a scale of 1-5 (Kutcher and Wolf 2006; Table A-1). The values derived from these ratings were percent incidence of infected plants (MDI) and the overall mean disease severity rating for the entire plot (MDS). Yields were determined from the harvested seed samples and are expressed as kg ha^{-1} on a clean seed basis and corrected to a uniform seed moisture content of 10%. Seed weight was determined by weighing and counting 1000-2000 seeds using automated seed counters and calculating g 1000 seeds^{-1} for each plot. Percent green seed was determined by crushing 200-500 seeds per plot and counting the number of distinctly green seeds. Seed size and percent clean seed were not measured at Melfort in 2013 or 2015 and plant densities were not measured at Melita in 2014; therefore these location-years were excluded from the analyses of these variables.

Response data were analysed using a combined Mixed model with the effects of location-year (L), hybrid (HYB), fungicide treatment (FUNG) and all potential interactions considered fixed with the effect of replicate considered random. Despite the large number of sites, the rationale for keeping location-year fixed at this stage was to improve our ability to identify and isolate responsive sites, recognizing the variability and importance of environmental conditions for this disease. Least squares means were separated using Fisher's protected least significant difference (LSD) test. Heterogeneous variance estimates were permitted across location-year; however, the more complex analyses was only utilized when it was a significant improvement over the simpler model assuming homogenous variance across all location years. For selected variables, single degree-of-freedom contrasts were used to compare to the control to the combined treated plots both across hybrids and separately for the susceptible and tolerant hybrids. Various transformations were explored for percentage and disease rating data; however, none improved the model fit so no transformations were utilized. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

Table 1. Dates of selected field operations and data collection activities completed in SaskCanola sclerotinia study at various locations in 2013.

Field Operation / Data Collection	Indian Head	Melfort	Outlook	Brandon	Melita
Previous Crop / Tillage System	Spring Wheat / Zero-Tillage	Spring Wheat / Zero-Tillage	Spring Wheat / Reduced Tillage	Fallow / Conventional Tillage	Oat / Zero-Tillage
Pre-Emergent Herbicide	May 17	May 22	May 13	May 24 (cultivation only)	n/a
Seeding Date	May 16	May 23	May 16	May 24	May 16
Row Spacing	30 cm	20 cm	25 cm	20 cm	24 cm
Fertility (kg N-P_2O_5-K_2O-S ha^{-1})	130-35-18-18	60-20-10-10	82-20-15-0	0-0-0-0[Z]	113-34-0-0
Emergence Counts	June 27	June 28	June 7	June 7	June 10
In-crop Herbicide 1	June 12 (440 g glyphosate ha^{-1})	June 24 (667 g glyphosate ha^{-1})	June 18 (667 g glyphosate ha^{-1})	June 11 (667 g glyphosate ha^{-1})	June 12 (445 g glyphosate ha^{-1})
In-crop Herbicide 2	June 27 (440 g glyphosate ha^{-1})	n/a	n/a	n/a	n/a
Foliar Fungicide 1	July 4	July 9	July 2	July 2	July 2
Foliar Fungicide 2	July 9	July 12	July 4	July 8	July 8
Sclerotinia Ratings	August 21-22	August 27	August 20	August 27	August 14
Swathing	n/a	n/a	August 27	August 26 [Y]	August 15
Combining	September 16	September 12	September 6	October 3	September 3

n/a – not applicable / available

[Z] Soil test residual nutrients exceeded estimated crop requirements – fertilizer was not applied at this site

[Y] Canola was pushed as opposed to swathed

Table 2. Dates of selected field operations and data collection activities completed in SaskCanola sclerotinia study at various locations in 2014.

Field Operation / Data Collection	Indian Head	Melfort	Outlook	Brandon	Melita
Previous Crop / Tillage System	Spring Wheat / Zero Tillage	Cereal / Zero Tillage	Spring Wheat / Reduced Tillage	Fallow / Conventional Tillage	Winter Wheat / Zero Tilliage
Pre-emergent Herbicide	May 18	n/a	May 12	June 9	May 22
Seeding date	May 14	May 21	June 3 [X]	June 10 [X]	May 22
Row spacing	30 cm	20 cm	25 cm	20 cm	24 cm
Fertility (kg N-P_2O_5-K_2O-S ha^{-1})	130-34-17-17	105-35-0-15	135-40-15-12	55-10-0-24	106-35-30-20
Emergence Counts	June 9	June 11	July 7	June 24	n/a
In-crop herbicide 1	July 5 (667 g glyphosate ha^{-1})	June 17 (667 g glyphosate ha^{-1})	July 8 (440 g glyphosate ha^{-1})	July 3 (667 g glyphosate ha^{-1})	June 16 (440 g glyphosate ha^{-1})
In-crop herbicide 2	n/a	n/a	n/a	n/a	n/a
Foliar fungicide 1	July 9	July 8	July 16	July 26	July 8
Foliar fungicide 2	July 12	July 10	July 20	July 30	July 11
Sclerotinia ratings	August 29 [Z]	August 26	September 9	September 17-18	August 18
Swathing	n/a	n/a	September 15	September 26	Aug 29
Combining	October 8 October 19 [Y]	September 9	September 24	October 16	September 3-5

n/a – not applicable / available
[Z] Ratings only completed on replicate #1 due to delayed maturity and poor establishment in remaining replicates
[Y] Replicate #1 combined on October 8 and replicates #3-4 combined on October 19 due to differences in maturity
[X] Reseeded due to poor establishment with initial seeding date

Table 3. Dates of selected field operations and data collection activities completed in SaskCanola sclerotinia study at various locations in 2015.

Field Operation / Data Collection	Indian Head	Melfort	Outlook	Brandon	Melita
Previous Crop / Tillage System	Spring Wheat / Zero-Tillage	Oats / Zero-Tillage	Spring Wheat / Reduced Tillage	Fallow / Conventional Tillage	Fallow / Zero-Tillage
Pre-Emergent Herbicide	May 9	none	May 4 (cultivation only)	May 12 (cultivation only)	May 4
Seeding Date	May 15	May 20	May 13	May 15	May 5
Row Spacing	30 cm	20 cm	25 cm	20 cm	24 cm
Fertility (kg $N\text{-}P_2O_5\text{-}K_2O\text{-}S$ ha^{-1})	130-35-18-18	62-31-0-31	90-20-0-0	170-10-24	119-35-30-25
Emergence Counts	June 9	June 23	June 4	June 9	June 10
In-crop Herbicide 1	June 15 (667 g glyphosate ha^{-1})	June 18 (667 g glyphosate ha^{-1})	June 18 (667 g glyphosate ha^{-1})	June 8 (667 g glyphosate ha^{-1})	June 15 (445 g glyphosate ha^{-1})
In-crop Herbicide 2	n/a	n/a	n/a	n/a	n/a
Foliar Fungicide 1	July 1	July 10	June 29	June 30	June 29
Foliar Fungicide 2	July 4	July 13	July 3	July 2	July 4
Sclerotinia Ratings	August 19	August 31	August 19	August 14	August 4
Swathing	n/a	n/a	August 20	August 18	August 4
Combining	September 10	September 12	September 11	September 2	August 14

n/a – not applicable / available

Results and Discussion:

Weather conditions

Mean monthly temperatures and precipitation amounts for the 2013-15 growing seasons (May-Aug) for each location are presented relative to the long-term averages (1981-2010) in Tables 4 and 5. Relative to the long-term average, temperatures varied widely across months and site-year. Generally speaking July, when initial infection is likely to occur, had relatively cool to normal temperatures in 2013-14 and above normal temperatures in 2015; however, precipitation levels during this month were extremely variable ranging from 11-268% of the long-term averages. When averaged across the four month growing season, mean temperatures ranged from 95-106% of normal for individual site-years while total precipitation ranged from 78-170%. Again, the sites at Outlook and Brandon received supplemental irrigation to maintain a moist crop canopy through flowering and early pod fill to increase the potential for disease development. Irrigation amounts are included in the precipitation levels reported for Outlook but specific details of the irrigation schedule at Brandon are not available. At Indian Head in 2014, extreme rainfall in June resulted in early flooding damage which was followed by a premature frost when the damaged canola was still quite green. While all measurements were still completed at this location-year, the data was considered unreliable and removed from the final combined analyses.

Table 4. Mean monthly temperatures relative to the long-term averages (1981-2010) for the 2013 and 2014 growing season at each trial location (Environment Canada 2016).

Month	Year	Indian Head	Melfort	Outlook	Brandon	Melita
		------- Mean Temperature (°C) -------				
May	2013	11.9 (110%)	12.0 (112%)	12.9 (109%)	10.8 (96%)	11.2 (105%)
	2014	10.2 (94%)	10.0 (94%)	10.8 (92%)	10.7 (96%)	11.6 (108%)
	2015	10.3 (95%)	9.9 (93%)	10.4 (88%)	9.0 (80%)	11.2 (105%)
	LT	10.8	10.7	11.8	11.2	10.7
June	2013	15.3 (97%)	15.4 (97%)	15.9 (97%)	16.9 (102%)	17.0 (106%)
	2014	14.4 (91%)	14.0 (88%)	14.7 90%)	15.8 (96%)	16.6 (103%)
	2015	16.2 (103%)	16.4 (103%)	17.3 (105%)	16.6 (101%)	16.9 (105%)
	LT	15.8	15.9	16.4	16.5	16.1
July	2013	16.3 (90%)	16.4 (94%)	17.5 (94%)	17.9 (94%)	18.7 (97%)
	2014	17.3 (95%)	17.5 (99%)	18.4 (99%)	17.9 (94%)	19.4 (101%)
	2015	18.2 (99%)	17.9 (102%)	19.2 (103%)	19.2 (101%)	20.6 (107%)
	LT	18.2	17.5	18.6	19.1	19.3
August	2013	17.1 (98%)	17.7 (105%)	18.8 (105%)	18.2 (100%)	19.0 (103%)
	2014	17.4 (100%)	17.6 (105%)	18.2 (102%)	17.9 (98%)	19.2 (104%)
	2015	17.0 (97.7%)	17.0 (101%)	17.4 (97%)	17.9 (98%)	19.4 (105%)
	LT	17.4	16.8	17.9	18.2	18.4
4-Month Average	2013	15.2 (97%)	15.4 (101%)	16.3 (101%)	16.0 (98%)	16.5 (102%)
	2014	14.8 (95%)	14.8 (97%)	15.5 (96%)	15.6% (96%)	16.7 (104%)
	2015	15.4 (99%)	15.3 (100%)	16.1 (99%)	15.7 (96%)	17.0 (106%)
	LT	15.6	15.2	16.2	16.3	16.1

Table 5. Mean monthly precipitation amounts relative to the long-term averages (1981-2010[Z]) for the 2013 and 2014 growing season at each trial location (Environment Canada 2016).

Month	Year	Indian Head	Melfort	Outlook[Z]	Brandon	Melita
		Total Precipitation (mm)				
May	2013	17.1 (33%)	18.0 (42%)	12.7 (30%)	58.6 (104%)	51.2 (83%)
	2014	36.0 (70%)	24.4 (57%)	81.2 (191%)	114.3 (203%)	104.7 (169%)
	2015	15.6 (30%)	7.1 (16%)	38.3 (90%)	0.7 (1%)	83.4 (135%)
	LT	51.8	42.9	42.6	56.4	61.9
June	2013	103.8 (134%)	96.9 (179%)	81.5 (128%)	122.9 (156%)	78.4 (103%)
	2014	199.2 (257%)	169.8 (313%)	117.2 (183%)	143.5 (182%)	152.6 (200%)
	2015	38.3 (50%)	54.8 (101%)	51.6 (81%)	26.2 (33%)	105.0 (137%)
	LT	77.4	54.3	63.9	78.8	76.4
July	2013	50.4 (79%)	100.0 (130%)	103 (183%)	60.4 (87%)	141.0 (248%)
	2014	7.8 (12%)	94.6 (123%)	66.4 (118%)	29.9 (43%)	40.7 (72%)
	2015	94.6 (148%)	149.8 (195%)	150.4 (268%)	67.6 (11%)	8.6 (15.1%)
	LT	63.8	76.7	56.1	69.1	56.9
August	2013	6.1 (12%)	10.6 (20%)	53.8 (126%)	70.0 (110%)	24.0 (56%)
	2014	142.2 (277%)	60.4 (115%)	51.5 (120%)	69.3 (109%)	102.3 (237%)
	2015	58.8 (115%)	57.4 (110%)	67.5 (158%)	73.4 (116%)	25.6 (59%)
	LT	51.2	52.4	42.8	63.4	43.2
4-Month Total	2013	177.4 (78%)	225.5 (100%)	251 (122%)	311.9 (117%)	294.6 (124%)
	2014	385.2 (170%)	349.2 (154%)	316.3 (154%)	357.0 (133%)	400.3 (168%)
	2015	207.3 (92%)	269.1 (119%)	307.8 (150%)	241.3 (90%)	222.6 (93%)
	LT	226.3	226.3	205.4	267.7	238.4

[Z] Precipitation amounts for Outlook include supplemental irrigation

Overall Analyses of Variance

The overall tests of fixed effects and their interactions are presented for all response variables in Table 6. The effects of location were highly significant ($P < 0.001$) for all variables. The main effects of hybrid were significant for sclerotinia incidence ($P = 0.005$), severity ($P = 0.007$), seed yield ($P < 0.001$) and seed weight ($P < 0.001$) while the main effects of fungicide were significant for sclerotinia incidence ($P < 0.001$), severity ($P = 0.015$) and seed yield ($P = 0.051$). Significant interactions between hybrid and fungicide treatment were detected for sclerotinia incidence and severity ($P = 0.02$-0.03) but no other variables. Interactions between location-year and hybrid were significant for emergence, yield and seed weight ($P < 0.001$) while location interactions with fungicide treatment were only significant for percent green seed ($P < 0.001$). The three-way interaction between location, hybrid and fungicide treatment was not significant for any variables except for plant density ($P = 0.012$).

Table 6. Analyses of variance for location, hybrid and fungicide treatment effects and their interactions for selected response variables.

	Effect						
Response Variable	**Location (L)**	**Hybrid (HYB)**	**Fungicide (FUNG)**	**HYB × FUNG**	**L × HYB**	**L × FUNG**	**L × HYB × FUNG**
	p-value						
Emergence [Z] *(plants m⁻²)*	< 0.001	0.155	0.456	0.717	< 0.001	0.093	0.012
Yield [X] *(kg ha⁻¹)*	< 0.001	< 0.001	0.051	0.248	< 0.001	0.947	0.475
Scl. Incidence [U] *(% infected)*	< 0.001	0.005	< 0.001	0.017	0.279	0.789	0.309
Scl. Severity [U] *(0-5)*	< 0.001	0.007	0.015	0.033	0.406	0.948	0.241
Green Seed [U] *(%)*	< 0.001	0.203	0.988	0.098	0.936	< 0.001	0.571
Seed Weight [U] *(g 1000 seeds⁻¹)*	< 0.001	< 0.001	0.551	0.612	< 0.001	0.880	0.440

[Z] 13 sites; [X] 14 sites; [U] 12 sites

Crop Establishment

Mean plant densities for location-year, hybrid and location-year by hybrid are presented in Table 7 along with p-values indicating whether hybrid effects were significant at individual location-years. Across sites, overall plant densities ranged from 40-159 plants m^{-2} so, while variable, canola establishment at all sites was considered sufficient to not be limiting to yield. While there was some variation in establishment between varieties amongst individual sites, the effects were not consistent and there was no difference in average plant populations between the two hybrids when averaged across sites. As expected, fungicide applications (which occurred after the emergence counts) did not affect canola emergence. While the three-way interaction (location-year × hybrid × fungicide) for plant density was significant ($P = 0.012$), these results are not presented and were presumably due to chance since, again, no fungicides had been applied when these measurements were completed.

Table 7. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P = 0.155$) and location x hybrid ($P < 0.001$) effects on canola emergence at 13 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	—— Effect ——	—————— Hybrid ——————		
	(HYB×LOC)	Location Avg.	Susceptible	Tolerant
Location-Year	----- p-value -----	---------- plants m^{-2} ----------		
Brandon-2013	0.006	159 a (4.3)	148 b (5.8)	170 a (5.8)
Brandon-2014	0.014	63 cd (3.5)	71 b (4.5)	56 b (4.6)
Brandon-2015	0.009	40 f (2.6)	45 a (3.2)	35 b (3.2)
Indian Head-2013	0.345	56 d (2.4)	55 a (2.8)	58 a (2.8)
Indian Head-2014	—	—	—	—
Indian Head-2015	0.139	63 c (2.6)	66.0 a (3.2)	61 a (3.2)
Melfort-2013	0.949	49 e (2.3)	49 a (2.7)	49 a (2.7)
Melfort-2014	< 0.001	46 ef (2.1)	39 b (2.4)	53 a (2.4)
Melfort-2015	0.410	83 b (3.0)	85 a (3.8)	81 a (3.8)
Melita-2013	0.121	149 a (5.7)	141 a (7.8)	158 a (7.8)
Melita-2014	—	—	—	—
Melita-2015	< 0.001	58 cd (2.5)	52 b (3.1)	65 a (3.1)
Outlook-2013	0.833	63 cd (3.7)	62 a (4.9)	64 (4.9)
Outlook-2014	0.028	62 cd (3.1)	56 b (4.0)	68 a (4.0)
Outlook-2015	0.973	90 b (5.7)	90 a (7.9)	90 a (7.9)
Average (all sites)	—	—	76.8 a	74.3 a

Sclerotinia Incidence and Severity

Mean disease incidence (MDI) and severity (MDS) were calculated from ratings (Kutcher and Wolf 2006) completed on 100 plants per plot just prior to physiological maturity. Mean MDI for location-year, hybrid and location-year by hybrid interactions are provided in Table 8. For the sites where all plots were rated, overall average MDI (across hybrids and fungicide treatments) ranged from 0-11% with the highest overall values generally observed at Brandon and the lowest at Indian Head. There was only one case where MDI exceed 10% therefore, at the majority of sites, disease pressure in the plots was too low to be expected to have much impact on yield. Significant differences in MDI were detected between the two hybrids at 17% of the individual sites and, when differences occurred, the values were lower for the tolerant hybrid. Regardless of overall disease levels or whether the differences were significant, the absolute MDI values trended higher for the susceptible variety in 67% of the sites and were slightly but significantly higher when averaged across sites (3.6% susceptible versus 2.7% tolerant).

Table 8. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P = 0.006$) and location x hybrid ($P = 0.255$) effects on mean sclerotinia incidence (MDI) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	---- Effect ----	---------------- Hybrid	----------------	
	(HYB×LOC)	Location Avg.	Susceptible	Tolerant
Location-Year	---- p-value ----	--------------- % of plants infected	---------------	
Brandon-2013	0.003	11.4 a (1.55)	13.2 a (1.66)	9.7 b (1.66)
Brandon-2014	0.261	2.6 c (1.55)	3.3 a (1.66)	1.9 a (1.66)
Brandon-2015	0.109	3.6 bc (1.55)	4.6 a (1.66)	2.7 a (1.66)
Indian Head-2013	0.521	1.1 c (1.55)	1.5 a (1.66)	0.8 a (1.66)
Indian Head-2014	—	—	—	—
Indian Head-2015	1.000	0.3 c (1.55)	0.3 a (1.66)	0.3 a (1.66)
Melfort-2013	1.000	0.0 c (1.55)	0.0 a (1.66)	0.0 a (1.66)
Melfort-2014	0.789	2.9 bc (1.55)	3.1 a (1.66)	2.8 a (1.66)
Melfort-2015	0.009	4.2 bc (1.55)	5.8 a (1.66)	2.7 b (1.66)
Melita-2013	—	—	—	—
Melita-2014	0.521	1.4 c (1.55)	1.0 a (1.66)	1.8 a (1.66)
Melita-2015	0.454	7.2 ab (1.55)	7.6 a (1.66)	6.8 a (1.66)
Outlook-2013	—	—	—	—
Outlook-2014	0.592	2.6 bc (1.55)	2.9 a (1.66)	2.3 a (1.66)
Outlook-2015	1.000	0.4 c (1.55)	0.4 a (1.66)	0.4 a (1.66)
All Sites (average)	—	—	3.6 A (0.48)	2.7 B (0.48)

Fungicide treatment and location-year by fungicide treatment means for MDI are provided in Table 9. While the effects of fungicide were not large enough to be considered significant at the majority of individual location-years, there was enough of a trend that the main effect of fungicide was significant. Averaged across all location-years, MDI of the unsprayed control was 4.3% and significantly higher than any of the treated plots (2.4-3.1%). In general, location effects on MDI were greater than either hybrid or fungicide effects. The most notable reduction in MDI with fungicides occurred at Melita in 2014 where the control averaged 5% (still likely too low to result in a detectable yield reduction) but incidence was less than 1% in the treated plots.

Table 9. Tests of effect slices and treatment means for fungicide ($P = 0.003$) and location x fungicide ($P = 0.744$) effects on mean sclerotinia incidence (MDI) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	--- Effect ---	------ Fungicide ------			
	FUNG×LOC	Control	1-20% bloom	2-50% bloom	Dual App.
Location-Year	--- p-value ---	------ % of plants infected ------			
Brandon-2013	0.043	13.6 a (1.85)	12.1 a (1.85)	10.9 a (1.85)	9.1 a (1.85)
Brandon-2014	0.655	3.4 a (1.85)	3.1 a (1.85)	2.4 a (1.85)	1.5 a (1.85)
Brandon-2015	0.725	4.9 a (1.85)	3.0 a (1.85)	3.8 a (1.85)	2.9 a (1.85)
Indian Head-2013	0.273	2.8 a (1.85)	1.6 a (1.85)	0.1 a (1.85)	0.0 a (1.85)
Indian Head-2014	—	—	—	—	—
Indian Head-2015	0.988	0.6 a (1.85)	0.1 a (1.85)	0.4 a (1.85)	0.1 a (1.85)
Melfort-2013	1.000	0.0 a (1.85)	0.0 a (1.85)	0.0 a (1.85)	0.0 a (1.85)
Melfort-2014	0.896	3.3 a (1.85)	2.8 a (1.85)	2.3 a (1.85)	3.4 a (1.85)
Melfort-2015	0.138	4.3 a (1.85)	5.3 a (1.85)	5.4 a (1.85)	2.0 a (1.85)
Melita-2013	—	—	—	—	—
Melita-2014	0.005	5.0 a (1.85)	0.0 b (1.85)	0.3 b (1.85)	0.3 b (1.85)
Melita-2015	0.109	9.3 a (1.85)	6.0 a (1.85)	5.8 a (1.85)	7.8 a (1.85)
Outlook-2013	—	—	—	—	—
Outlook-2014	0.204	4.6 a (1.85)	2.4 a (1.85)	2.3 a (1.85)	1.3 a (1.85)
Outlook-2015	0.999	0.4 a (1.85)	0.5 a (1.85)	0.3 a (1.85)	0.4 a (1.85)
All Sites (average)	—	4.3 A (0.53)	3.1 B (0.53)	2.8 B (0.53)	2.4 B (0.53)

Despite the relative low disease pressure, when MDI data from all location-years were combined the interaction between hybrid and fungicide treatment was significant (Table 10). The interaction showed a reduction in sclerotinia incidence with fungicide applications, regardless of timing, for the susceptible hybrid but not the tolerant hybrid. Without fungicide, MDI averaged 5.8% and was approximately reduced by half 2.2-3.2% for all remaining treatments. This interaction was further verified by the contrasts which detected an overall reduction in MDI with fungicides for the susceptible hybrid ($P < 0.001$) but not the tolerant hybrid ($P = 0.555$). It is possible that this interaction may not have occurred under heavy disease pressure as increased symptoms on both hybrids would have been expected. In the current study, even the highest overall incidence level of 5.8% was likely too low to result in significant yield reductions.

Table 10. Treatment means and contrast results for hybrid x fungicide ($P = 0.017$) effects on mean sclerotinia incidence (MDI) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

Fungicide Treatment	Hybrid: Susceptible (45H29)	Hybrid: Tolerant (45S54
	% of plants infected	
Control	5.8 a (0.63)	2.9 b (0.63)
1-20% bloom	3.2 b (0.63)	2.9 b (0.63)
2-50% bloom	2.9 b (0.63)	2.7 b (0.63)
Dual App.	2.6 b (0.63)	2.2 b (0.63)
	p-value	
Check vs Treated (both hybrids)	< 0.001	
Check vs Treated (susceptible)	< 0.001	—
Check vs Treated (tolerant)	—	0.555

While MDI does not take the severity of infection in individual plants, mean disease severity is the average overall severity (on a scale of 0-5) of all of the individual plants rated. Consequently, MDS takes into account both percent incidence and potential yield loss on the basis of where the infection occurs on the plant. For example, while infection that is isolated to a few pods (rating of 1) may affect less than 10% of the seeds on that plant, lower stem infections (rating of 5) have potential to inhibit seed development on the entire plant (5). Overall, the results for MDS mimicked those already discussed for MDI and are reported in Tables 11-13.

Similar to MDI, MDS was affected by location-year and cultivar but the interaction between these two factors was not significant. Disease severity was highest as Brandon in 2013 followed by Melita, Melfort and Brandon in 2015. All remaining sites had MDS values of less than 0.1 which indicated that incidence was ≤ 2% and considered negligible. While there were relatively few sites where the hybrid effect was significant on its own, when averaged across locations, MDI was higher for the susceptible hybrid (0.117) than for the tolerant hybrid (0.078).

Table 11. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P = 0.006$) and location x hybrid ($P = 0.255$) effects on mean sclerotinia severity (MDS) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —		— Hybrid —	
	(HYB×LOC)	Location Avg.	Susceptible	Tolerant
Location-Year	— p-value —		— 0-5 —	
Brandon-2013	0.051	0.383 a (0.05)	0.432 a (0.056)	0.334 a (0.056)
Brandon-2014	0.334	0.079 b-e (0.05)	0.103 a (0.056)	0.055 a (0.056)
Brandon-2015	0.064	0.146 bcd (0.05)	0.192 a (0.056)	0.099 a (0.056)
Indian Head-2013	0.475	0.044 cde (0.05)	0.062 a (0.056)	0.026 a (0.056)
Indian Head-2014	—	—	—	—
Indian Head-2015	0.930	0.013 de (0.05)	0.016 a (0.056)	0.011 a (0.056)
Melfort-2013	1.000	0.000 e (0.05)	0.000 a (0.056)	0.000 a (0.056)
Melfort-2014	0.930	0.031 de (0.05)	0.033 a (0.056)	0.029 a (0.056)
Melfort-2015	0.002	0.175 bc (0.05)	0.253 a (0.056)	0.098 b (0.056)
Melita-2013	—	—	—	—
Melita-2014	0.841	0.015 de (0.05)	0.010 a (0.056)	0.020 a (0.056)
Melita-2015	0.821	0.193 b (0.05)	0.199 a (0.056)	0.188 a (0.056)
Outlook-2013	—	—	—	—
Outlook-2014	0.564	0.078 b-e (0.05)	0.093 a (0.056)	0.064 a (0.056)
Outlook-2015	0.960	0.014 de (0.05)	0.015 a (0.056)	0.013 a (0.056)
All Sites (average)	—	—	0.117 A (0.016)	0.078 B (0.016)

Also consistent with the results for MDI, MDS was affected by fungicide treatment but the interaction between fungicide treatment and location-year was not significant. As expected, MDI was highest in the control and significantly reduced with fungicide applications. Although differences amongst the treatments where fungicides were applied were not significant, the general trend was for the least disease with a dual application followed by single applications at 50% bloom and then 20% bloom (Table 12).

Table 12. Tests of effect slices and treatment means for fungicide ($P = 0.003$) and location x fungicide ($P = 0.744$) effects on mean sclerotinia severity (MDS) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	Fungicide			
	FUNG×LOC	Control	1-20% bloom	2-50% bloom	Dual App.
Location-Year	p-value	0-5			
Brandon-2013	0.021	0.485 a (0.07)	0.428 ab (0.07)	0.338 bc (0.07)	0.283 c (0.07)
Brandon-2014	0.857	0.103 a (0.066)	0.098 a (0.066)	0.066 a (0.066)	0.050 a (0.066)
Brandon-2015	0.585	0.199 a (0.066)	0.120 a (0.066)	0.154 a (0.066)	0.110 a (0.066)
Indian Head-2013	0.331	0.111 a (0.066)	0.063 a (0.066)	0.003 a (0.066)	0.000 a (0.066)
Indian Head-2014	—	—	—	—	—
Indian Head-2015	0.983	0.028 a (0.066)	0.005 a (0.066)	0.019 a (0.066)	0.003 a (0.066)
Melfort-2013	1.000	0.000 a (0.066)	0.000 a (0.066)	0.000 a (0.066)	0.000 a (0.066)
Melfort-2014	0.998	0.035 a (0.066)	0.028 a (0.066)	0.025 a (0.066)	0.036 a (0.066)
Melfort-2015	0.081	0.178 a (0.066)	0.213 a (0.066)	0.241 a (0.066)	0.070 a (0.066)
Melita-2013	—	—	—	—	—
Melita-2014	0.834	0.055 a (0.066)	0.000 a (0.066)	0.003 a (0.066)	0.003 a (0.066)
Melita-2015	0.277	0.245 a (0.066)	0.158 a (0.066)	0.133 a (0.066)	0.238 a (0.066)
Outlook-2013	—	—	—	—	—
Outlook-2014	0.340	0.155 a	0.064 a	0.059 a	0.035 a
Outlook-2015	1.000	0.015 a	0.016 a	0.011 a	0.013 a
All Sites (average)	—	0.134 A (0.02)	0.099 AB (0.02)	0.088 B (0.02)	0.070 B (0.02)

While the main effects of both hybrid and fungicide were significant on their own, the interaction between these factors was also significant. The interaction for MDS was identical to that observed for MDI whereby disease severity was highest with the untreated, susceptible hybrid while all other treatments were lower and did not significantly differ from each other (Table 13). Similar to MDI, the contrasts for the control versus all treated plots was significant for the susceptible but not the tolerant canola hybrid.

Table 13. Treatment means and contrast results for hybrid x fungicide ($P = 0.017$) effects on mean sclerotinia severity (MDS) at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

Fungicide Treatment	Hybrid	
	Susceptible (45H29)	Tolerant (45S54
	0-5	
Control	0.191 a (0.0239)	0.077 b (0.0239)
1-20% bloom	0.107 b (0.0239)	0.091 b (0.0239)
2-50% bloom	0.094 b (0.0239)	0.081 b (0.0239)
Dual App.	0.077 b (0.0239)	0.063 b (0.0239)
	p-value	
Check vs Treated (both hybrids)	0.004	
Check vs Treated (susceptible)	< 0.001	—
Check vs Treated (tolerant)	—	0.967

Seed Yield

Canola seed yield was affected by both location-year and hybrid with a significant interaction between these two factors (Table 14). Overall mean yields ranged from 1898-4420 kg ha^{-1} for individual location-years and, generally speaking, were more variable from year-to-year than from location-to-location. On average, the susceptible hybrid (3105 kg ha^{-1}) yielded 8% higher than the tolerant hybrid (2878 kg ha^{-1}); however, disease pressure was relatively low in all cases and, with the significant interaction, this yield separation did not occur at all location-years. Yield differences between hybrids were detected at Brandon in all three years, Indian Head in 2015, Melita in 2013 and Outlook in 2015 (6/14 location-years). In all cases where a hybrid effect was detected, yields favoured the susceptible cultivar; however, the effects did not appear to be specifically attributable to low disease pressure or any particular environmental conditions (i.e. drier versus excess moisture). For example, disease pressure at Brandon was generally higher than any other locations yet the susceptible variety appeared to have the greatest yield advantage at this location, despite exhibiting fewer sclerotinia symptoms. At the locations where yield differences between the hybrids were detected, the 45H29 advantage ranged from 9-21%.

Table 14. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P < 0.001$) and location x hybrid ($P < 0.001$) effects on canola seed yield at 14 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	Hybrid		
	HYB×LOC	Location Avg.	Susceptible	Tolerant
Location-Year	--- p-value ---	kg ha^{-1}		
Brandon-2013	< 0.001	2139 fg (121.8)	2346 a (131.6)	1932 b (131.6)
Brandon-2014	< 0.001	4071 ab (141.6)	4429 a (162.4)	3713 b (170.7)
Brandon-2015	0.046	2942 e (140.2)	3113 a (162.3)	2770 b (166.2)
Indian Head-2013	0.987	3596 cd (114.8)	3596 a (118.3)	3596 a (118.3)
Indian Head-2014	—	—	—	—
Indian Head-2015	< 0.001	3079 e (113.7)	3209 a (116.2)	2949 b (116.2)
Melfort-2013	0.305	2171 fg (130.5)	2241 a (147.3)	2101 a (147.3)
Melfort-2014	0.731	2002 g (118.2)	1989 a (124.9)	2016 a (124.9)
Melfort-2015	0.577	2965 e (119.6)	2990 a (127.5)	2941 a (127.5)
Melita-2013	0.033	4420 a (177.4)	4717 a (221.3)	4124 b (228.4)
Melita-2014	0.981	1898 g 122.8)	1899 a (132.4)	1896 a (133.4)
Melita-2015	0.138	2430 f (116.2)	2480 a (121.0)	2379 a (121.0)
Outlook-2013	0.706	3862 bc (128.9)	3886 a (144.2)	3838 a (144.2)
Outlook-2014	0.076	2849 e (115.8)	2907 a (120.3)	2791 a (120.3)
Outlook-2015	0.005	3452 d (134.5)	3665 a (154.3)	3239 b (154.3)
All Sites (average)	—	—	3105 A (38.5)	2878 B (39.0)

The overall effect of fungicide treatment on canola yield was just barely considered significant at $P = 0.051$ and there was no interaction with location-year ($P = 0.947$). Fungicide treatment effects on yield were never significant for individual location-years; however there was a tendency for slightly lower yields in the control at several locations which, combined, contributed to the significant overall effect (Table 15). While marginally significant, the overall yield response to fungicide was relatively weak with only the only difference between the control and the T2 fungicide application considered significant according to the multiple comparisons test.

Table 15. Tests of effect slices and treatment means for fungicide ($P = 0.051$) and location x fungicide ($P = 0.947$) effects on canola seed yield at 14 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	Fungicide			
	FUNG×LOC	Control	1-20% bloom	2-50% bloom	Dual App.
Location-Year	--- p-value ---	kg ha^{-1}			
Brandon-2013	0.125	2044 a (149.2)	2012 a (149.2)	2311 a (149.2)	2188 a (149.2)
Brandon-2014	0.636	4082 a (200.9)	3972 a (200.9)	4256 a (200.9)	3972 a (200.9)
Brandon-2015	0.168	2649 a (200.8)	3106 a (200.8)	2890 a (200.8)	3122 a (213.1)
Indian Head-2013	0.391	3510 a (125.1)	3619 a (125.1)	3635 a (125.1)	3620 a (125.1)
Indian Head-2014	—	—	—	—	—
Indian Head-2015	0.898	3055 a (121.0)	3071 a (121.0)	3085 a (121.0)	3105 a (121.0)
Melfort-2013	0.581	2245 a (176.2)	2060 a (176.2)	2285 a (176.2)	2094 a (176.2)
Melfort-2014	0.872	1979 a (137.3)	2035 a (137.3)	2036 a (137.3)	1960 a (137.3)
Melfort-2015	0.687	2956 a (142.1)	2894 a (142.1)	3045 a (142.1)	2966 a (142.1)
Melita-2013	0.681	4150 a (292.5)	4465 a (313.7)	4603 a (292.5)	4464 a (292.5)
Melita-2014	0.763	1812 a (150.0)	1888 a (144.4)	1964 a (166.6)	1927 a (144.4)
Melita-2015	0.064	2406 a (130.0)	2428 a (130.0)	2569 a (130.0)	2314 a (130.0)
Outlook-2013	0.862	3838 a (175.2)	3858 a (175.2)	3803 a (166.8)	3949 a (166.8)
Outlook-2014	0.316	2780 a (128.8)	2855 a (128.8)	2944 a (128.8)	2816 a (128.8)
Outlook-2015	0.514	3439 a (187.9)	3615 a (187.9)	3462 a (187.9)	3292 a (187.9)
All Sites (average)	—	2925 b (45.8)	2991 ab (46.4)	3064 a (46.2)	2985 ab (46.1)

With a weak overall response, the interaction between hybrid and cultivar for seed yield was not significant (Table 16) and the control versus treated contrasts were only significant when both hybrids were combined ($P = 0.029$). While not significant at the desired probability level, the contrasts did suggest a somewhat greater response with the susceptible hybrid ($P = 0.060$) relative to the tolerant hybrid ($P = 0.223$). Despite the lack of statistical significance, the average yield gain with fungicide was 107 kg ha^{-1} (3.5%) for 45H29 and 71 kg ha^{-1} (2.5%) for 45S54.

Table 16. Treatment means and contrast results for hybrid x fungicide ($P = 0.248$) effects on canola seed yield at 14 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

Fungicide Treatment	Hybrid: Susceptible (45H29)	Hybrid: Tolerant (45S54
	kg ha^{-1}	
Control	3024 abc (57.4)	2825 d (57.6)
1-20% bloom	3081 ab (57.6)	2904 cd (59.4)
2-50% bloom	3153 a (57.4)	2974 cd (58.9)
Dual App.	3160 a (57.1)	2810 e (58.9)
	p-value	
Check vs Treated (both hybrids)	0.029	
Check vs Treated (susceptible)	0.060	—
Check vs Treated (tolerant)	—	0.223

Percent Green Seed and Seed Weight

Percent green seed varied with location-year but there were no differences between the two hybrids either combined across sites or at individual sites (Table 17). Percent green averaged from 0.0-1.6% for individual location-years with variation attributable to differences in environmental conditions and timing of operations.

Table 17. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P = 0.203$) and location x hybrid ($P = 0.936$) effects on percent green seed at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	---- Effect ----	—————— Hybrid ——————		
	HYB×LOC	Location Avg.	Susceptible	Tolerant
Location-Year	---- p-value ----	----------- % -----------		
Brandon-2013	1.000	0.04 ghi (0.057)	0.04 a (0.080)	0.04 a (0.080)
Brandon-2014	0.659	0.16 fgh (0.057)	0.14 a (0.080)	0.19 a (0.080)
Brandon-2015	0.912	0.01 hi (0.057)	0.01 a (0.080)	0.00 a (0.080)
Indian Head-2013	1.000	0.21 ef (0.057)	0.21 a (0.080)	0.21 a (0.080)
Indian Head-2014	—	—	—	—
Indian Head-2015	0.825	0.39 d (0.057)	0.40 a (0.080)	0.38 a (0.080)
Melfort-2013	—	—	—	—
Melfort-2014	1.000	0.00 i (0.057)	0.00 a (0.080)	0.00 a (0.080)
Melfort-2015	—	—	—	—
Melita-2013	0.048	1.23 b (0.058)	1.34 a (0.083)	1.11 a (0.083)
Melita-2014	0.168	0.33 de (0.057)	0.41 a (0.080)	0.25 a (0.080)
Melita-2015	0.782	0.61 c (0.057)	0.63 a (0.080)	0.59 a (0.080)
Outlook-2013	0.724	0.07 f-i (0.059)	0.09 a (0.083)	0.04 a (0.083)
Outlook-2014	0.825	1.61 a (0.057)	1.63 a (0.080)	1.60 a (0.080)
Outlook-2015	0.782	0.18 efg (0.057)	0.20 a (0.080)	0.17 a (0.080)
All Sites (average)	—	—	0.42 A (0.023)	0.38 A (0.023)

While the overall effect of fungicide was not significant ($P = 0.989$) for percent green seed, there was a location-year by fungicide interaction detected ($P < 0.001$; Table 18). The interaction was due to a significant response at Outlook in 2014; however, this response appeared somewhat random and was not observed in any other instances.

Table 18. Tests of effect slices and treatment means for fungicide ($P = 0.989$) and location x fungicide ($P < 0.001$) effects on percent green seed at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	Fungicide			
	FUNG×LOC	Control	1-20% bloom	2-50% bloom	Dual App.
Location-Year	-- p-value --	%			
Brandon-2013	0.842	0.00 a (0.113)	0.03 a (0.113)	0.13 a (0.113)	0.00 a (0.113)
Brandon-2014	0.367	0.20 a (0.113)	0.13 a (0.113)	0.30 a (0.113)	0.03 a (0.113)
Brandon-2015	0.998	0.00 a (0.113)	0.00 a (0.113)	0.00 a (0.113)	0.03 a (0.113)
Indian Head-2013	0.970	0.20 a (0.113)	0.18 a (0.113)	0.23 a (0.113)	0.25 a (0.113)
Indian Head-2014	—	—	—	—	—
Indian Head-2015	0.970	0.38 a (0.113)	0.40 a (0.113)	0.35 a (0.113)	0.43 a (0.113)
Melfort-2013	—	—	—	—	—
Melfort-2014	1.000	0.00 a (0.113)	0.00 a (0.113)	0.00 a (0.113)	0.00 a (0.113)
Melfort-2015	—	—	—	—	—
Melita-2013	0.004	1.31 a (0.113)	0.85 a (0.122)	1.44 a (0.113)	1.31 a (0.113)
Melita-2014	0.446	0.38 a (0.113)	0.31 a (0.113)	0.44 a (0.113)	0.19 a (0.113)
Melita-2015	0.099	0.44 a (0.113)	0.75 a (0.113)	0.75 a (0.113)	0.50 a (0.113)
Outlook-2013	0.982	0.03 a (0.122)	0.08 a (0.122)	0.06 a (0.113)	0.09 a (0.113)
Outlook-2014	< 0.0001	1.85 ab (0.113)	2.08 a (0.113)	0.88 c (0.113)	1.65 b (0.113)
Outlook-2015	0.463	0.15 a (0.113)	0.08 a (0.113)	0.19 a (0.113)	0.33 a (0.113)
All Sites (average)	—	0.134 A (0.02)	0.099 AB (0.02)	0.088 B (0.02)	0.070 B (0.02)

Canola seed weight was affected by location-year and hybrid with a significant interaction between these factors ($P < 0.001$; Table 19). Across location-years, mean seed weights ranged from 2.6-6.4 g 1000 $seeds^{-1}$ and this variation was presumably due to differences in environmental conditions and, perhaps to a lesser extent, management. The interaction was presumably due to the variation in the magnitude of the observed differences between hybrids as these results were quite consistent with significant differences at all locations and always in favour the tolerant hybrid 45S54.

Table 19. Tests of effect slices and treatment means for location ($P < 0.001$), hybrid ($P < 0.001$) and location x hybrid ($P < 0.001$) effects on canola seed weight at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	— Hybrid —		
	HYB×LOC	Location Avg.	Susceptible	Tolerant
Location-Year	---- p-value ----	g 1000 seeds^{-1}		
Brandon-2013	0.001	3.83 b (0.047)	3.72 b (0.056)	3.94 a (0.056)
Brandon-2014	0.001	2.56 f (0.047)	2.46 b (0.056)	2.66 a (0.056)
Brandon-2015	< 0.001	3.03 d (0.047)	2.86 b (0.056)	3.21 a (0.056)
Indian Head-2013	< 0.001	3.53 c (0.047)	3.23 b (0.056)	3.83 a (0.056)
Indian Head-2014	—	—	—	—
Indian Head-2015	< 0.001	3.11 d (0.047)	2.88 b (0.056)	3.35 a (0.056)
Melfort-2013	—	—	—	—
Melfort-2014	< 0.001	2.99 d (0.047)	2.71 b (0.056)	3.28 a (0.056)
Melfort-2015	—	—	—	—
Melita-2013	< 0.001	3.03 d (0.048)	2.91 b (0.056)	3.15 a (0.056)
Melita-2014	< 0.001	2.54 f (0.047)	2.38 b (0.056)	2.70 a (0.056)
Melita-2015	< 0.001	2.64 ef (0.047)	2.43 b (0.056)	2.86 a (0.056)
Outlook-2013	< 0.001	6.36 a (0.048)	6.21 b (0.058)	6.50 a (0.058)
Outlook-2014	< 0.001	2.73 e (0.047)	2.55 b (0.056)	2.91 a (0.056)
Outlook-2015	< 0.001	3.92 b (0.047)	3.68 b (0.056)	4.15 a (0.056)
All Sites (average)	—	—	3.17 A (0.016)	3.54 A (0.016)

Fungicide treatment did not affect seed weight ($P = 0.989$) and there was no interaction between fungicide treatment and location-year ($P = 0.880$; Table 20). When averaged across all location-years, seed weight ranged from 3.34-3.56 g 1000 seeds^{-1} amongst the four fungicide treatments.

Table 20. Tests of effect slices and treatment means for fungicide ($P = 0.989$) and location x fungicide ($P = 0.880$) effects on canola seed weight at 12 location-years in Saskatchewan and Manitoba. Standard errors of the treatment means are enclosed in parentheses.

	— Effect —	Fungicide			
	FUNG×LOC	Control	1-20% bloom	2-50% bloom	Dual App.
Location-Year	--- p-value ---	g 1000 seeds^{-1}			
Brandon-2013	0.984	3.83 a (0.071)	3.83 a (0.071)	3.82 a (0.071)	3.85 a (0.071)
Brandon-2014	0.623	2.51 a (0.071)	2.59 a (0.071)	2.61 a (0.071)	2.53 a (0.071)
Brandon-2015	0.900	3.05 a (0.071)	3.05 a (0.071)	2.99 a (0.071)	3.05 a (0.071)
Indian Head-2013	0.686	3.50 a (0.071)	3.54 a (0.071)	3.50 a (0.071)	3.59 a (0.071)
Indian Head-2014	—	—	—	—	—
Indian Head-2015	0.890	3.09 a (0.071)	3.09 a (0.071)	3.13 a (0.071)	3.15 a (0.071)
Melfort-2013	—	—	—	—	—
Melfort-2014	0.772	3.03 a (0.071)	3.03 a (0.071)	2.98 a (0.071)	2.95 a (0.071)
Melfort-2015	—	—	—	—	—
Melita-2013	0.007	2.90 b (0.076)	3.18 a (0.071)	2.95 b (0.071)	3.10 ab (0.071)
Melita-2014	0.655	2.50 a (0.071)	2.52 a (0.071)	2.60 a (0.071)	2.53 a (0.071)
Melita-2015	0.887	2.62 a (0.071)	2.68 a (0.071)	2.66 a (0.071)	2.62 a (0.071)
Outlook-2013	0.446	6.40 a (0.076)	6.39 a (0.076)	6.37 a (0.071)	6.27 a (0.071)
Outlook-2014	0.686	2.70 a (0.071)	2.71 a (0.071)	2.72 a (0.071)	2.80 a (0.071)
Outlook-2015	0.815	3.95 a (0.071)	3.92 a (0.071)	3.93 a (0.071)	3.87 a (0.071)
All Sites (average)	—	3.38 A (0.021)	3.34 A (0.021)	3.35 A (0.021)	3.56 A (0.021)

Summary and Conclusions:

Overall, this study showed that sclerotinia incidence and severity were reduced by either using tolerant hybrid or fungicide applications; however, overall disease pressure was low and neither technology eliminated the disease when it was present at notable levels. Under the low disease pressure encountered, there was little benefit to applying fungicide for tolerant hybrid as there were no further reductions in disease and effects on yield were generally not significant or likely to be economical. That being said, yields were frequently higher with the susceptible hybrid and, even there, the economic viability of fungicide applications was questionable at best for the vast majority of individual locations-years. In most cases where there was evidence of a yield increase with fungicides, yields tended to be higher at the later of the two fungicide applications; however, these results would not be expected under all conditions. Furthermore, at 50% bloom, the application window for controlling sclerotinia with fungicide application is rapidly closing. Because early infection generally has the greatest potential to yield loss therefore it is generally advisable to apply fungicide between 20-50% bloom and before a significant number of petals have dropped. Not surprisingly given the low levels of disease, there were no benefits to dual fungicide applications with regard to either visual symptoms or actual seed yields. Overall, these results showed that tolerant hybrids are effective for reducing disease and less likely to benefit from fungicide; however, susceptible hybrids may frequently yield higher, at least under low disease pressure as encountered in these trials.

Concerns are occasionally raised as to whether small plots are appropriate for evaluating diseases such as sclerotinia, primarily due to edge effects and increased air flow through the canopy. In addition, this disease tends to be more severe in low-lying, wet areas of the field while plot trials tend to be situated on well-drained, uniform sites. Nonetheless, all sites strived to make plot sizes as large as possible and, at Indian Head, the current results are consistent with those of field-scale evaluations conducted with susceptible hybrids over the same period. While we know that fungicides can dramatically reduce yield loss under heavy disease pressure, we saw few responses despite repeating the trial 14 times at locations which were specifically selected to have moderate to high disease pressure. Due the relatively small and inconsistent responses, the challenge for managing sclerotinia in canola continues to be accurately predicting whether yield responses to fungicide applications are likely and future research should continue to develop and improve predictive tools. While this can be a challenge for all diseases, it is especially the case for sclerotinia which can only be controlled well before the first symptoms develop. Genetic tolerance is an exciting advancement that has could help to reduce our dependence on fungicides and provide adequate protection under the relatively low disease pressure than is not uncommon in western Canada. However, to be widely adopted and utilized to its full potential, sclerotinia tolerance incorporated into broader range of hybrids and, given the sporadic and unpredictable nature of this disease, yields must remain competitive with susceptible hybrids.

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Appendices:

Table A-1. Rating system used to quantify sclerotinia infection levels at each location (Kutcher and Wolf 2006)

Disease Rating (0-5)	Lesion Location	Canola Symptoms
0	None	No symptoms
1	Pod	Infection of pods only
2	Upper	Lesion situated on main stems or branch(es) with potential to affect up to ¼ of seed formation and filling on plant
3		Lesion situated on main stems or a number of branches with potential to affect up to ½ of seed formation and filling on plant
4		Lesion situated on main stems or a number of branches with potential to affect up to ¾ of seed formation and filling on plant
5	Lower	Main stem lesion with potential effects on seed formation and filling of entire plant