Bionomics and Integrated Control of the Sunflower Seed Maggot, (*Neotephritis finalis*) and the Sunflower Bud Moth (*Suleima helianthana*) in the Northern Plains Sunflower Production Region: 2009 Results

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Executive Summary

In the past several years, sunflower producers, field scouts and seed companies have expressed concern about the injury to sunflower resulting in deformed and misshapen areas in the head. The head damage was unlike that caused by sunflower midge and was attributed to feeding injury caused by the sunflower seed maggot, *Neotephritis finalis* (Loew) (Fig. 1) and/or sunflower bud moth, *Suleima helianthana* (Riley) (Fig. 2). Although reported from a number of sources, the exact extent and economic loss from these insect pests are not known. Although sunflower seed maggot and sunflower bud moth have been reported in the literature as insect pests of sunflower, a better understanding of their economic impact and potentially useful pest management strategies is needed.

Figure 1. Head injury from sunflower seed maggot.

Figure 2. Head injury from sunflower sunflower bud moth.

This research determined the biology of sunflower seed maggot in North Dakota, and examined two different pest management strategies for control of sunflower seed maggot and sunflower bud moth in North Dakota:

1) Planting dates, and
2) Insecticide timing and insecticide mode of action.

Biology of Sunflower Seed Maggot: The bionomics of sunflower seed maggot was determined and findings are summarized in this report.

Planting Dates: Late planting date (early to mid-June) was effective in reducing the damage ratings and percentage of damaged heads for sunflower seed maggot at three of the five locations examined in 2009 in North Dakota. Overall, population densities of sunflower seed maggots were low in 2009 and decreased from previous years (source NSA Sunflower Survey) making damage assessments between early (early to late May) and late (early to mid-June) planting dates difficult. For sunflower seed maggot, the late planting date had a lower percentage of damaged heads than the early planting date at three of the five research sites examined. For sunflower bud moth, the late planting date also had a lower percentage of damage heads than the early planting date at two of the five research sites examined. However, sunflower bud moth also had very low population levels and was reported only in sporadic 'hot spots' in 2009. Yield differences were attributed to other agronomic factors or bird damage, and not due to head damage caused by sunflower seed maggot or sunflower bud moth.

Efficacy of Insecticide Timing and Mode of Action: Neither insecticide timing nor mode of action had any significant effect on the sunflower seed maggot damage ratings, nor the percentage of heads damaged from sunflower seed maggot or sunflower bud moth at any location. The lack of differences could be due to low population densities of adults or missed application timing. Therefore, future plans include the addition of insecticide applications at the R1 growth stage in addition to the R3 and R5 stages. For insecticide mode of action, the pyrethroid insecticide (Asana) and the organophosphate + pyrethroid insecticide (Cobalt) typically had higher yields than the organophosphate insecticide (Lorsban) alone. This is probably due to organophosphate insecticide having a shorter residual effect than pyrethroids. Given that the lowest yields were those treatments with insecticides applied at R3, yield differences are probably due to later (R5.1) infestations of other insect pests, like banded sunflower moth and/or red sunflower seed weevil. In conclusion, it was difficult to assess the insecticide efficacy and mode of action due to low population densities of adult insects. 2009 results indicate that there is no insecticide treatment correlation to damage assessment for sunflower seed maggot and sunflower bud moth and yield. Additional research is necessary to determine viable pest management strategies for control of sunflower seed maggot and sunflower bud moth.

Introduction

Sunflower (*Helianthus annuus* L.) is one of only a very few domesticated crops native to North America. It is commercially cultivated on a large scale in the United States in the northern Great Plains (North Dakota and South Dakota) and the southern High Plains (western Nebraska and Kansas, plus areas of Colorado and Texas) where the growing season is often too dry and/or too short for more profitable soybean and corn production (Tatta 2001). North Dakota ranked first in the United States for sunflower production in 2008, with 1,080,000 acres harvested (2009 National Agricultural Statistics Service).

Sunflowers are subject to attack by several insect species (Charlet et al. 1997). The major insect pests of sunflower in the northern Great Plains include banded sunflower moth (*Cochylis hospes* Walsingham), sunflower beetle (*Zygogrammma exclamationis* (Fabricius)), sunflower stem weevil (*Cylindrocopturus adsperus* (Le Conte)), red sunflower seed weevil (*Smicronyx fulvus* Le Conte), and sunflower midge (*Contarinia schulzi* Gagné) (Charlet et al. 1997). High insect pest densities have reduced yields and have led to reductions in acreage in some production areas. Among the insect species associated with sunflower, one of the most important and damaging pest groups is head-feeding insects (Arthur and Cambell 1979a, 1979b; Charlet et al. 1997).

The sunflower seed maggot (*Neotephritis finalis* (Loew)), can be a serious pest of sunflower and is distributed throughout North America. It ranges from southern Alberta to Manitoba south to Virginia and Georgia and west to California and into northern Mexico (Arthur and Campbell 1979b). In the early 1970s, the sunflower seed maggot was described as potentially the most destructive pest of sunflower seed in northern Georgia and was reported to infest plants throughout the growing season (Beckham and Tippins 1972). Recent field observations have revealed that sunflower seed maggot is widely distributed throughout North Dakota and can cause substantial damage to sunflower heads (annual NSA sunflower surveys). As such, knowledge about the biology of sunflower seed maggot and its natural enemies is important for developing and adopting pest management strategies.

Sunflower seed maggot is a polyphagous insect. It is reported to attack wild sunflowers and other species of the family Asteraceae (Goeden et al. 1987). Many of the hosts are members of the tribe Heliantheae. Other hosts include deltoid balsamroot (*Balsamorhiza deltoidea* Nutt.), bush encelia (*Encelia frutescens* (Gray) Gray), virgin river brittlebush (*Encelia virginensis* A. Nels.), California brittlebush (*Encelia californica* Nutt.), desert sunflower (*Geraea canescens* Torr. & Gray), slender sunflower (*Helianthus gracilentus* Gray), snowy sunflower (*Helianthus niveus* (Benth.) Brandeg.), triangle goldeneye (*Viguiera deltoidea* Gray), southern mule ears (*Wyethia ovata* Torr. & Gray ex Torr.), spiny aster (*Chloracantha spinosa* (Benth.) Nesom), arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), common woolly sunflower (*Eriophyllum lanatum* (Pursh Forbes), common gaillardia (*Gaillardia aristata* Pursh), coneflower helianthella (*Helianthella uniflora* (Nutt.) Torr. & Gray) and crownbeard (*Verbesina* sp.) (Goeden et al. 1987).

The biology and behavior of sunflower seed maggot in other parts of the United States and Canada were described by Kamali (1973), Goeden et al. (1987) and Arthur and Mason (1989). However, there are no detailed studies to date on the biology and pest management of this species in the northern Great Plains, especially North Dakota.

Sunflower bud moth has two generations per year in North Dakota (Knodel and Charlet 2007). Adults emerge from overwintering pupae from the last week of May to mid-June. A few days after adult emergence, eggs are deposited in leaf axils or on the terminals of immature sunflower or on the receptacles of mature sunflower (Michaud weblink). Newly emerged larvae begin tunneling into the sunflower plant. The larval infestation is characterized by an entrance hole surrounded by black frass (insect excrement). Mature larvae pupate within the sunflower plant. Pupae move to the opening of the entrance holes formed in the stem or head tissue so that adults can emerge easily. The second generation adults appear in July and August. Overall, little is known of its ecology.

Major economic losses are caused from bud moth larvae burrowing into unopened buds and preventing proper head development (Knodel and Charlet 2007). Larvae of the second generation typically do not cause economic yield loss because the head is already developed. The larvae normally do not feed on developing seeds but confine feeding activities to the fleshy part of the head. When plants are attacked in the early reproductive stages, flower buds are the preferred oviposition site and the entire head can be severely deformed and lost. Yield loss has not been correlated with population density or other agronomic factors, such as planting date. A field monitoring protocol and economic threshold for this insect has not been established. Insecticide use has generally not been recommended for control of sunflower bud moth, since the larvae feed internally in the stem, bud or head. Based on field reports from 2008, sunflower fields that were sprayed with rescue insecticides for control of bud moth were not efficacious (pers. comm., L. Olson, Ag Extension Agent, Grand Forks County). However, it is not known if a more well-timed insecticide spray targeted at the adult moth would be more effective.

Therefore, the current study was undertaken to assess pest management strategies for control of sunflower seed maggot and sunflower bud moth and to determine those strategies that offer potential to reduce damage and economic losses to sunflower production. Through a series of field studies, the potential of different management strategies including insecticides timing and mode of actions, and planting dates were investigated for control of sunflower seed maggot and sunflower bud moth.

Materials and Methods

Field and laboratory biological studies

In 2009, field studies of sunflower seed maggot biology were conducted at the NDSU Agricultural Research site near Prosper and at a cooperator site near Mapleton. Supplementary biological and behavioral observations were made in laboratories the NDSU Department of Entomology and USDA-ARS Northern Crop Science Laboratory in Fargo. Field studies were made on a 40 m x 40 m study plot from May through October. Sunflower seeds of Dekalb DKF 29-30 NS/DM were sown on 30 May 2009 using accepted agronomic practices.

Source of insects and plant materials: Adult seed maggots used in biological studies came from three sources: adults (male and female) were collected from the field using sweep nets, adults that emerged from puparia collected in the field, and adults that emerged from harvested mature sunflower heads in the laboratory. Two types of sunflower heads were used in tests: sunflower grown in the greenhouse and field collected heads, which were covered with specialized ventilated (Delnet ®) plastic bags at bud stage to avoid oviposition from other sunflower insect pests.

Biological studies: Males and females of seed maggot were kept in a 30 cm x 30 cm wooden cage with a glass top. The cage had a door for introducing plant materials and insects. Insects were fed a 10% sucrose solution. Mated females were exposed to excised sunflower heads, which were not infested with other insects. Cut ends of each sunflower stalk were placed in a water-filled glass flask. Heads were observed every day for the presence of eggs. Once the females started to lay eggs on a sunflower head, it was replaced with a new head.

Incubation period was studied under laboratory conditions (23 ± 2 C). Sunflower heads which were exposed to mated females were carefully observed under a light microscope for the presence of eggs. The number of eggs was counted and the sunflower head was kept in a small plastic container 12 cm in diameter and 10 cm in height with moist cotton to prevent it from drying. Eggs were observed daily until hatching. After recording the incubation period, larvae were allowed to develop on the same sunflower head. However, the old sunflower head was replaced with a new head if necessary. Larvae were observed daily until pupation to determine the length of the larval developmental period. After the puparia formed, puparia were removed from each sunflower head and kept on moist filter paper placed on a small covered glass dish to observe the pupal period. Subsamples of eggs (n = 4), larvae (n = 3) and pupae (n = 14) were measured to determine their respective sizes.

An attempt was made to determine the number of larval instars. Infested sunflower heads (mainly R3-R5 stages) were taken from the field and brought in to the laboratory. Heads were dissected under microscope and larvae were collected and preserved in 90% ethanol. Length of each larva was measured using a stage micrometer mounted on a light microscope.

In a separate experiment, newly emerged adult males (n = 20) and females (n = 20) were collected from rearing cages and from field-collected pupae and placed separately in rearing jars. A 10% sucrose solution was provided for food. Insects in the cages were monitored daily until all the insects died in order to determine the longevity of adults.

Pre-oviposition, oviposition, and post-oviposition periods were studied under laboratory conditions. Newly emerged adult males and females were collected from puparia. Batches of four males and one female were placed separately in seven rearing cages. Insects were fed with a 10% sucrose solution. An excised sunflower head, which was not infested with other insects, was placed in each cage. The cut end of each sunflower stalk was placed in a water-filled glass flask. Heads were observed every day for the presence of eggs. Heads were replaced with new heads as necessary. Once the females started to lay eggs, heads were destructively observed under a microscope in order to count the total number of eggs. In a separate experiment, five females were caged with ten males and exposed to sunflower heads to determine the fecundity of females.

Oviposition Choice Test: Sunflower plants were grown in the greenhouse under controlled conditions. Excised sunflower heads of R1, R2, R3, R4 and R5 growth stages were placed at a uniform height in a circular manner by positioning them in water-filled glass flasks in a 30 cm x 30 cm x 30 cm rearing cage. There were two separate experiments. For each cage, 10 mated females 20 days in age were introduced at 10:00 am. Heads were observed every day and the number of eggs on each head was counted.

Behavioral studies: Behavioral studies of resting, mating, and oviposition were observed in the field as well as in the laboratory. Focal animal sampling (observing one individual until the end of the desired behavior) (Martin and Bateson 1986) was used record these behaviors.

Overwintering strategy: During mid-October, twenty soil samples (size: 60cm x 60cm x23cm deep) were taken from sunflower field plots at Prosper. Soil samples were collected in plastic containers (40 cm diameter x 50 cm height). Soil samples were washed and examined for overwintering puparia. In a separate experiment, 25 adults were placed in a growth chamber where the temperature was changed gradually from 20^{o}C to 0^{o}C. Percent mortality was recorded.

Seasonal abundance – Trap Monitoring for Sunflower Seed Maggot

Eighteen yellow sticky traps (3x5 inches) were placed on nine galvanized poles (two traps per pole set up in 3 x 3 grid at the Prosper Agricultural Research site, at a producer's field near Mapleton, and at the Carrington Research Extension Center. The sunflower block used for trapping was insecticide-free and located near the planting date and insecticide efficacy studies at each site. Trap height was adjustable and traps were always positioned just above the plant canopy. Traps were monitored from VE plant stage (June) through plant maturity (September), and were replaced twice per week at Prosper and Mapleton and weekly at Carrington. Traps were brought to the laboratory for insect identification and counting. In the laboratory, traps were observed under a magnifying lens and the number of sunflower seed maggot on each trap was recorded. Date and plant stage also were recorded.

Impact of Planting Date

The purpose of this study was to determine if planting date has an effect on damage caused by sunflower seed maggot and sunflower bud moth. The study was conducted at the Prosper Agricultural Research site, at a producer's field near Mapleton, at the Carrington Research Extension Center, at the North Central Research Extension Center in Minot, and at the Langdon Research Extension Center.

Dekalb DKF29-30 NS/DM sunflower seed was planted in all locations. The two planting dates for each location are shown in Table 1. The trial was conducted in a randomized complete block design with six replications. Plots measured 25 m long by eight rows wide with 76 cm row spacing. Alley width between replications was 1.5 m and space between borders and plots was 3 m.

When sunflower reached the R7 stage, twenty heads from the four middle rows were randomly selected and rated for seed maggot damage using a 0-8 scale, with 0 having no damage and 8 having the most severe damage. Percentage of damaged heads was recorded for both sunflower seed maggot and sunflower bud moth by observing 100 plants at random in each plot. Finally, the four middle rows were harvested at maturity and yields were computed. Yields were adjusted to 10% moisture and are given in lbs/acre.

Table 1. Planting dates at all locations.

Location	Early Planting Date	Late Planting Date
Prosper	30 May 2009	15 June 2009
Mapleton	02 June 2009	15 June 2009
Carrington	29 May 2009	17 June 2009
Minot	28 May 2009	16 June 2009
Langdon	21 May 2009	04 June 2009

Efficacy of Insecticide Timing and Mode of Action

The purpose of this study was to evaluate the effect of insecticide application timing and insecticide mode of action on sunflower seed maggot and sunflower bud moth damage. The study was conducted at the Prosper Agricultural Research site, at a producer's field near Mapleton, at the Carrington Research Extension Center, and at the North Central Research Extension Center in Minot. Dekalb DKF29-30 NS/DM sunflower seed was used at all locations. Trials were planted on 30 May at Prosper, 2 June at Mapleton, 29 May at Carrington and 28 May at Minot. Plots were arranged in a randomized complete block design with four replications.

Plots were 7.6 m long by 8 rows wide with 76 cm row spacing. Alley width between replicates was 3 m and space between borders and plots was 3 m.

Treatments included an untreated check, and foliar applications of Asana XL (esfenvalerate, a pyrethroid) at 5.8 fl oz/acre, Lorsban (chlorpyrifos, an organophosphate) at 16 fl oz/acre and Cobalt (chlorpyrifos + gamma-cyhalothrin, organophosphate + pyrethroid) at 19 fl oz/acre. Treatments were applied at the R3 and R5.1 sunflower growth stages (Table 2).

Table 2. Insecticide application dates at all locations.

Location	R3 Application	R5 Application
Prosper	29 July 2009	10 August 2009
Mapleton	29 July 2009	10 August 2009
Carrington	04 August 2009	12 August 2009
Minot	01 August 2009	12 August 2009

When sunflower reached the R7 stage, twenty heads from the four middle rows were randomly selected and rated for seed maggot damage using a 0-8 scale. The percentage of damaged heads was recorded for sunflower seed maggot and sunflower bud moth by examining 100 plants at random in each plot. Finally, the four middle rows were harvested at maturity and plot yields were computed. Yields were adjusted to 10% moisture and are given in lbs/acre.

Statistical Analysis

Statistical analyses were performed in JMP 5.01 (SAS Institute Inc, 2002). For the planting date study, two planting dates were compared for seed maggot damage ratings as well as the percentage of damaged heads from sunflower seed maggot and sunflower bud moth and yield. For the insecticide timing study, application timing and mode of action were compared for seed maggot damage ratings, as well as the percentage of damaged heads from sunflower seed maggot and sunflower bud moth, and yield. The data were first tested for homogeneity of variance (O'Brien's test, $P<0.05$). When variances were homogeneous, an analysis of variance was used. When variances were heteroscedastic, data were transformed prior to analysis of variance. If transformations did not rectify problems with variances, Welch's ANOVA was used. When treatment effects were significant ($P<0.05$), the Tukey – Kramer HSD test was used to separate means ($P<0.05$).

Results and Discussion

Biological studies of Sunflower Seed Maggot

The adult sunflower seed maggot is a fly about 6 mm long and a wing span of approximately 7 mm. The wings have a brown lacelike appearance. Sexes are different in size with males is slightly smaller than females. Females can be distinguished from males by their abdomen. In females, the tip of the abdomen is pointed (Appendix A, Figure 1) while in males it is rounded (Appendix A, Figure 2). In the field, adult maggots were observed on sunflower heads either resting, mating, or probing the heads for oviposition during the day. Behavioral experiments in the laboratory also showed that oviposition is a daytime behavior. Mating was observed in nature as well as in the laboratory. In the field, mating was observed from 7:45 am to 10:20 am (n = 8). In the laboratory, it was observed from 2:30 pm to 3:45 pm. Mating lasted from about 10 min to 5 hours (n = 8) with multiple matings occurring in a single day. Ovipositor probing was observed from about 11:00am to noon. However, the process of oviposition was not observed.

As reported by Arthur and Mason (1989), female seed maggots were observed to oviposit on all developing stages of sunflower heads (R1-R6). Like several other tephritids, the pre-oviposition period of sunflower seed maggot is considerably long with an average of 19 days under laboratory conditions. Eggs are laid either singly or in small groups containing four to five eggs. Under laboratory conditions, eggs were deposited on sunflower heads usually in the corolla of the inflorescence. Arthur and Mason (1989) observed that females lay eggs between two bracts near the point of separation in the bud stage of sunflower. Eggs are elongate, tapered at both ends, and white in color. They are about 1.2 mm long. One end has a nipple like projection, and the other end is rounded (Appendix A, Figure 3). Eggs hatched 4 days after oviposition (n = 17). A female during her lifespan produces 20-30 eggs with an average of 27 during her 20 day oviposition period.

Measurements of larval length clearly indicated that sunflower seed maggot has three larval instars. First instar larvae are white in color with dark brown mandibles. The body of the second instar larvae also is white in color with brown to black mandibles. The third instar larvae are creamy white in color (Appendix A, Figure 4). Mandibles are uniformly black. Total larval period ranged from 14-16 days (n = 15).

Larvae pupated in the puparium in developing sunflower heads. The puparium (Appendix A, Figure 5) is barrel shaped, brown in color and about 4 mm long (n = 14). The total development period of the pupae ranged from 8-9 days (n = 12). In this study, it was observed that development from eggs to adult emergence takes about 26-29 days. The longevity of the adults ranged from 64-87 days with an average of 78 days.

Observations during 2008-2009 indicated that only a few puparia were found in a given sunflower head even though many larvae were found in the same head. The maximum number of puparia found in a single head for all locations was four. This indicates that unknown larval mortality occurs during its development period. One pupal parasitoid was observed from field-collected pupal cocoons. It was identified as *Pteromalus* sp. (Hymenoptera: Pteromalidae). Percent parasitism ranged from 50-90% in four separate collections (n = 24).

It is reported that sunflower seed maggots overwinteras puparia in the soil. Therefore, soil sampling was conducted in the fall of 2009 to test this finding. Although some puparia (n = 4) were found in the soil, results were inconclusive and further research needs to be conducted.

Seasonal abundance – Trap Monitoring for Sunflower Seed Maggot

Sunflower seed maggot is a multivoltine pest in southern California and adults are present throughout the year (Goeden et al 1987). However, sunflower seed maggot appears to be a bivoltine pest in the northern Great Plains region. Sampling with yellow sticky traps indicated that sunflower seed maggot has two complete generations per year in North Dakota. Adults of the first generation began to emerge during the last week of June when plants were at V-12 to R1 stage, and the second generation began to emerge toward the end of the August. Adults of the second generation are more active on late blooming sunflower. At Prosper and Mapleton, first generation adults peaked on 23 Jul and second generation adults peaked on 27 Aug (Figure 3). At Carrington, the first generation adults had an extended peak from 9 Jul through 30 Jul. Second generation adults at Carrington peaked from 20 Aug through 27 Aug (Figure 4).

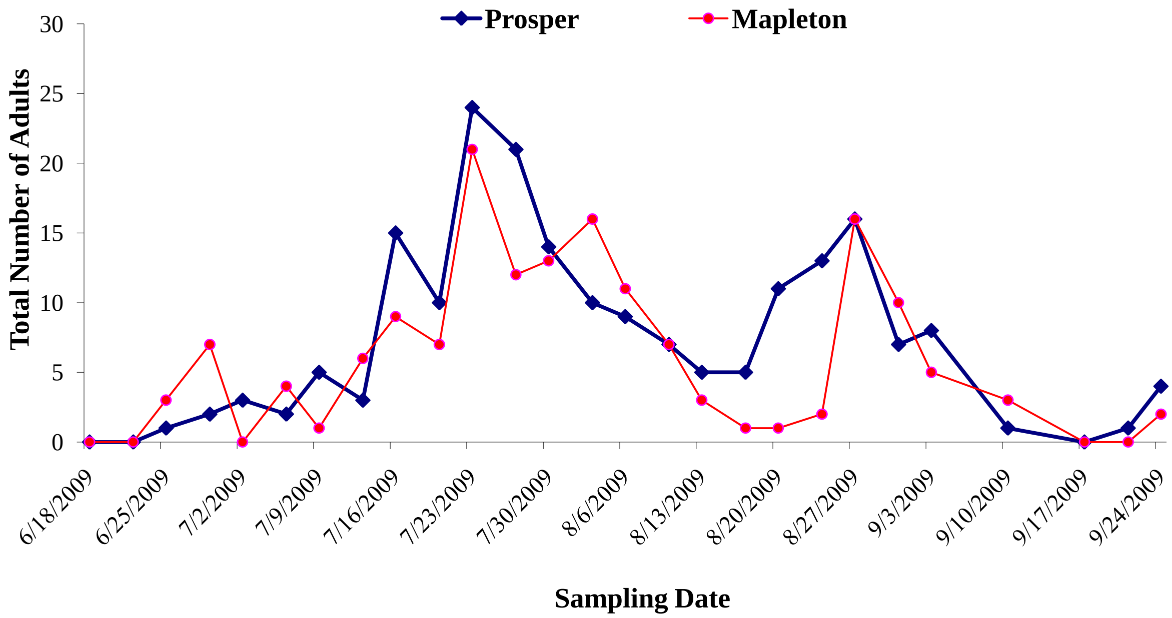

Figure 3. Flight period of sunflower seed maggot at Prosper and Mapleton, 2009.

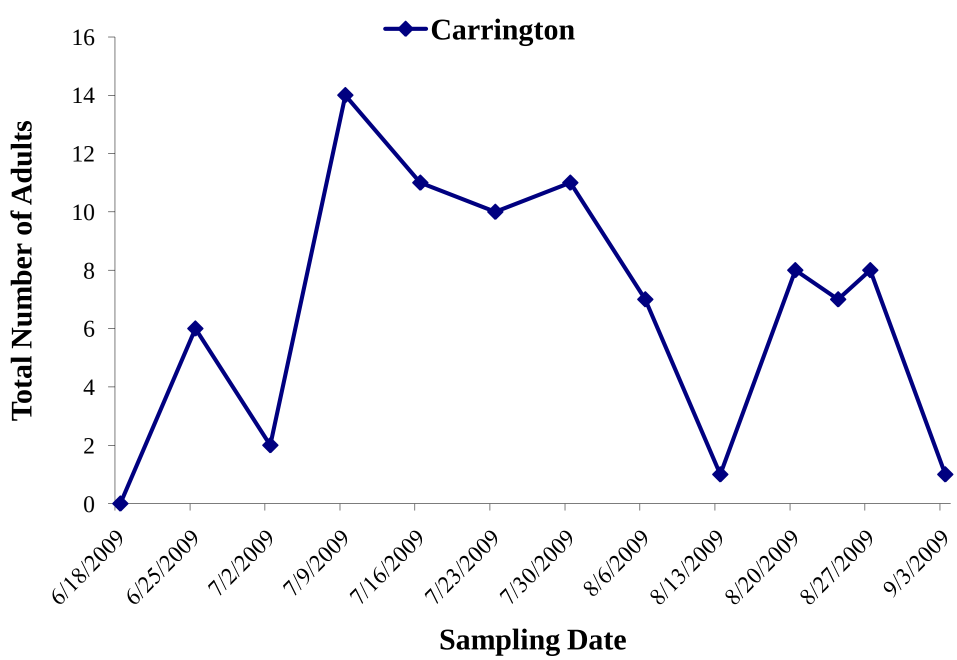

Figure 4. Flight period of sunflower seed maggot at Carrington, 2009.

Planting Date Studies

Planting date studies with other sunflower pests, such as banded sunflower moth, sunflower stem weevil, sunflower moth, sunflower midge, and sunflower beetle have demonstrated that delayed planting is effective in reducing damage (Oseto et al. 1982, 1987, 1989, Charlet 1998, Charlet 1999, Charlet and Knodel 2003). Planting date treatment mean damage ratings for sunflower seed maggot at each location are presented in Table 3 and Figure 5. Data indicated that there were no significant differences in damage ratings between the two planting dates at Prosper ($F_{1,238}$ = 0.08, P = 0.76) and Mapleton ($F_{1,238}$ = 1.35, P = 0.24). However, planting date had a significant effect on damage ratings at Carrington ($F_{1,238}$ = 15.19, P = 0.0001), Minot ($F_{1,238}$ = 6.67, P = 0.01) and Langdon ($F_{1,238}$ = 7.02, P = 0.0086).

Table 3. Planting date treatment means and standard errors for sunflower seed maggot damage rating at each location, 2009.

Treatment	**Location**				
	Prosper	**Mapleton**	**Carrington**	**Minot**	**Langdon**
Early	0.35 ±0.10	0.40 ± 0.08	0.41 ± 0.10*	0.31 ± 0.10*	0.22 ± 0.08*
Late	0.30 ± 0.09	0.25 ± 0.10	0	0.03 ± 0.03	0

****Significant at P ≤ 0.05.***

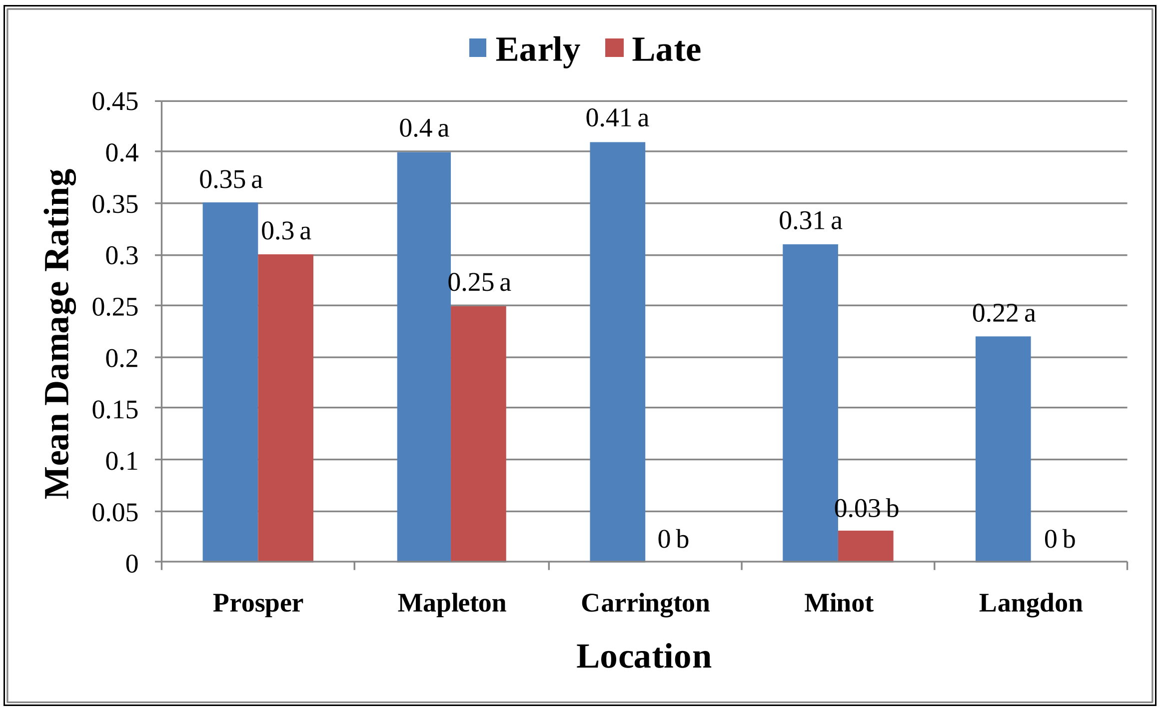

Figure 5. Planting date treatment means for sunflower seed maggot damage rating at each location, 2009. Means at each location with the same letter are not significantly different (P ≤ 0.05).

Planting date treatment means for the percentage of damaged heads from sunflower seed maggot is presented in Table 4 and Figure 6 for each location. Data indicated that percent damage incidence was not significant for planting date at Prosper ($F_{1,10}$ = 1.15, P = 0.30) and Mapleton ($F_{1,10}$ = 4.60, P = 0.06). However, planting date did have a significant effect on the percentage of damaged heads at Carrington ($F_{1,10}$ = 11.09, P = 0.007), Minot ($F_{1,10}$ = 5.86, P = 0.03) and Langdon ($F_{1,10}$ = 5.88, P = 0.03).

Table 4. Planting date treatment means and standard errors for the percentage of damaged heads from sunflower seed maggot at each location, 2009.

Treatment	**Location**				
	Carrington	**Langdon**	**Mapleton**	**Minot**	**Prosper**
Early	7.16 ± 2.15*	6.5 ± 1.84*	10.00 ± 2.33	4.5 ± 1.70*	14.55 ± 2.44
Late	0	0.16 ± 0.16	5.66 ± 1.50	0.33 ± 0.21	11.33 ± 1.64

Significant at P ≤ 0.05.

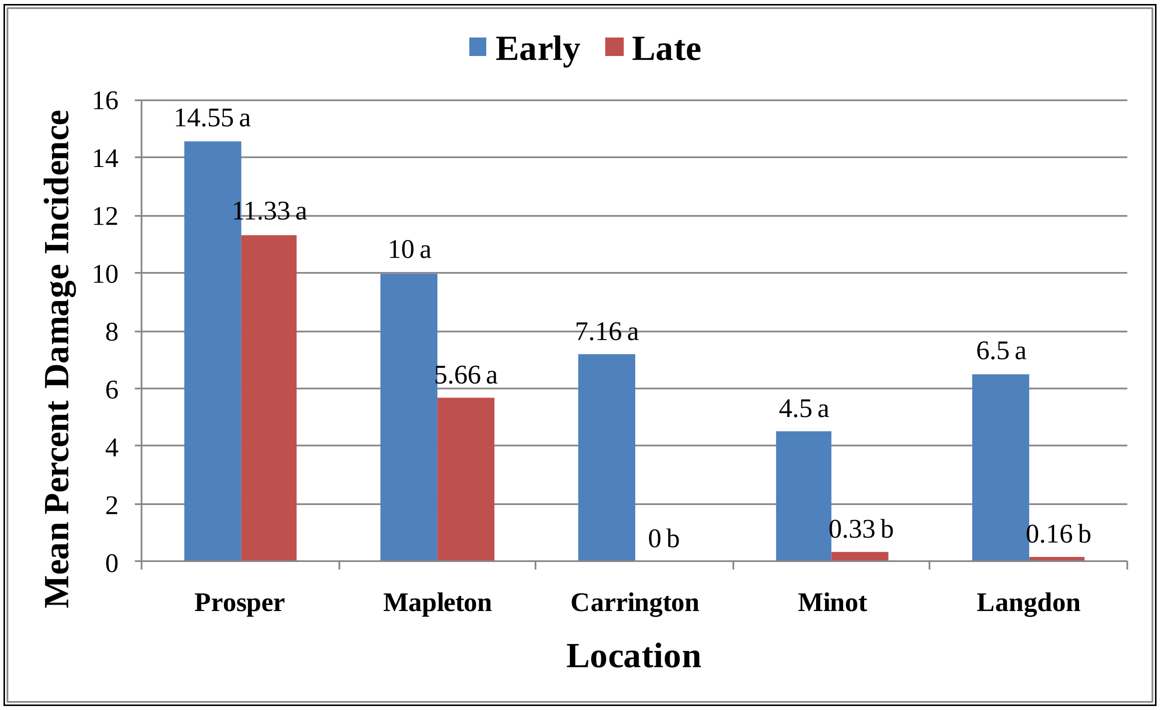

Figure 6. Planting date treatment means for the percentage of damaged heads from sunflower seed maggot at each location, 2009. Means at each location with the same letter are not significantly different (P ≤ 0.05).

Planting date means for the percentage of damaged heads from sunflower bud moth is presented in Table 5 and Figure 7 for each location. There were no significant differences between planting dates at Prosper (F = 4.95, P = 0.08), Minot (F = 3.91, P = 0.11) and Langdon (F = 2.21, P = 0.20). Planting date had a significant effect at Mapleton (F = 19.86, P = 0.001) and Carrington (F = 9.76, P = 0.03).

Table 5. Treatment means and standard errors for the percentage of damaged heads from sunflower bud moth at each location, 2009.

	Location				
Treatment	**Prosper**	**Mapleton**	**Carrington**	**Minot**	**Langdon**
Early	1.67 ± 1.51	11.67 ± 6.83*	3.17 ± 2.48*	1.83 ± 1.83	3.33 ± 5.24
Late	5.00 ± 3.95	4.67 ± 3.78	0.00 ± 0.00	0.17 ± 0.41	0.33 ± 0.52

Significant at $P \leq 0.05$.

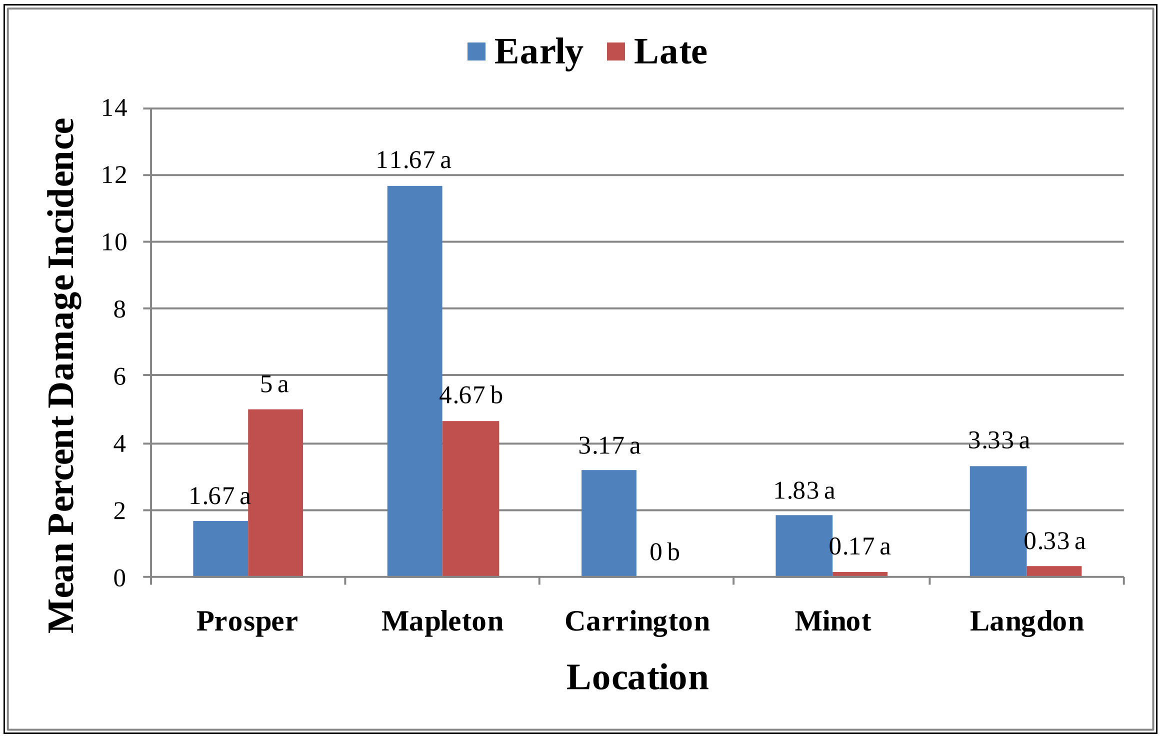

Figure 7. Planting date treatment means for the percentage of damaged heads from sunflower bud moth at each location, 2009. Means at each location with the same letter are not significantly different ($P \leq 0.05$).

Yields for Prosper, Mapleton, Minot and Langdon are presented in Table 6. At Prosper, the early planting date had significantly higher yield than the late planting date (F = 10.22, P = 0.24). At Mapleton, there was no significant difference for yield between planting dates (F = 0.88, P = 0.39). At Minot, there was no significant difference for yield between planting dates (F = 0.49, P = 0.51). At Langdon, the early planting date had significantly higher yield than the late planting date (F = 27.11, P = 0.003). Any yield differences were attributed to other agronomic factors and not due to seed maggot or bud moth insect problems. Planting date study plots at Carrington were inadvertently harvested without measuring yield.

Table 6. Planting date treatment means for yield (lbs/acre) at Prosper, Minot and Langdon, 2009.

Treatment	Location			
	Prosper	**Mapleton**	**Minot**	**Langdon**
Early	3032.9 a	2620.6 a	610.4 a	2429.2 a
Late	2535.1 b	2382.0 a	694.1 a	1942.1 b
LSD	***400.4***	***654.5***	***306.3***	***240.5***
CV	***9.7***	***17.6***	***31.6***	***7.4***
Grand Mean	***2784.0***	***2501.3***	***652.3***	***2185.6***

Means within a column sharing the same letter are not significantly different ($P \leq 0.05$).

Efficacy of Insecticide Timing and Mode of Action

Neither insecticide timing nor insecticide mode of action had any significant effect on sunflower seed maggot damage ratings or the percentage of damaged heads from sunflower seed maggot or bud moth at any location (Tables 7-10). The lack of differences could be due to low population densities of adults or missed application timing. Therefore, future plans include adding an insecticide application at the R1 growth stage in addition to the R3 and R5 stages.

Table 7. Statistical values for sunflower seed maggot damage ratings, the percentage of damaged heads from sunflower seed maggot and sunflower bud moth for insecticide timing at Prosper, Mapleton, Carrington and Minot, 2009.

Location	Sunflower Seed Maggot Damage Rating		Sunflower Seed Maggot Percent of Damaged Head		Sunflower Bud Moth Percent of Damaged Head	
Prosper	F = 0.57	P = 0.75	F = 1.21	0.33	F = 0.66	P = 0.68
Mapleton	F = 0.26	P =0.95	F = 0.48	0.81	F = 0.41	P = 0.86
Carrington	F = 1.24	P = 0.28	F = 0.64	0.69	F = 1.51	P = 0.23
Minot	F = 1.29	P = 0.25	F = 0.52	0.77	F = 0.57	P = 0.75

Table 8. Treatment means and standard errors for sunflower seed maggot damage ratings for insecticide timing at Prosper, Mapleton, Carrington and Minot, 2009.

	Location			
Treatment and Timing	**Prosper**	**Mapleton**	**Carrington**	**Minot**
Asana XL R3	0.36 ± 0.13	0.32 ± 0.17	0.20 ± 0.10	0.13 ± 0.09
Asana XL R5.1	0.43 ± 0.13	0.36 ± 0.16	0.20 ± 0.07	0.38 ± 0.17
Cobalt R3	0.57 ± 0.15	0.41 ± 0.17	0.10 ± 0.10	0.56 ± 0.28
Cobalt R5.1	0.51 ± 0.14	0.18 ± 0.11	0.43 ± 0.14	0.26 ± 0.13
Lorsban R3	0.42 ± 0.12	0.28 ± 0.13	0.05 ± 0.03	0.11 ± 0.05
Lorsban R5.1	0.67 ± 0.17	0.23 ± 0.13	0.28 ± 0.12	0.13 ± 0.06
Untreated check	0.63 ± 0.18	0.37 ± 0.16	0.30 ± 0.11	0.45 ± 0.15

Table 9. Treatment means and standard errors for the percentage of damaged heads from sunflower seed maggot for insecticide timing at Prosper, Mapleton, Carrington and Minot, 2009.

Treatment and Timing	Location			
	Prosper	Mapleton	Carrington	Minot
Asana XL R3	10.75 ± 1.43	6.00 ± 1.77	4.25 ± 2.65	2.50 ± 1.25
Asana XL R5.1	13.25 ± 2.28	8.75 ± 2.88	4.75 ± 2.85	4.50 ± 2.32
Cobalt R3	12.25 ± 1.25	3.50 ± 2.55	10.50 ± 5.72	5.75 ± 1.43
Cobalt R5.1	19.00 ± 5.80	6.75 ± 1.31	7.75 ± 2.80	5.25 ± 2.62
Lorsban R3	9.50 ± 1.70	5.75 ± 3.90	9.50 ± 5.96	3.75 ± 1.31
Lorsban R5.1	12.75 ± 2.42	5.00 ± 1.22	4.50 ± 2.25	6.50 ± 1.91
Untreated check	10.25 ± 2.39	6.00 ± 1.08	2.50 ± 1.32	6.50 ± 2.75

Table 10. Treatment means and standard errors for the percentage of damaged heads from sunflower bud moth at Prosper, Mapleton, Carrington and Minot, 2009.

Treatment and Timing	Location			
	Prosper	Mapleton	Carrington	Minot
Asana XL at R3	5.25 ± 4.35	6.00 ± 3.56	3.50 ± 1.73	2.25 ± 2.63
Asana XL at R5.1	3.25 ± 2.75	8.75 ± 5.62	4.50 ± 2.65	1.00 ± 2.00
Cobalt at R3	5.25 ± 5.12	3.50 ± 5.07	4.25 ± 1.26	2.00 ± 2.83
Cobalt at R5.1	3.25 ± 5.85	6.75 ± 2.63	4.75 ± 0.96	1.00 ± 1.41
Lorsban at R3	4.50 ± 1.91	6.75 ± 9.74	7.00 ± 2.94	2.00 ± 2.45
Lorsban at R5.1	2.75 ± 3.59	5.00 ± 2.45	4.75 ± 1.89	0.75 ± 1.50
Untreated Check	1.75 ± 0.96	6.00 ± 2.16	6.25 ± 1.71	1.50 ± 3.00

Yield data for the 2009 insecticide timing study are presented in Table 11. At Prosper, there were no significant differences among treatments ($F = 0.42$, $P = 0.85$). Yield data for Mapleton indicated significant differences among treatments ($F = 3.59$, $P = 0.02$). Asana XL at R5.1 had significantly greater yield than all other treatments except Cobalt at R5.1. Asana XL at R3 and Cobalt at R3, were not significantly different from each other or the untreated check, but had significantly lower yield than Asana XL at R5.1 and Cobalt at R5.1. Lorsban at R3 and Lorsban at R5.1 were not significantly different from each other or the untreated check. There appears to be no correlation between insecticide treatment timing and seed maggot/bud moth damage assessments. Given that the lowest yields were those treatments with insecticides applied at R3, yield differences are probably due to later (R5.1) infestation of other insect pests, like banded sunflower moth and/or red sunflower seed weevil. Yield data from Carrington also indicated significant differences among treatments ($F = 9.68$, $P < 0.0001$). Lorsban at R3 and the untreated check had significantly lower yield than all other treatments, and were not significantly different from each other. There were no other significant differences among treatments. The difference in yield of Lorsban at R3 compared to other treatments is probably due to mode of action. Organophosphate insecticides do not have as long of a residual effect as pyrethroids. Again, there appears to be no correlation between insecticide timing and seed maggot/bud moth damage assessments. At Minot, the ANOVA for yield was not significant ($F = 1.85$, $P = 0.145$). Post-hoc treatment mean comparisons showed that Lorsban at R3 had significantly lower yield than Asana XL at R3, the untreated check, and Lorsban at R5.1.

Table 11. Treatment means for yield (lbs/acre) for insecticide timing study at Prosper, Mapleton, Carrington and Minot, 2009.

Treatment and Timing	Location			
	Prosper	Mapleton	Carrington	Minot
Asana XL R3	2912.2 a	2681.6 c	630.5 a	1574.0 a
Asana XL R5.1	2933.0 a	3217.9 a	640.7 a	1410.2 ab
Cobalt R3	2883.9 a	2585.6 c	688.9 a	1510.8 ab
Cobalt R5.1	2970.9 a	3034.4 ab	681.7 a	1548.2 ab
Lorsban R3	2896.8 a	2692.0 bc	482.2 b	1255.4 b
Lorsban R5.1	2844.0 a	2840.7 bc	600.0 a	1695.7 a
Untreated Chk	2813.7 a	2857.4 bc	433.3 b	1623.4 a
LSD	**241.33**	**346.27**	**94.3**	**318.11**
CV	**5.6**	**8.2**	**10.7**	**14.1**
Grand Mean	**2893.5**	**2844.2**	**593.9**	**1516.8**

Means within a column with the same letter are not significantly different ($P \leq 0.05$).

Conclusion

The biology of sunflower seed maggot is described in detail. Studies during 2009 indicated that delayed planting date can be an effective way to mitigate head damage from sunflower seed maggot and sunflower bud moth. It was difficult to assess the insecticide efficacy and insecticide mode of action study due to low population densities of adult sunflower seed maggots and sunflower bud moth or a missed application timing of insecticides. Results from the 2009 NSA Sunflower Survey showed that damage from the sunflower seed maggot and sunflower bud moth have decreased from previous years, in spite of some localized 'hot spots' of moderate-severe infestations. Since little is known of the biology of these insects, the recent observations of low population densities may be due to unknown larval mortality, pupal parasitoids, low fecundity and/or environmental conditions. Additional research is needed to determine viable pest management strategies for control of sunflower seed maggot and sunflower bud moth if they become problems in the future.

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Appendix A. Images of sunflower seed maggot life stages.

Figure: 1. Sunflower seed maggot female (Pointed abdomen tip)

Figure: 2. Sunflower seed maggot male (Rounded abdomen tip)

Figure: 3. Sunflower seed maggoteggs

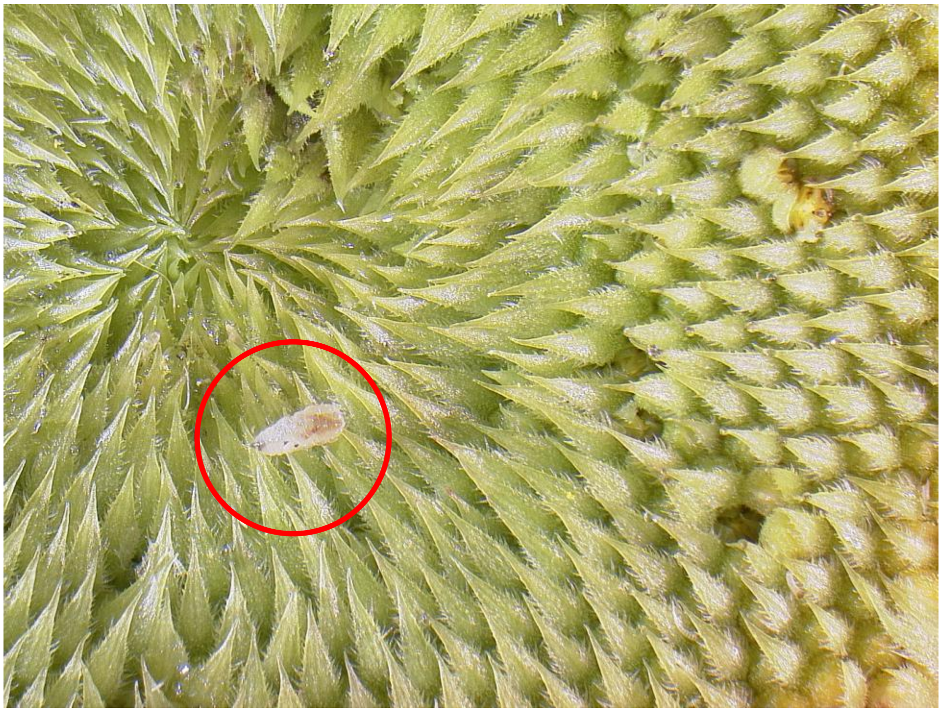

Figure: 4. Sunflower seed maggot, mature larva.

Figure: 5. Sunflower seed maggot puparia.