Sugarbeet Root Maggot Resistance of Hybrids with a Maggot Resistant Pollinator

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ABSTRACT

Sugarbeet root maggot (*Tetanops myopaeformis*) is a major insect pest of sugarbeet (*Beta vulgaris*) throughout much of North America. Host plant resistance is a potential alternative to the few chemical insecticides currently being used to control the root maggot. Germplasm lines with root maggot resistance have been identified but only minimal information about the resistance of hybrids created by crossing these lines with a susceptible cms parental line is available. This study compared the performance of four hybrids with a maggot resistant pollinator, F1015, and a susceptible commercial hybrid, with and without insecticide. With insecticide, the yield of the susceptible commercial hybrid was 7.8 Mg ha^{-1} greater than the root yield without insecticide. In contrast, the average root yield increase attributable to the application of insecticide for the four hybrids with F1015 as the pollinator was only 0.8 Mg ha^{-1}. With insecticide, the root yield of the susceptible hybrid was equal to or greater than the root yield of the four resistant hybrids with insecticide; however, without insecticide, the yield of the susceptible hybrid was significantly lower than all the hybrids except one that also had a relatively low yield when insecticide was applied. These root yield and similar sucrose yield patterns indicated that when F1015 was used as a pollinator the resulting hybrid would have substantial root maggot resistance. The results

of this study were consistent with an earlier report involving different resistant hybrids; together they corroborate the potential of commercially useful sugarbeet root maggot resistant hybrids.

Additional key words: *Beta vulgaris*, host plant resistance, insect resistance, *Tetanops myopaeformis*.

The sugarbeet root maggot (*Tetanops myopaeformis* von Röder), often characterized as the most destructive insect pest of sugarbeet (*Beta vulgaris* L.) in the United States, occurs in Colorado, Idaho, Minnesota, Montana, Nebraska, North Dakota, and Wyoming (Yun, 1986). Adults migrate from fields that were planted to sugarbeet the previous year to recently emerged sugarbeet fields. Females deposit eggs in the soil near seedlings and developing larvae feed on the root by tunneling along the surface. Yield reductions may be the result of stand loss early in the season, but damage occurs primarily from larval feeding throughout the growing season (Campbell et al., 1998). The primary control is chemical insecticides that reduce larval populations in sugarbeet fields. There is a possibility that the most widely used insecticides may be removed from the market because of concerns about detrimental effects they may have on the environment. The development of insecticide-resistant root maggot strains is also a threat. A potential remedy to these concerns is the development of sugarbeet root maggot resistant hybrids (Campbell, 2005).

Theurer et al. (1982) were the first to demonstrate genetic variability for resistance to the root maggot. They reported a linear trend in increasing and decreasing maggot damage in response to selection for high- and low-maggot damage, respectively. Both tolerance and antibiosis appeared to contribute to resistance. Two root maggot resistant germplasm lines, F1015 (PI605413) and F1016 (PI608437), have been developed and released (Campbell et al., 2000). These lines incur significantly less damage than commercial hybrids and unselected populations, but the number of genes controlling resistance and the inheritance of resistance has not been determined. A seedling bioassay conducted by Smigocki et al., (2006) showed that root maggot larvae aggregated in clusters on root maggot susceptible genotypes but dispersed away from resistant genotypes. Feeding damage on roots of susceptible seedlings was more prominent than on the resistant seedlings. A serine protease inhibitor not present in susceptible genotypes was identified in F1016 (Puthoff and Smigocki 2006). Serine protease appears to have a functional role in the gut of root maggot larvae (Wilhite et al., 2000).

Applied breeders need some indication of the resistance level they

might obtain in a commercially acceptable hybrid when the resistance is introduced through one of the parental lines before they devote substantial resources to the incorporation of host plant resistance into their elite breeding populations. A recent assessment of hybrids in which the female parent was a root maggot susceptible cytoplasmic male sterile (cms) line and the four pollinators were recently developed resistant lines indicated that the resulting hybrids could provide substantial protection from yield losses due to root maggot feeding (Campbell et al., 2008). This study examines the performance of hybrids produced by crossing a maggot resistant germplasm, F1015, and four susceptible elite female parental lines. This information will complement the previous report and provide an initial indication of the impact the susceptible parent may have on the expression of root maggot resistance in a hybrid.

MATERIALS AND METHODS

Yield trials were established near St. Thomas, ND in 1998 and 1999. Experimental units were four-row, 10.6 m long plots with rows spaced 56 cm apart. The 1998 and 1999 trials were planted 13 and 14 May, respectively. Natural infestations of sugarbeet root maggot were relied on at both sites. All plots were thinned to approximately 53,000 plants ha^{-1} before colonization of the field by *T. myopaeformis* adult flies. Weeds were controlled with herbicides, cultivation, and hand weeding on an as needed basis. Foliar fungicides were applied when needed to control Cercospora leaf spot (caused by *Cercospora beticola* Sacc.).

A split-plot design with four replications was used each year. The two main plot treatments were insecticide (chlorpyrifos) and no insecticide. The sub-plot treatments were six sugarbeet cultivars (five hybrids and one germplasm line). Years were considered random effects and cultivars and insecticide treatments were considered fixed effects for the analysis of variance (MacIntosh 1983). Means were compared using Fisher's protected LSD (Carmer 1976) with $\alpha = 0.10$.

One of the six cultivars evaluated was a sugarbeet root maggot resistant germplasm, F1015 (Campbell et al. 2000), one was a locally adapted commercial hybrid, Beta-3712 (B-3712), with no known resistance to the root maggot, and the other four were hybrids (resistant hybrids) obtained by crossing F1015 as a pollinator with four diverse susceptible proprietary (Crystal Beet Seed) cms females. At sowing, chlorpyrifos granules (Lorsban 15G, Dow Agrosciences, Indianapolis, IN) were applied to the plots receiving insecticide at a

rate of 2.2 kg (ai) ha^{-1} to a 13-cm band and lightly incorporated with drag chains.

Roots were visually assessed for *T. myopaeformis* feeding injury after most larval feeding activity had ceased (late July or early August). Five roots from the center of each of the two outer rows of each plot were hand dug, washed , and immediately rated on a scale of 0 = no visible feeding damage to 9 = 75% or more of the root surface blackened by feeding scars (Campbell, 2005). The mean of the ten roots from each plot was the basis for the analysis of variance.

Harvest dates were 29 and 27 September in 1998 and 1999, respectively. The two center rows of each plot were mechanically defoliated and harvested with a commercial two-row lifter modified to harvest experimental plots. Harvest stand was determined by counting the roots in each plot after defoliation and before harvest. Harvested roots were weighed in the field and a random sample of 10 to 12 roots from each plot was sent to the American Crystal Sugar Co. quality laboratory (East Grand Forks, MN) for determination of the sucrose and the impurity (sodium, potassium, and amino-nitrogen) concentrations needed to calculate recoverable sucrose. Recoverable sucrose yield is the product of recoverable sucrose concentration and root yield. Recoverable sucrose is an estimate of the sucrose in the root that would be extracted in normal commercial refining operations. Root yield and sucrose concentration are reported on a fresh-weight basis.

RESULTS

Cultivar, year, and interactions between cultivars and insecticide treatments had a significant impact on root yield (Table 1 & 2). Root yield means ranged from 34 Mg ha^{-1} for F1015 without insecticide in 1998 to 49.8 Mg ha^{-1} for A-204 with insecticide in 1999. Cultivar means ranged from 36.6 Mg ha^{-1} for A-206 to 45.9 Mg ha^{-1} for A-204. With insecticide, the yield of B-3712 was 7.8 Mg ha^{-1} greater than the root yield without insecticide. The only other cultivar with a significant difference between the insecticide and no insecticide treatment was A-204 with a 3.7 Mg ha^{-1} advantage when chlorpyrifos was applied. The average root yield increase attributable to the application of chlorpyrifos for the four hybrids with F1015 as the pollinator was 0.8 Mg ha^{-1}; approximately one-tenth of the increase observed for B-3712. With insecticide, the yield of B-3712 (46.5 Mg ha^{-1}) was equal to or greater than the root yield of the four resistant hybrids with insecticide; however, without chlorpyrifos, the yield of B-3712 (38.7 Mg ha^{-1}) was significantly lower than all the resistant hybrids

Table 1. Root yield, sucrose concentration, recoverable sucrose yield, and damage ratings of a sugarbeet root maggot resistant germplasm, F1015, four testcross hybrids with F1015 as the pollen parent, and a commercial hybrid, B-3712, with and without insecticide, St. Thomas, North Dakota, 1998-1999.

Hybrid or line	Insecticide	Root yield			Sucrose			Recoverable			Damage Rating		
		1998	1999	Mean	1998	1999	Mean	1998	1999	Mean	1998	1999	Mean
		---- Mg ha^{-1} ----			---- g kg^{-1} ----			---- kg ha^{-1} ----			---- 0 – 9 ----		
A-204	Chlorpyrifos	45.7	49.8	47.8	145	151	148	5687	6541	6115	3.8	5.8	4.8
	None	43.8	44.3	44.1	145	143	144	5463	5457	5461	3.4	5.9	4.7
	Mean	44.8	47.1	45.9	145	147	146	5576	5999	5788	3.6	5.8	4.7
A-205	Chlorpyrifos	39.2	44.2	41.7	142	142	142	4784	5388	5086	3.8	5.6	4.7
	None	39.8	45.1	42.5	139	136	137	4693	5191	4943	4.1	6.0	5.1
	Mean	39.5	44.7	42.1	141	139	140	4738	5290	5015	4.0	5.8	4.9
A-206	Chlorpyrifos	33.4	39.5	36.5	150	145	147	4278	4964	4621	3.8	5.6	4.7
	None	33.4	40.7	37.1	149	137	143	4270	4674	4472	4.1	6.4	5.2
	Mean	33.4	40.1	36.8	149	141	145	4274	4819	4547	4.0	6.0	5.0
A-207	Chlorpyrifos	41.2	44.6	42.9	147	145	146	5253	5655	5454	3.7	6.1	4.9
	None	38.0	45.8	41.9	148	143	145	4909	5701	5305	3.8	6.1	4.9
	Mean	39.6	45.2	42.4	147	144	146	5081	5678	5380	3.7	6.1	4.9
F1015	Chlorpyrifos	36.7	42.7	39.7	135	136	136	4155	4969	4562	3.9	5.6	4.7
	None	34.0	43.0	38.5	134	132	133	3806	4817	4312	3.1	5.8	4.5
	Mean	35.4	42.9	39.1	135	134	135	3981	4893	4437	3.5	5.7	4.6
B-3712	Chlorpyrifos	43.8	49.1	46.5	159	163	161	6280	7058	6669	3.6	6.1	4.8
	None	36.3	41.2	38.7	155	162	159	4931	5950	5440	4.1	6.0	5.0
	Mean	40.1	45.1	42.6	157	162	160	5650	6505	6055	3.8	6.0	4.9
Mean	Chlorpyrifos	40.0	45.0	42.5	146	147	147	5072	5763	5418	3.8	5.7	4.8
	None	37.6	43.4	40.4	145	142	144	4679	5299	4989	3.8	6.0	4.9
	Mean	38.8	44.2	41.5	146	145	145	4876	5530	5203	3.8	5.9	4.8

Table 2. Value of the F statistic (F) and the corresponding significance level (P) associated with each source of variation and Fisher's protected LSDs ($\alpha = 0.10$) for comparing root yield, sucrose concentration, recoverable sucrose yield, and damage rating means in Table 1.

Source of variation	Root yield			Sucrose			Recoverable sucrose			Damage rating		
	F	P	LSD	F	P	LSD	F	P	LSD	F	P	LSD
	---- Mg ha^{-1} ----			---- g kg^{-1} ----			---- kg ha^{-1} ----			---- 0 – 9 ----		
Years	17.78	0.01	2.5	0.30	0.62	ns	17.41	0.01	305	294.1	0.01	0.2
Insecticide	24.23	0.13	ns	2.93	0.33	ns	149.4	0.05	222	1.31	0.46	ns
Insecticide X Years	0.06	0.82	ns	1.48	0.27	ns	0.04	0.85	ns	0.67	0.44	ns
Cultivar (hybrids and F1015)	12.41	0.01	2.6	12.91	0.01	7	41.80	0.01	289	1.97	0.24	ns
Cultivar X Year	0.62	0.68	ns	3.73	0.01	5	0.51	0.77	ns	0.74	0.59	ns
Cultivar X Insecticide	5.23	0.05	2.8	0.62	0.69	ns	3.67	0.09	326	1.07	0.47	ns
Cultivar X Insecticide X year	0.38	0.86	ns	0.74	0.60	ns	0.65	0.66	ns	1.51	0.20	ns

except A-206, a hybrid that also had a relatively low root yield when chlorpyrifos was applied.

Only the cultivar main effect and the cultivar X year interaction were significant for sucrose concentration. The susceptible commercial hybrid, B-3712, had a higher sucrose concentration (160 g kg^{-1}) than all other cultivars. F1015 had a significantly lower sucrose concentration (135 g kg^{-1}) than all hybrids except A-205 (140 g kg^{-1}). Differences among the four resistant hybrids in sucrose concentration were not significant. The cultivar X year interaction occurred as the consequence of some hybrids having higher sucrose concentrations in 1998 than in 1999 and other cultivars having higher concentrations in 1999 than in 1998. Insecticide treatment did not have an apparent role in determining relative sucrose concentration.

All main effects, years, insecticide, and cultivar, had a significant impact on recoverable sucrose yield (Table 1 & 2). In general, insecticide increased both root yield and sucrose concentration and consequently, recoverable sucrose yield. Cultivars X year, insecticide X year, and cultivar X year X insecticide interactions were not significant for root yield, sucrose concentration, or recoverable sucrose yield, indicating differences among these traits was due to inherent differences in cultivars, a general increase when insecticide was applied, and differences among cultivars in their response to insecticide application (cultivar X insecticide interaction), or, for years, environmental factors that primarily influenced root yield and therefore recoverable sucrose yield.

When insecticide was applied to B-3712, recoverable sucrose yields were 1228 kg ha^{-1} more than when no insecticide was applied (Fig. 1). In contrast, the recoverable sucrose yield increase associated with insecticide application for three of the four testcross hybrids (A-205, A-206, and A-207) averaged 147 kg ha^{-1}. The slightly higher sucrose yield increase (250 kg ha^{-1}) observed in F1015, the resistant pollinator for all the testcross hybrids, was not significantly greater than the difference observed for A-205, A-206, and A-207. The sucrose yield increase associated with insecticide application for A-204, 654 kg ha-1, was between that of B-3712 and the other three testcross hybrids. This suggests that the susceptible female used to produce a root maggot resistant hybrid may influence the resistance level of the resulting hybrid.

Except for the difference between years, differences among damage ratings were small and not significant (Table 1). Yield differences associated with plant resistance and the application of insecticide in 1998 could have been due to differential root maggot feeding on small lateral roots. The damage rating scale used would not reflect differ-

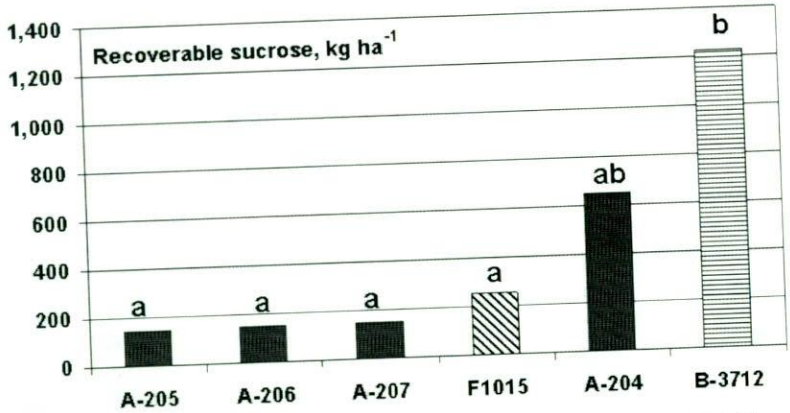

Fig. 1: Increase in recoverable sucrose yield when insecticide (chlorpyrifos) was applied to F1015, four hybrids with F1015 as the pollen parent (A-204, A-205, A-206, and A-207), and an adapted root maggot susceptible commercial hybrid (B-3712), St. Thomas, ND, 1998-1999 (differences among bars with a common letter are not significant according to Fisher's protected $LSD_{0.10}$).

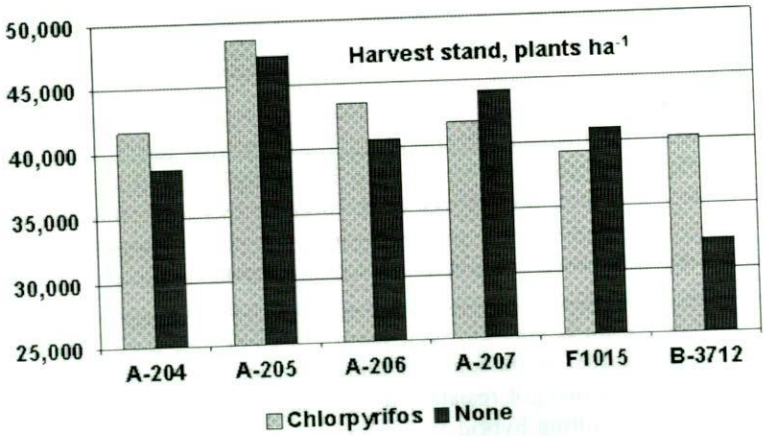

Fig. 2: Harvest stand of F1015, four hybrids with F1015 as the pollen parent (A-204, A-205, A-206, and A-207), and an adapted root maggot susceptible commercial hybrid (B-3712) with and without insecticide (chlorpyrifos), St. Thomas, ND, 1999.

ences in feeding on these small roots. In 1999, the year with the higher damage ratings, differences in harvest stands appeared to have a role in determining relative root yields (Fig. 2). The difference in harvest stand between the average of the four resistant hybrids and B-3712 when chlorpyifos was applied was 3,662 plants ha^{-1} (SE = 3,035, P = 0.25), compared to 10,487 plants ha^{-1} (SE = 2,955, P = 0.01) when no insecticide was applied, a 2.85 fold increase in the absence of the insecticide. A correlation between harvest stand and root yield of 0.34 (P = 0.02) suggested that stand loss had at least some detrimental affect on root yield in 1999. Furthermore in the absence of insecticide in 1999 the frequency of sprangled or branched roots increased. For example B-3712 had 10% sprangled roots when chlorpyifos was applied and 60% sprangled roots when no insecticide was used. Loss of stand and sprangling can occur when root maggots sever the taproot of young plants early in the season. Differences in harvest-stand and sprangling were smaller in 1998 than in 1999 and did not appear to be a major factor in determining relative root yields in 1998.

DISCUSSION

There was not an apparent relationship between root maggot damage ratings and relative yield of the hybrids or insecticide treatments. The effect of environmental conditions on the magnitude of yield losses associated with root maggot feeding has been documented. In an analysis involving 42 insecticide trials, the yield loss associated with each increment of the damage rating scale fluctuated between near 0 and 16 Mg ha^{-1} (Campbell et al, 1998). Root maggot damage was the only insect damage observed in these trials. Therefore, it was assumed that yield differences among hybrids and insecticide treatments resulted from differences in ability to prevent and/or compensate for damage caused by root maggot. Because F1015 is susceptible to root aphid, *Pemphigus populivenae* Fitch, (Campbell et al., 2000) and wireworm, *Hemicrepidius memnonius* Herbst. and *Limonius* spp. (unpublished), it would not be expected to provide any protection against these pests, or other insects, if they were present but not detected. Typically, some maggot feeding is observed on F1015 roots; however, F1015 is capable of maintaining relatively high yields in spite of the maggot feeding. The sucrose concentration of F1015 is often 15 to 20 g kg^{-1} less than that of adapted commercial hybrids (Campbell et al., 2000), so hybrids with F1015 as the pollinator would be expected to have sucrose concentrations lower than most commercial hybrids, unless the female parent used to produce the resistant hybrid had especially high sucrose concentration or excellent specific combining ability. There is no

reason to believe root maggot resistance and higher sucrose concentration could not be combined in a single elite breeding population.

Damage ratings were generally low and differences among cultivars and insecticide treatments were not significant in 1998. B-3712 without insecticide had a damage rating of 4.1 and with insecticide a rating of 3.6. However, the corresponding root yield advantage for the insecticide treatment was 7.5 Mg ha^{-1} (Table 1). The damage rating for F1015 without insecticide in 1998 was 3.1. A cool spring and early summer prevented a distinct peak in adult fly activity and as a result emergence of the adults and early instar maggot feeding occurred over an extended time in 1998 (Armstrong et al., 1999).

Although average damage ratings were higher in 1999 than in 1998 the differences among hybrids and treatments remained small. B-3712 had a damage rating of 6.0 and 6.1 without and with insecticide, respectively. However, the difference between the insecticide and no insecticide treatment in root yield was 7.9 Mg ha^{-1} (Table 1). The damage rating for F1015 was 5.7 in 1999. Stand loss between the time root maggot eggs were deposited near the plants and harvest appeared to impact relative yields in 1999. In 1999, adults emerged in relatively high numbers throughout June. As a result, some insecticides that provide early control that would have been adequate in many seasons were unsuccessful in preventing substantial maggot feeding. In an adjacent registered insecticide trial, damage ratings were relatively high for some insecticide treatments; however, all insecticide treatments had root yields greater than the no insecticide treatment (Boetel et al., 2000).

The relative root (Table 1) and sucrose yields (Table 1, Fig. 1) indicated that when F1015 was used as a pollen parent the resulting hybrid would have a substantial reduction in the economic damage resulting from sugarbeet root maggot feeding. The relative low damage ratings in 1998, the absence of significant differences among damage ratings within years, and the few environments examined limit the extent the results of these trials should be extrapolated to a large production area. However, when the results of this study are considered along with results from a recent more extensive trial, the case for maggot resistant hybrids is strengthened. In the more recent study (Campbell et al., 2008), which compared the performance of four hybrids with root maggot resistant pollinators to two susceptible hybrids with and without insecticide in four environments, hybrids with the root maggot resistant pollinators and no insecticide had root yields equal to or greater than the root maggot susceptible hybrids with insecticide. The two studies encompassed six environments, four maggot resistant pollinators, and five elite female (cms) parental lines. In all of the environments, except one with inconsequential root maggot damage, the yield loss attributable to

root maggot feeding in hybrids with a maggot resistant pollen parent was substantially less than the corresponding yield loss in adapted susceptible commercial hybrids.

In portions of the Red River Valley of North Dakota and Minnesota where root maggot populations are consistently high, growers spent an average of \$43.70 ha^{-1} on planting-time granular insecticides in 2007. In years or locales with especially high maggot populations, growers often apply an addition liquid formulation near the time of peak adult activity. Insecticide costs for post-emergence insecticides averaged \$11.20 ha^{-1}. These costs are for insecticide only; equipment and application expenses would be additional. Root maggot-resistant hybrids might benefit from an insecticide application in areas where the threat of substantial root maggot damage is greatest. However, their use would likely reduce the amount of insecticide required and make feasible the use of lower-cost or more environment-friendly insecticides that are not adequate with current commercial (susceptible) hybrids. Resistant hybrids would provide protection against catastrophic losses when insecticide effectiveness is reduced by adverse weather conditions or problems with application timing. In areas where root maggot is an occasional or less severe threat, host plant resistance might provide sufficient protection without insecticide.

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