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Resistance in Cultivated Sunflower to the Sunflower Moth (Lepidoptera: Pyralidae)[1]

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ABSTRACT A five-year field study evaluated 42 sunflower (*Helianthus annuus* L.) accessions, 25 breeding lines, and 40 interspecific crosses for resistance to infestation and damage from larval feeding by naturally occurring populations of the sunflower moth, *Homoeosoma electellum* (Hulst) (Lepidoptera: Pyralidae). Accessions PI 175728 and PI 307946 had less than 3% feeding damage per head in all three years they were tested. Some interspecific crosses showed evidence of resistance; PAR 1673-1 had less than 2% seed damage in 2002 and 2003 and less than 3% in 2005. PRA PRA 1142 sustained less than 3% seed damage and STR 1622-1 had less than 2% seed damage in three years of trials. Breeding lines with potential resistance included 01-4068-2, which had the least amount of seed damage per head in 2002 (<1%) and in 2003 averaged only 2% damage. Line 01-4080-1, with less than 1% damage in 2002 and in 2003, was the least damaged entry in these evaluations. Hybrid '894' was included as a standard check; however, it consistently had among the lowest average seed damage from *H. electellum* feeding. Our investigation showed the potential for developing resistant genotypes for the sunflower moth to reduce seed feeding injury and to prevent yield losses for sunflower producers. The development of germplasm with host plant resistance would provide another tool in an integrated pest management approach for *H. electellum*. Additional effort is in progress to use the identified lines to introgress resistance genes into cultivated sunflower through conventional breeding facilitated by marker-assisted selection.

KEY WORDS Cultivated sunflower, *Helianthus annuus*, pest management, host plant resistance, sunflower moth, *Homoeosoma electellum*

The sunflower moth, *Homoeosoma electellum* (Hulst) (Lepidoptera: Pyralidae), has been the most widespread and damaging insect pest of sunflower, *Helianthus annuus* L. (Asteraceae), in North America (Schulz 1978, Rogers 1988, Charlet et al. 1997). The moth occurs from Mexico to both coasts of the United States and to the Canadian Prairie Provinces (Chippendale & Cassatt 1986). Larval feeding has been reported on more than 40 different composite plant species including four species of native sunflowers, *Helianthus debilis* Nuttall, *H. maximiliani* Schrader, *H. petiolaris* Nuttall, and *H. tuberosus* L. (Teetes & Randolph 1969,

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Chippendale & Cassatt 1986, DePew 1986, Goodson & Neunzig 1993). The northern limit of the sunflower moth is approximately 40°N latitude, beyond which it does not overwinter (Arthur 1978). However, moths are transported north on southerly winds to the northern Plains of the United States and the Canadian Provinces of Saskatchewan and Manitoba (Arthur & Bauer 1981, Rogers & Underhill 1983).

Eggs are deposited on the surface of open sunflower heads. First instars feed primarily on pollen. Second instars feed on pollen and disk flowers. Feeding by third instars may sever the style preventing the ovary from being fertilized, resulting in empty seeds. Third instars also feed on the kernel of mature seeds. Larval feeding to maturity results in an average of about 96 damaged disk flowers and about 23 damaged ovaries per larva (Rogers 1978). As they feed, larvae spin a web over the face of the sunflower head, which accumulates destroyed disk flowers and frass, giving the head a trashy appearance. Larval feeding in the head also may provide a site for entrance of the fungal pathogen of *Rhizopus* head rot, which can further reduce yield and affect oil quality. Larvae exit the sunflower head when mature and drop into the soil to overwinter in silken cocoons covered with soil particles (Rogers 1978, 1992, Rogers & Westbrook 1985, Charlet et al. 1997).

Despite research on cultural and biological control and plant resistance, chemical control is frequently relied upon to manage sunflower moth infestations in commercial sunflower (Archer et al. 1983, Bynum et al. 1985, DePew 1988, Charlet et al. 1997). Although a large assemblage of tachinid and hymenopteran parasitoids have been reported to attack the sunflower moth in both agricultural and native sunflower habitats (Teetes & Randolph 1969, Beregovoy 1985, Charlet 1999, Chen & Welter 2002), control has often not been sufficient to reduce crop losses. Research by Chen & Welter (2007) revealed that larval densities were much lower and parasitism was higher on wild sunflowers than on cultivated sunflowers, because domesticated sunflower heads provided a structural refuge for the larvae from parasitoids. In Kansas, Aslam & Wilde (1991) showed that early June plantings usually had higher infestations than later plantings. Early studies showed that phytomelanin, a hard acellular layer that develops between the hypodermis and sclerenchyma in the pericarp of some sunflower lines, imparts mechanical resistance to the sunflower moth (Rogers & Kreitner 1983). Spring et al. (1987) found that sunflower species have simple, noncapitate glandular, and capitate glandular trichomes, with the capitate trichomes producing at least six different sesquiterpene lactones. Research showed that sesquiterpene lactones were feeding deterrents and toxins to the sunflower moth (Gershenzon et al. 1985, Rogers et al. 1987). Other sunflower compounds may also affect sunflower moth development; Elliger et al. (1976) and Rogers et al. (1987) found that sunflower diterpenes in artificial diet resulted in reduced larval performance. Although Rogers et al. (1984) released three germplasm lines for resistance to sunflower moth, there has been limited recent effort to evaluate lines for reduced seed injury by *H. electellum* in cultivated sunflower. Studies were initiated in 2002 to evaluate sunflower germplasm for potential resistance to the sunflower moth. Diverse sunflower germplasm was exposed to naturally occurring moth infestations to evaluate differences in seed damage caused by this insect pest.

Materials and Methods

During the 2002 to 2007 growing seasons, 42 sunflower accessions (Plant Introductions [PI]), 25 breeding lines in early generation selection for resistance to the banded sunflower moth, *Cochylis hospes* Walsingham (Lepidoptera: Tortricidae), and 40 interspecific crosses derived from ten annual and five perennial *Helianthus* species were evaluated for resistance to infestation by naturally occurring populations of the sunflower moth. Each year, USDA sunflower Hybrid '894' was included in the trials because of its historical use as a standard check. Sunflower accessions were obtained from the USDA-ARS North Central Regional Plant Introduction Station, Ames, IA. The USDA, ARS Germplasm Resources Information Network (GRIN) online database was used to select accessions. Descriptors in the database were used to select lines with similar days to flowering and plant height. Interspecific crosses were provided by one of the authors (G.J.S.). Trials were conducted at the Northwest Research Extension Center, Kansas State University, Colby, Kansas. Twenty-one to 59 entries were evaluated annually in single row plots that were 8-m long. Rows were 76 cm apart, and plants were spaced 30.5 cm apart within rows, so that there were approximately 54,000 plants/ha. Entries with relatively low levels of seed damage per head along with some susceptible lines were selected for retesting in subsequent years. Plots were planted between 7 and 10 May each year in a randomized complete block design with four replicates, except for 2005 to 2007 when only three replicates were examined. Plots received a preplant application of fertilizer and herbicide, but no other chemical treatments were used.

Five heads per row (total of 15–20 heads per treatment) were removed after plants had senesced. Sunflower heads were harvested from late August to early September and sent to Fargo, ND. Heads were dried, threshed, and the seed cleaned prior to evaluation. Subsamples of 100 seeds per head were randomly selected and evaluated for number of seeds damaged by moth larval feeding. The degree of infestation was the percentage of seeds with *H. electellum* feeding injury per head. Visual examination of the pericarp was found to be an effective and reliable method to distinguish damage by the sunflower moth from other important seed feeding pests including the banded sunflower moth and red sunflower seed weevil, *Smicronyx fulvus* LeConte (Coleoptera: Curculionidae) (Peng & Brewer 1995).

The PROC GLM analysis of variance procedure (SAS 2008) was used to compare percentage of seed damaged per head among the different treatments for each study year. Percentages were transformed to the square root of the arcsine prior to analysis. Means were separated using the Fisher's protected least significant difference (LSD) test (Carmer & Walker 1985) at $P < 0.05$.

Results

The determination of feeding damage in 2002 showed high levels of sunflower moth infestation within the trial based on the percentage of damaged seeds in individual heads sampled. The percentage of *H. electellum* seed damage per head ranged from 0 to 73% in the individual heads evaluated. The mean larval seed damage varied from 1 to 22% among the germplasm tested and the data did show significant differences among a number of those tested (Table 1). Twenty four of the 59 lines included in the study showed less than 2% seed damage. Among the material in the trial, those less than 1% damage included the four lines 01-4059-1, 01-4043-1, 01-4080-1, 01-4068-2; the interspecific crosses RF ANN 1742, PRA-HIR 437, PRA RUN 417-1, ANO 1509-1; accession PI 243078; and Hybrid 894. The line 01-4094-1 was the most susceptible entry (22%) in 2002.

High levels of sunflower moth infestation occurred within the 2003 trial, based on the percentage of seed damage to individual heads. The percentage of *H. electellum* seed damage ranged from an average of 0.2 to 47% (Table 1). The line 01-4094-1 was again the most susceptible of all material in the trial. Seven of the 54 lines in the study, including Hybrid 894, had 2.2% or less seed damage per head. Although statistical differences were not always clearly defined, these lines were significantly different from over 25% of the germplasm tested. Resistant lines included the interspecific crosses HIR 1734-1, PAR 1673-1, and STR1622-2; the accessions PI 170414 and PI 372259; and the line 01-4080-1 (less than 1% damage in the 2002 trial).

There was a reduced level of infestation of *H. electellum* in the 2004 trial, which was reflected in a low amount of feeding damage among all the germplasm tested. The percentage of seed damage per head from *H. electellum* larval feeding ranged from 0 to 2% in the 36 lines tested. Because of the low level of damage from sunflower moth feeding, it was difficult to make meaningful comparisons among the germplasm tested. Thus, the trial was repeated in 2005 with the same lines.

In 2005, only two germplasm lines had over 36% damage, while the remaining 34 lines showed an average of about 10% or less *H. electellum* seed damage per head (Table 1). Although some inconsistencies in the results were evident compared to those in previous years, a number of lines that had shown low damage levels in 2002 and 2003 also had a low percentage of seed damage per head in 2005. The susceptible line 01-4094-1 was again the most heavily damaged (42% of seeds damaged) by sunflower moth feeding. HIR 1734-1 had over 36% damaged seed per head in 2005, but averaged only 2% damage per head in 2003. Four lines with low damage ($\leq$2%) in 2003 also sustained an average of 2% or less damage per head in 2005 and were statistically lower than 25% of the germplasm in the trial. These lines included Hybrid 894, the accessions PI 170414 and PI 372259, and the interspecific cross STR 1622-2. Nine accessions that were new in the 2005 trial also had less than 2% seed damage per head from sunflower moth feeding, and of these, three averaged 1% or less damage per head: PI 193775, PI 494861, and PI 650497.

Insect pressure from the sunflower moth was very heavy in 2006 as shown by the amount of seed damage in the trial; the mean ranged from 1 to 80% seed damage among the selected germplasm lines evaluated (Table 1). The amount of damage sustained by the germplasm tested was surprising because, other than the susceptible checks, lines included in the 2006 trial had shown 4% or less damage in 2005. The interspecific cross HIR 1734-3 sustained an average of 56% seed damage per head in 2006, but had only 1% and 4% damage per head in 2005 and 2003, respectively. However, Hybrid 894 again had the lowest amount of seed damage per head in 2006, which is consistent with results from 2002, 2003, and 2005. During all four years, this line sustained no more than 2.2% damage per head, which was significantly lower than eight of the 22 lines evaluated. Others in the 2006 trial with low seed damage levels included PI 170414 (10.6%), PI 170385 (10.7%), and PI 650375 (10.9%), which averaged 0%, 2.5%, and 1.1% damage, respectively, in 2005.

There was a high infestation pressure of *H. electellum* in 2007 based upon the amount of seed damage in the trial; the damage ranged from 8 to 82% seed damage per head among the 21 selected accessions, interspecific crosses, and the hybrid evaluated (Table 1). This year had the highest mean in the six years of evaluations with an average of 43% seed damage per head. Even though Hybrid 894 sustained 14% damage in 2007, this was still among the lowest damage levels and was statistically lower than eight of the lines tested. PI 170414 consistently had one of the lowest levels of damage from *H. electellum* with an average of 9.3% damage in 2007, 10.6% damage in 2006 and 0% damage in 2005. The accession with the lowest damage in 2007 was PI 177399 with only 8.8% feeding damage per head. However, this was the only year this accession was tested.

Discussion

Germplasm with resistance to attack and damage from larval feeding by the sunflower moth was evident from this six-year study, although in some cases differences were not clearly defined statistically. It is likely that large variation among plots, as reflected by large standard errors, reduced the statistical significance among lines. PI 175728 and PI 307946 both showed less than 3% feeding damage per head in three years they were tested. However, these lines were not tested during 2006 and 2007 when high populations of *H. electellum* were present and seed damage averaged 32% and 43%, respectively. PI 170414 exhibited less than 1% feeding damage per head in two years of trials, but suffered over 10% damage in 2006 and 9% in 2007. Two lines (PI 170401 and PI 372259) that appeared promising in both 2003 and 2005 with less than 3% seed damage per head, were heavily damaged in the final two trial years. This reaction could possibly be because resistance mechanisms were overwhelmed in 2006 and 2007. Additional research would be needed to determine whether mechanisms such as antibiosis or antixenosis were responsible for the resistance and broke down due to high *H. electellum* population pressure. PI 177399 may have potential because it significantly had the least damage in 2007 among all germplasm tested; however, this was the only year of testing for this line.

A number of interspecific crosses showed evidence of resistance in three years of trials. PAR 1673-1 (*H. paradoxus* Heiser) had less than 2% seed damage per head in both 2002 and 2003 and less than 3% in 2005. PRA PRA 1142 (*H. praecox* Engleman and Gray) also sustained less than 3% seed damage per head in three years of testing (2002, 2003, and 2005), and STR 1622-1 (*H. strumosus* L.) showed less than 2% seed damage per head for the same three years. However, another selection from this interspecific cross, STR 1622-2 (*H. strumosus*) had inconsistent results; it had only 1% seed damage per head in 2003 and 2005, but over 20% in the subsequent two years of trials due to high populations of *H. electellum*. Two other interspecific crosses, DEB CUC 1810 (*H. debilis* Nuttall ssp. *cucumerifolius* (Torrey & Gray) Heiser) and HIR 1734-3 (*H. hirsutus* Rafinesque) had similar conflicting results with low damage in two of four years of testing.

Table 1. Percentage of seeds damaged by *Homoeosoma electellum* in selected sunflower accessions evaluated at Colby, KS, 2002 to 2007.

	Percent damaged seed per head (mean ± SE)				
Accession	2002	2003	2005[a]	2006	2007
PI 162453	—	—	3.8 ± 0.2cdefghi	53.3 ± 15.0abcde	—
PI 162675	—	16.5 ± 6.3bcdef	—	—	—
PI 167387	1.4 ± 0.4hijkl	19.4 ± 2.8b	2.7 ± 1.3defghijk	—	—
PI 170385	—	—	2.5 ± 1.3defghijk	10.7 ± 7.8fg	65.9 ± 18.9abcd
PI 170387	3.2 ± 0.8defghijkl	—	—	—	—
PI 170391	—	5.4 ± 4.2fghijkl	—	—	—
PI 170399	1.8 ± 0.8ghijkl	6.0 ± 2.9cdefghijkl	—	—	—
PI 170401	—	2.7 ± 0.8hijkl	2.0 ± 1.0efghijk	13.6 ± 7.1fg	62.4 ± 15.1abcd
PI 170405	—	—	1.4 ± 0.4fghijk	21.5 ± 12.8cdefg	23.7 ± 2.0efg
PI 170412	4.0 ± 2.5defghijkl	—	—	—	—
PI 170414	—	0.9 ± 0.7kl	0.0k	10.6 ± 4.8fg	9.3 ± 6.5fg
PI 170415	—	3.9 ± 1.6ghijkl	2.9 ± 0.9defghijk	18.5 ± 14.9cdefg	13.3 ± 5.5efg
PI 170417	11.0 ± 3.7b	—	—	—	—
PI 170418	—	—	5.3 ± 0.9bcdefg	—	—
PI 170419	—	17.4 ± 7.5bcde	—	—	—
PI 175728	1.9 ± 1.0fghijkl	2.7 ± 1.2hijkl	1.3 ± 0.5ghijk	—	—
PI 177396	—	—	—	—	64.3 ± 9.9abcd
PI 177399	—	—	—	—	8.8 ± 6.5g
PI 193775	—	—	0.5 ± 0.2ijk	28.2 ± 12.5bcdefg	41.8 ± 9.3cdef
PI 232905	3.0 ± 2.4fghijkl	—	—	—	—
PI 243078	0.8 ± 0.4kl	7.0 ± 3.0defghijkl	5.7 ± 2.0bcdef	—	—
PI 250855	9.6 ± 2.9bc	—	—	—	—
PI 251902	1.9 ± 0.6fghijkl	5.8 ± 2.5cdefghijkl	—	—	—
PI 253773	2.1 ± 0.6fghijkl	—	—	—	—
PI 253776	—	—	9.5 ± 3.5bc	—	—

Table 1. Continued.

Accession	Percent damaged seed per head (mean ± SE)				
	2002	2003	2005[a]	2006	2007
PI 267665	—	—	10.5 ± 4.0b	—	—
PI 287233	—	—	—	—	24.1 ± 5.1efg
PI 291403	—	—	1.8 ± 0.8efghijk	26.4 ± 4.5bcdefg	72.5 ± 2.7abcd
PI 291407	—	—	—	—	76.3 ± 9.2ab
PI 307946	1.7 ± 0.8ghijkl	2.3 ± 0.5ghijkl	0.5 ± 0.3hijk	—	—
PI 343785	2.0 ± 0.5fghijkl	9.5 ± 4.1cdefghijkl	—	—	—
PI 372259	—	1.5 ± 0.9jkl	0.8 ± 0.5hijk	38.1 ± 21.8bcdef	46.4 ± 14.8abcde
PI 386230	—	—	5.4 ± 3.3cdefghi	—	—
PI 431516	—	—	2.0 ± 2.0cdefghij	79.8 ± 13.6a	—
PI 431542	—	—	6.7 ± 3.2bcde	—	—
PI 494859	—	—	1.3 ± 1.0hijk	60.1 ± 11.5ab	—
PI 494861	—	—	0.5 ± 0.2ijk	15.8 ± 6.7efg	43.5 ± 17.3bcde
PI 497939	—	—	6.5 ± 4.5bcd	—	—
PI 505651	—	—	1.6 ± 0.2efghijk	33.4 ± 17.3bcdefg	39.8 ± 4.8def
PI 650375	—	—	1.1 ± 0.5ghijk	10.9 ± 6.1fg	19.2 ± 7.2efg
PI 650497	—	—	1.0 ± 0.5ghijk	43.3 ± 21.0bcdef	21.1 ± 8.6efg
PI 650558	—	—	5.8 ± 5.8cdefgh	56.2 ± 2.4abcd	—
ANO 1509-1	0.7 ± 0.4jkl	3.0 ± 2.6hijkl	—	—	—
ANO 1509-2	—	3.0 ± 2.8ijkl	—	—	—
ARG 420-1	3.8 ± 2.0defghijkl	—	—	—	—
ARG 1575-2	2.2 ± 1.3fghijkl	—	—	—	—
ARG 1575-4	—	6.6 ± 2.7bcdefghijkl	—	—	—
BOL 774	4.8 ± 1.2bcdef	—	—	—	—
DEB CUC 1810	—	2.9 ± 1.3ghijkl	0.7 ± 0.5hijk	20.3 ± 3.6cdefg	81.5 ± 6.4a
DEB SIL 367-2	3.3 ± 2.6ghijkl	—	—	—	—
DES 1474-2	3.0 ± 1.4defghijkl	—	—	—	—
DES 1474-3	—	16.8 ± 8.8bc	—	—	—

Table 1. Continued.

Accession	Percent damaged seed per head (mean ± SE)				
	2002	2003	2005[a]	2006	2007
GIG 1616-2	3.3 ± 1.6defghijk	—	—	—	—
HIR 1734-1	—	2.0 ± 0.8hijkl	36.5 ± 11.5a	31.1 ± 13.5bcdefg	72.3 ± 26.0abc
HIR 1734-3	—	4.3 ± 1.7cdefghijkl	1.0 ± 1.0fghijk	55.7 ± 27.6abc	78.1 ± 21.9a
NEG 1255	3.1 ± 2.0defghijkl	—	—	—	—
PAR 1084-1	5.0 ± 4.0cdefghijkl	—	—	—	—
PAR 1671-1	1.9 ± 0.8ghijkl	16.8 ± 5.1b	—	—	—
PAR 1673-1	1.4 ± 0.6hijkl	1.7 ± 0.2jkl	2.6 ± 1.7efghijk	—	—
PAR 1673-2	—	10.8 ± 4.1bcdefghij	—	—	—
PET PET 1741-2	5.9 ± 2.6cdefgh	—	—	—	—
PRA HIR 437	0.8 ± 0.3jkl	8.4 ± 1.6bcdefghij	—	—	—
PRA PRA 1142	1.9 ± 0.7ghijkl	2.7 ± 1.2hijkl	1.7 ± 1.2ghijk	—	—
PRA RUN 417-1	0.6 ± 0.3kl	7.2 ± 3.1bcdefghijkl	—	—	—
PRA RUN 1329	—	7.6 ± 1.9bcdefghijk	—	—	—
RES 834-1	—	11.0 ± 3.8bcdefghi	—	—	—
RES 834-3	—	7.4 ± 2.6bcdefghijk	—	—	—
RF ANN 19	—	10.9 ± 5.0bcdefgh	—	—	—
RF ANN 48	—	8.2 ± 6.2bcdefghijkl	—	—	—
RF ANN 783	—	5.9 ± 3.6cdefghijkl	—	—	—
RF ANN 892	—	6.3 ± 0.7bcdefghijk	—	—	—
RF ANN 1064	—	5.5 ± 3.1defghijkl	—	—	—
RF ANN 1742	0.9 ± 0.5jkl	15.8 ± 5.0bcde	—	—	—
RF ARG 420	—	16.6 ± 9.6bcd	—	—	—
RF ARG 1575	—	13.7 ± 3.4bcd	—	—	—
RF PRA 417	—	16.4 ± 5.3bcdefg	—	—	—
RF TUB 346	—	13.2 ± 2.5bcd	—	—	—
STR 1622-1	1.3 ± 0.5ghjkl	2.3 ± 1.0hijkl	1.5 ± 0.9efghijk	—	—

Table 1. Continued.

Accession	Percent damaged seed per head (mean ± SE)				
	2002	2003	2005[a]	2006	2007
STR 1622-2	—	1.3 ± 0.3jkl	1.0 ± 0.5ghijk	20.4 ± 19.9defg	23.9 ± 5.8efg
TUB 346	2.6 ± 0.4defghijkl	—	—	—	—
TUB 365	1.8 ± 0.3defghijkl	10.6 ± 6.7bcdefghij	—	—	—
TUB 1709-1	4.5 ± 1.6cdefghi	—	—	—	—
01-4023-1	1.4 ± 0.8hijk	8.7 ± 3.6bcdefghijk	—		
01-4027-2	4.1 ± 1.1cdefgh	—	—	—	—
01-4039-2	21.5 ± 3.0a	42.1 ± 6.4a	8.4 ± 1.3bcd	—	—
01-4043-1	0.9 ± 0.6kl	—	—	—	—
01-4047-1	2.0 ± 1.4ghijkl	—	—	—	—
01-4048-2	2.2 ± 0.9defghijkl	8.9 ± 3.3bcdefghijk	—	—	—
01-4050-1	3.1 ± 1.6defghijkl	—	—	—	—
01-4051-1	5.0 ± 2.2cdefghi	—	—	—	—
01-4056-2	2.7 ± 1.0efghijkl	—	—	—	—
01-4058-3	2.1 ± 1.4ghijkl	—	—	—	—
01-4059-1	0.9 ± 0.4ijkl	4.0 ± 1.3efghijkl	—	—	—
01-4060-3	3.5 ± 0.3cdefghij	—	—	—	—
01-4061-2	3.7 ± 1.0defghijkl	—	—	—	—
01-4062-1	1.8 ± 0.6hijkl	4.6 ± 2.9cdefghijkl	—	—	—
01-4063-1	1.8 ± 0.5fghijkl	3.2 ± 0.9defghijkl	—	—	—
01-4066-2	3.0 ± 0.6defghijkl	—	—	—	—
01-4068-2	0.7 ± 0.4l	2.4 ± 1.3jkl	—	—	—
01-4072-2	7.9 ± 3.6bcde	—	—	—	—
01-4078-2	1.3 ± 1.2ijkl	7.9 ± 2.9bcdefghijkl	—	—	—
01-4080-1	0.8 ± 0.3hijkl	0.2 ± 0.2l	—	—	—
01-4085-2	2.0 ± 0.6fghijkl	—	—	—	—
01-4089-1	10.2 ± 5.2bcd	—	—	—	—
01-4090-1	5.9 ± 2.1bcdefg	—	—	—	—

Table 1. Continued.

	Percent damaged seed per head (mean ± SE)				
Accession	2002	2003	2005[a]	2006	2007
01-4094-1	22.3 ± 10.1a	46.5 ± 19.1a	42.2 ± 6.5a	47.3 ± 10.3abcdef	—
01-4097-1	2.2 ± 1.0fghijkl	—	—	—	—
Hybrid 894	0.7 ± 0.2jkl	2.2 ± 1.0jkl	0.3 ± 0.1k	1.2 ± 0.4g	14.0 ± 5.0efg
Mean	3.6	8.8	4.5	31.7	43.0

Means followed by the same letter within each year are not significantly different ($P < 0.05$; LSD); percentages transformed to square root of the arcsine before analysis and untransformed means are presented; 2–67 heads examined per accession each year.

[a]2004 data were not included because of reduced infestation levels.

Comparison of breeding lines evaluated in 2002 and 2003 revealed some potential resistant germplasm. The line 01-4068-2 had the least amount of seed damage per head in the 2002 trial with less than 1%, and in the next year averaged only 2% damage, while 01-4080-1 sustained less than 1% the first year and in 2003 was the lowest in the trial at 0.2% seed damage per head. The line 01-4094-1 was used as a susceptible check based on results from 2002 when it had the highest level of damage in the trial (22% seed damage per head). In the four years (2002, 2003, 2005, and 2006) that 01-4094-1 was included in the trials it sustained the greatest amount of *H. electellum* damage in three of those years.

Hybrid 894 was included in these trials as a standard check. It is a public-domain hybrid that has been produced by a number of commercial sources. In the past, it was used as a susceptible check in research studies for another sunflower pest, the banded sunflower moth (Brewer and Charlet 1989, Jyoti and Brewer 1999). However, in the current investigation, this hybrid consistently had among the lowest average seed damage from *H. electellum* feeding. In the first five years of evaluation, it had less than 2.2% seed damage each year, and it had among the lowest levels of seed damage in the final trial (2007) when overall damage levels were higher than in other years. In screening trials for resistance to stem-infesting pests, Hybrid 894 was not very resistant to attack by the sunflower stem weevil, *Cylindrocopturus adspersus* (LeConte) (Coleoptera: Curculionidae), a longhorned beetle, *Dectes texanus* LeConte (Coleoptera: Cerambycidae), or a root boring moth, *Pelochrista womonana* (Kearfott) (Lepidoptera: Tortricidae) (Charlet et al. 2009). However, in another study in which germplasm was evaluated for resistance to the banded sunflower moth, Hybrid 894 was also the most resistant line (Charlet et al. 2010).

Our investigation showed potential for developing sunflower moth-resistant genotypes that would reduce seed feeding injury, prevent yield loss, and increase grower profit. Host plant resistance would provide another tool in an integrated pest management approach for *H. electellum*. Although chemical control has been beneficial (Archer et al. 1983, Bynum et al. 1985, DePew 1988), it can be expensive and relies on field monitoring to be effective. An added benefit of host plant resistance is that it can be effectively combined with delayed planting, which has also been shown to reduce densities of *H. electellum* and reduce crop losses (Aslam & Wilde 1991). In addition, reduced chemical treatments would be less detrimental to the natural enemies of the sunflower moth (Teetes & Randolph 1969, Beregovoy 1985, Charlet 1999). The nature of the resistance mechanisms resulting in the reduced seed damage in the germplasm is not known, but will be the subject of future research. The resistance may be due to phytomelanin (Rogers et al. 1992), sesquiterpene (Gershenson et al. 1985, Rogers et al. 1987, Spring et al. 1987), or diterpene (Elliger et al. 1976, Rogers et al. 1987) feeding deterrents. Additional effort is in progress to use the identified lines to introgress resistance genes into cultivated sunflower through conventional breeding facilitated by marker-assisted selection.

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