Current status and future perspectives on sunflower insect pests

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ABSTRACT

- While occasional insect pests of cultivated sunflowers may be managed by conventional or reduced-risk insecticides, the cumulative costs and risks of relying on insecticides to suppress perennial or severe pests (common in North America) call for exploration of broader pest management strategies.
- Recent research with the sunflower moth (*Homoeosoma electellum* [Pyralidae]) and banded sunflower moth (*Cochylis hospes* [Tortricidae]) in North America has focused on finding host plant resistance in *Helianthus* spp. and understanding the mechanisms of resistance. Two flies, the sunflower midge (*Contarinia schulzi* [Cecidomyiidae]) in North America, and sunflower head fly (or mosquita del capítulo, *Melanagromyza minimoides* [Agromyzidae]) in South America provide examples of severe pests which can be particularly problematic over limited areas of their geographic ranges; management of both fly species could benefit from additional research.
- Work with insect pests of sunflower in North America shows the increasing potential of using integrated pest management (IPM) tactics, particularly forms of host plant resistance (antibiosis, antixenosis, tolerance) often derived from interspecific hybrids or accessions of *Helianthus annuus*.
- Economic and other practical considerations may preclude significant use of transgenic insect-resistance (e.g., expressing toxins from *Bacillus thuringiensis* [*Bt*]), but because single traits native to *Helianthus* spp. do not appear capable of providing resistance equivalent to insecticides, two or more independent types of resistance should be combined whenever possible.
- With few scientists working on sunflower insects, a reasonable approach to address insect problems includes using (i) existing sunflower defensive traits (e.g., pericarp hardness, terpenoids, coumarins), (ii) interdisciplinary approaches for efficient screening and breeding, and (iii) international collaboration to test or transfer useful traits for insects that are related or share feeding behaviors.

Key words: *Cochylis hospes – Contarinia schulzi – Homoeosoma – Melanagromyza minimoides*

INTRODUCTION

As with other food and feed crops, *Helianthus annuus* is fed upon by hundreds of insects that collectively attack throughout crop development and utilize every part of the plant. Most insects that feed on sunflower produce damage less than the cost of management (e.g., an insecticide application), limiting their status to that of non-pests (or subeconomic pests). However, literature on sunflower production across six continents still documents dozens of insects which have caused significant losses of sunflower yield (Rogers, 1992). Within any region, most insects are considered occasional pests, which do not consistently produce economic damage and are best managed with conventional or reduced-risk insecticides. However, perhaps two or three species in a region are considered perennial or severe pests; generally the cumulative costs and risks for managing these insects solely with insecticides provide incentive to develop broader pest management plans. Low-cost components for managing perennial or severe pests include crop rotation, modified planting dates, host plant resistance, and conservation of natural enemies (predators, parasitoids, and pathogens). While these components are usually not sufficient to control pests alone, in combination they can reduce the need for or increase the efficacy of insecticides.

Problems with insect pests are particularly difficult in North America, the native range of sunflowers. While some insects on other continents have recently adapted to utilize sunflower as a host, several species in North America are believed to have evolved with *Helianthus* spp. as their sole or primary hosts. Once production of cultivated sunflower began increasing in Canada and the United States (U.S.), insects accustomed to feeding on small, occasional patches of wild sunflower began to take advantage of large fields of suitable hosts. In addition to the concentration of host plants, morphological and chemical differences between wild and cultivated sunflower make the crop more susceptible to herbivores coevolved with wild sunflowers. For example, contrasts between wild and cultivated *H. annuus* indicate that for the stem-boring beetle, *Dectes texanus* (Cerambycidae), the softer petioles and lower amount of resin in cultivated sunflower increase the frequency with which adult beetles oviposit (lay eggs) in sunflower petioles (Michaud and Grant, 2009). In wild sunflowers, pest populations may be limited by natural enemies, especially parasitoids. Often there are several parasitoid species associated with a perennial pest, but they are not sufficient to keep insects below economically damaging levels (Charlet and Seiler, 1994).

While many occasional insect pests of sunflower can produce locally high levels of damage, they are not consistent enough to justify the long-term resources needed to develop integrated management plans. However, for several pests of cultivated sunflower in North America, including the sunflower moth (*Homoeosoma electellum* [Pyralidae]), banded sunflower moth (*Cochylis hospes* [Tortricidae]), red sunflower seed weevil (*Smicronyx fulvus* [Curculionidae]), and sunflower stem weevil (*Cylindrocopterus adspersus* [Curculionidae]), efforts are underway to employ host plant resistance as a primary tool to limit insect damage. Plant resistance to these pests may include combinations of mechanisms, including antibiosis (adverse biological effects of the plant), antixenosis (or non-preference; reduced attractiveness of the host plant), or tolerance (ability to recover from or withstand injury). Reviews of the biology and management of two of the perennial insect pests of sunflower in North America are provided below, with an emphasis on research conducted in the past ten to fifteen years; for brevity, references to the primary literature concerning their basic biology are omitted but well-summarized elsewhere (e.g., Charlet et al., 1997). Also reviewed are fly species in North and South America which have been particularly problematic over limited areas of their geographic ranges. Understanding the biology and research progress for these insects can help develop an approach to address insect problems with limited resources.

Sunflower moth, *Homoeosoma electellum* (Pyralidae). The sunflower moth is the most widespread and damaging sunflower insect in North America. Though it can be found in Mexico, throughout the U.S. and in southern Canada, larvae only successfully overwinter in areas with mild winter temperatures. Because there are several generations in southern parts of North America, there is a gradual migration of moths into the primary sunflower-producing U.S. states (North Dakota, South Dakota, Minnesota) and Canada. Adult moths are attracted to pollinating sunflowers, laying eggs among the florets. As larvae grow, they feed in succession on pollen, disk florets, and seeds. As in the closely related European sunflower moth (*Homoeosoma nebulella*), the host range of sunflower moth includes *Helianthus* as well as other genera of Asteraceae. In most areas, late planting is considered useful to limit the severity of sunflower moth infestation. Adult populations can be monitored using pheromone traps, which help determine if insecticides are needed and when any treatment should be applied. If high numbers of moths are present during bloom, two or three insecticide applications several days apart may be used.

Recent research has focused on better understanding the reasons for lower susceptibility to sunflower moth in wild sunflower and exploring *Helianthus* spp. germplasm for plants with reduced attractiveness or suitability to the moth. In general, because cultivated sunflowers are nutritionally superior for sunflower moth, larvae develop more quickly and find shelter from parasitoids within achenes (Chen and Welter, 2007). Some of the nutritional and morphological differences (e.g., size of florets and achenes) exploited by sunflower moth are produced by the crop environment (high nitrogen availability, synchronized flowering and low plant competition; Chen and Welter, 2005); this research emphasizes the need to incorporate native plant resistance into inbreds and hybrids, as changes to basic agronomic practices that significantly limit yield cannot be justified for improved sunflower moth control. Excluding crop environment effects, interspecific crosses, non-*annuus* species, and *H. annuus* accessions all show some resistance to sunflower moth (Whitney et al., 2006; Charlet et al., 2008; Mphosi and Foster, 2010). Though the causes of resistance in these sources is not yet understood, there appears to be potential for multiple types of resistance to be utilized, as the lines on which female moths deposited fewer eggs also tended to have lower survival of sunflower moth larvae (Mphosi and Foster, 2010). Table 1 provides recent data on potential damage from sunflower moth for commercial hybrids and germplasm being developed for insect resistance with and without conventional management practices.

Table 1. Sunflower moth damage in Kansas research plots and grower fields, 2010

Sunflower germplasm (n)	Plot type	Insect management	Damage (% ± SD)
Commercial hybrids (4)	Research	None	12.0 ± 8.5
Resistant testcrosses (10)	Research	None	3.6 ± 0.8
Commercial hybrids (7)	Grower fields	Late planting, insecticides	0.3 ± 0.5

1 In research plots, n=number of hybrids used as controls or top 25% of testcrosses. For grower fields, n=number of oilseed sunflower fields included in annual fall survey sponsored by National Sunflower Association.

Banded sunflower moth, *Cochylis hospes* (Tortricidae). As another moth whose larvae feed on sunflower florets and seeds, the banded sunflower moth is superficially similar to the sunflower moth. However, the two insects are from distinct families and significant differences exist between the species' distribution and life history. Banded sunflower moths are found throughout the U.S. and in Canada, but are most common and problematic in the northern extent of their range, particularly in North Dakota. Though multiple generations are possible in the southern U.S., only a single generation occurs in areas where banded sunflower moths are significant pests. Adult moths are attracted to sunflower heads prior to flowering, laying eggs on involucral bracts and the back of the head. Just after hatch, larvae are found on the bracts, but later move to feed on pollen, disk florets and seeds. Banded sunflower moths feed on several species of *Helianthus*. In some cases, apparent infestation by banded sunflower moth may actually be produced by the very similar but far less common Arthurs' sunflower moth (*Cochylis arthuri*). Management of banded sunflower moth relies on a combination of pest avoidance using late planting and insecticide application. Pheromone lures specific to banded sunflower moths are needed to monitor using traps, but procedures to scout for eggs or adults along with economic thresholds are also available. Timing of insecticide application for banded sunflower moth is important, and typically should be made prior to bloom at the late bud stage.

Alternatives to reliance on conventional insecticides have been a recent focus for research with banded sunflower moth. A variety of insect pathogens, including the bacterium *Bacillus thuringiensis* (hereafter *Bt*) have been tested for their potential to reduce banded sunflower moth damage when applied as biological insecticides. Commercial sprays of *Bt* in the field indicate that some formulations can provide similar results to conventional insecticides (Jyoti and Brewer, 1999); however, because the effectiveness of a given dose of *Bt* toxin declines as larvae mature, timing of applications is still likely a key to effective management of banded sunflower moth (Barker, 1998). Recent field trials show evidence for host plant resistance in *H. annuus* (Charlet et al., 2009), some of which appear to act though plant toxins or antifeedants (i.e., antibiosis) based on decreased larval survival and increased parasitism (Chirumamilla et al., 2009). Identification of compounds that act as oviposition stimulants for banded sunflower moth (Morris et al. 2005, 2009) also increase the likelihood that germplasm with decreased attractiveness to female moths can be identified or developed. Table 2 provides recent data on potential damage from banded sunflower moth for commercial hybrids and germplasm being developed for insect resistance with and without conventional management practices.

Table 2. Banded sunflower moth damage in North Dakota research plots and grower fields, 2010

Sunflower germplasm (n)	Plot type	Insect management	Damage (% ± SE)
Commercial hybrids (4)	Research	None	11.5 ± 5.0
Resistant testcrosses (14)	Research	None	5.4 ± 1.9
Commercial hybrids (69)	Grower fields	Late planting, insecticides	0.9 ± 2.8

1 In research plots, n=number of hybrids used as controls or top 25% of testcrosses. For grower fields, n=number of oilseed sunflower fields included in annual fall survey sponsored by National Sunflower Association.

Sunflower midge, *Contarinia schulzi* (Cecidomyiidae). Though sunflower midge is found from Canada south into Texas, its economic impact to sunflowers has generally been limited to Minnesota, North Dakota, and Manitoba. First described in 1972, in the northern part of its range the midge may have two generations with the first capable of causing significant damage. Adult flies emerging in the spring live only two to three days, but during this brief adult period, females mate and lay eggs, preferring to oviposit between bracts of heads. Larvae usually feed on bracts before moving into the head and feeding at the base of developing seeds. Feeding may produce symptoms of infestation that range from minor (some necrosis at base of bracts) to extreme (concave distortion of head with little or no seed produced). Early losses from sunflower midge ranged from 5–20% (Schulz, 1973), but even today may cause losses significant enough to discourage grower planting of sunflower in subsequent years. Management of sunflower midge is typically through cultural practices, including planting away from fields where sunflower was grown in the previous year and using several planting dates to avoid the short-lived adults. Because planting location and timing can have significant practical constraints, sunflowers may still be planted at locations and times where sunflower midge causes damage. In those cases, management options are limited; insecticide applications are only effective if perfectly timed with adult midge activity, and there are currently no simple methods to monitor for adults (e.g., pheromone traps). Partial resistance to midge injury though antibiosis, antixenosis and tolerance appears to exist in hybrid sunflower (Anderson and Brewer, 1991) and some inbreds appear nearly immune to sunflower midge (Crompton, 2004). Tolerance to the synthetic auxin 2,4-dichlorophenoxyacetic acid (2,4-D) has been shown to correlate with tolerance to midge (Brewer et al., 1994), as the distortion of heads may be caused by elevated levels of auxins produced in response to midge larval feeding.

Sunflower head fly (Mosquita del capítulo), *Melanagromyza minimoides* (Agromyzidae). The sunflower head fly has been found in the eastern U.S. (Ohio, Florida, Arkansas) where it feeds in the seed heads of at least seven genera of Asteraceae (Spencer and Steyskal, 1986), but is significant as a pest of sunflower in South America. The small adult flies can be seen in the field resting on the heads of sunflower, where females lay eggs within the disc florets. Larvae damage sunflower by feeding both on florets and developing seeds. Feeding by larvae produces visible symptoms, as damaged florets are darkened from drying prematurely. Damage has been reported as reaching 20-30% in Argentina and Uruguay (Ves Losada and Figueruelo, 2006; Zerbino, 1991). Sunflower head fly is most serious when sunflowers are planted late. Detailed observations during the 2005–2006 season in La Pampa, Argentina show increased severity of damage to plants flowering in late December (<5%), to January (6–12%) and February (12–18%), and regression of damage onto planting date indicated that planting date explained as much as 70% of variation in damage to selected hybrids (Ves Losada and Figueruelo, 2006). Insecticides are a management option, but concern over possible adverse effects on pollinators encourages timely planting where head fly causes significant losses. In areas where sunflower head fly is most problematic, some growers have resorted to using insecticide applications to prevent adults from laying eggs (Abelardo de la Vega, personal comunication).

DISCUSSION

Recent data on insect damage from grower fields (Tables 1–2) suggests that cultural and insecticide-based management can combine for effective insect control. However, when planting dates are constrained or insecticide applications are poorly-timed, high levels of damage (> 15%) make the need for more broadly-based management apparent. For future management of sunflower pests, transgenic insect-resistant sunflower (e.g., *Bt* sunflower) could provide a simple technology for growers to limit the severity of several insect pests. However, the transgenic approach to pest management has at least three significant limitations in sunflower. First, in North America, transgene escape from cultivated *H. annuus* into wild *Helianthus* spp. presents a risk of worsening problems with sunflowers as an agricultural weed (Snow et al., 2003). Second, in many parts of the world, including the European Union, low acceptance of *Bt* and other transgenic crops probably eliminates any gains from increased yields in transgenic insect-resistant sunflowers. Third, there is increasing evidence that reliance on transgenic insect-resistance (to the exclusion of other methods of pest management) may simply produce pests that overcome the transgenic resistance. These and other limitations have helped direct research towards native plant resistance traits in *Helianthus* spp. in the U.S. However, this method also presents significant challenges. The primary challenge of using host plant resistance in sunflower is that native defense traits are generally not as effective as insecticides or transgenic insect resistance (i.e., a single trait is not a standalone solution). Additionally, breeding for host plant resistance generally requires significant investment of resources which may be difficult to justify for a pest that causes severe damage, but only over a small geographic area (e.g., sunflower head fly). However, as noted for both sunflower moth and banded sunflower moth, there appear to be multiple resistance traits within *Helianthus* spp. which could be used in combination. To address resource limitations within the small community of entomologists and other professionals working on sunflower insects, a reasonable approach to insect problems includes the use of (i) existing sunflower defensive traits, (ii) interdisciplinary collaboration for more efficient screening and breeding, and (iii) international collaboration to work on insects that are closely related or share feeding behaviors.

The use of existing sunflower defenses seeks to maximize the value of useful traits already known and partially understood. For management of sunflower moth, there are two well-known plant defenses. The first is the phytomelanin (or "armor") layer in *Helianthus* spp. pericarps, which provides significant physical resistance to feeding (Rogers and Kreitner, 1983) and was first used against the European sunflower moth. The phytomelanin trait has dominant, single-gene inheritance (Johnson and Beard, 1977) and is present in many public breeding lines (Seiler et al., 1984), though the frequency of this trait in current sunflower hybrids is not known. Terpenoids (especially sesquiterpene lactones), secondary plant compounds found in sunflower glandular trichomes, are another plant defense against sunflower moth. Terpenoids on florets act as feeding deterrents or toxins (Rogers et al., 1987) and are most effective against young sunflower moth larvae. *Helianthus* spp. resistant to sunflower moth may have more glandular trichomes or high levels of specific terpenoids, but insect defense related to glandular trichomes has not been successfully incorporated into breeding lines of cultivated sunflower. The value of these traits for other insects is not clear, but they likely provide some protection; pericarp hardness (including the contribution of phytomelanin) is a physical defense that may be general, while tests with terpenoids have indicated feeding deterrence or toxicity to other insects not closely related to sunflower moth (Gershenzon et al., 1985). For other types of insects, including foliar-feeders, there are also plant defenses that show variation in sunflower germplasm (e.g., coumarins against sunflower beetle; Roseland and Grosz, 1997).

The production of insect resistant inbreds and hybrids is an interdisciplinary process, though the infrequent use of known insect defense traits suggests more collaboration is needed for efficient screening and breeding. Limitations to be addressed include difficulty in screening material for insect resistance (inconsistent pest pressure, labor-intensive evaluation of phenotypes) and transferring identified traits. Screening could be facilitated "by proxy," where the trait of interest (e.g., the concentration of a defensive compound) is quantified directly without the use of natural or artificial insect infestation. Across a suite of chemical or physical traits, botanists, chemists and others could reduce the amount of time and money needed to phenotype plants for resistance. Eventually direct assessment of insect damage to will be needed for validation, but even this can be made more efficient by the use of engineering (automated sample processing) or statistics (improved experimental design or sampling). Similarly, work with breeders and geneticists to develop markers for desired traits should greatly reduce the time and cost needed to produce hybrids with significant insect resistance.

Finally, though potential damage may be most significant in North America, the presence of insect pests outside sunflowers' native range suggests that exchange of information, techniques and germplasm could help improve management of pests. Such international collaboration could be based on similar feeding habits of sunflower insects or on close taxonomic relationships between pests. For example, efforts to use resistance for managing *Melanagromyza minimoides* could logically start by testing whether inbreds or hybrids resistant to other floret- and achene-feeding species found elsewhere (i.e., sunflower moth, banded sunflower moth) show any resistance to sunflower head fly. Alternatively, research in other crops with closely-related insects may be useful; work with pod fly, *Melanagromyza obtusa* (Agromyzidae), in pigeonpea indicates that plants with higher levels of phenols and tannins show some resistance (Moudgal et al., 2007), suggesting traits in cultivated sunflower germplasm that could limit damage by sunflower head fly.

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