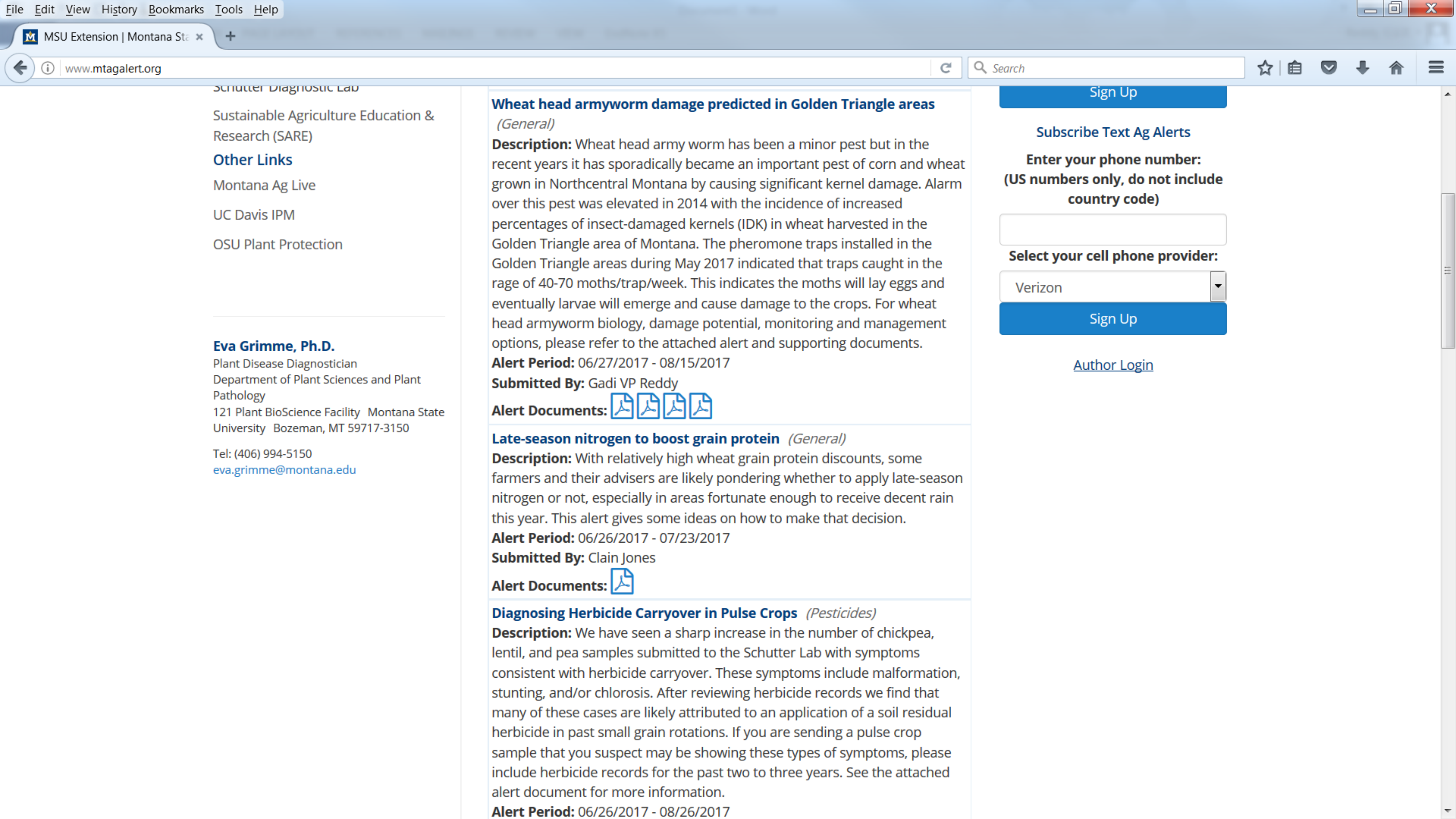

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Eva Grimme, Ph.D.
Plant Disease Diagnostician
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Wheat head armyworm damage predicted in Golden Triangle areas *(General)*

Description: Wheat head army worm has been a minor pest but in the recent years it has sporadically became an important pest of corn and wheat grown in Northcentral Montana by causing significant kernel damage. Alarm over this pest was elevated in 2014 with the incidence of increased percentages of insect-damaged kernels (IDK) in wheat harvested in the Golden Triangle area of Montana. The pheromone traps installed in the Golden Triangle areas during May 2017 indicated that traps caught in the rage of 40-70 moths/trap/week. This indicates the moths will lay eggs and eventually larvae will emerge and cause damage to the crops. For wheat head armyworm biology, damage potential, monitoring and management options, please refer to the attached alert and supporting documents.
Alert Period: 06/27/2017 - 08/15/2017
Submitted By: Gadi VP Reddy
Alert Documents:

Late-season nitrogen to boost grain protein *(General)*

Description: With relatively high wheat grain protein discounts, some farmers and their advisers are likely pondering whether to apply late-season nitrogen or not, especially in areas fortunate enough to receive decent rain this year. This alert gives some ideas on how to make that decision.
Alert Period: 06/26/2017 - 07/23/2017
Submitted By: Clain Jones
Alert Documents:

Diagnosing Herbicide Carryover in Pulse Crops *(Pesticides)*

Description: We have seen a sharp increase in the number of chickpea, lentil, and pea samples submitted to the Schutter Lab with symptoms consistent with herbicide carryover. These symptoms include malformation, stunting, and/or chlorosis. After reviewing herbicide records we find that many of these cases are likely attributed to an application of a soil residual herbicide in past small grain rotations. If you are sending a pulse crop sample that you suspect may be showing these types of symptoms, please include herbicide records for the past two to three years. See the attached alert document for more information.
Alert Period: 06/26/2017 - 08/26/2017

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MONTANA STATE UNIVERSITY
College of AGRICULTURE & MONTANA AGRICULTURAL EXPERIMENT STATION

Western Triangle Agricultural Research Center
9546 Old Shelby Rd., PO Box 656, Conrad, MT 59425
Tel. (406) 278-7707; Fax (406) 278-7797
http://agresearch.montana.edu/wtarc/

Tuesday, June 27, 2017

Wheat head armyworm damage predicted in Golden Triangle areas

Gadi V.P. Reddy
Western Triangle Agricultural Research Center, Montana State University, 9546 Old Shelby Rd., P. O. Box 656, Conrad, MT 59425, email: reddy@montana.edu

Wheat head army worm (*Dargida diffusa*) has been a minor pest but in the recent years it has sporadically became an important pest of corn and wheat grown in Northcentral Montana by causing significant kernel damage. Alarm over this pest was elevated in 2014 with the incidence of increased percentages of insect-damaged kernels (IDK) in wheat harvested in the Golden Triangle area of Montana (Reddy and Frank 2014). The pheromone traps (four traps/location, baited with a combination of the sex attractant compounds Z11-16Ac and Z11-16Ald) were installed in the Golden Triangle areas (Dutton, Brady, Shelby and Valier/Conrad) during May 2017. Overall, traps caught in the rage of 40-70 moths/trap/week. This indicates the moths will lay eggs and eventually larvae will emerge and cause damage to the crops.

There are currently no integrated pest management thresholds or recommended treatments for this pest due to its sporadic late season appearance (Peairs et al. 2010). The use of pheromone baited traps are limited to monitoring, and control is based on use of insecticides, despite the fact such applications may not be labeled for use near harvest. Growers are urged to read and follow the label prior to any application of insecticides.

The pheromone traps in the winter wheat field at WTARC, Conrad.

For wheat head armyworm biology, damage potential, monitoring and management options, please refer to the attached alert documents. The growers with the problem of wheat head armyworm are advised to contact, Gadi VP Reddy or Debra Miller at 406-278-7707 or email (reddy@montana.edu/debra.miller13@montana.edu)

References

Peairs, F.B., Hein, G.L., Brewer, M.J., 2010. High Plains Integrated Pest Manage-ment: Wheat Head Armyworm, http://wiki.bugwood.org/HPIPM:Wheat HeadArmyworm.

Reddy, G.V.P**.** and F.B. Antwi. 2016. Toxicity of natural insecticides on the larvae of wheat head armyworm, *Dargida diffusa* (Lepidoptera: Noctuidae). *Environmental Toxicology and Pharmacology* 42: 156–162.

Author: Frank B. Peairs[1] (http://www.colostate.edu/Depts/bspm/people/faculty indiv/peairs.html), Gary L. Hein & Michael J. Brewer

Identification (and life cycle/seasonal history)

Wheat head armyworm larvae, *Faronta diffusa* (Walker), are grayish or greenish gray caterpillars with distinct white, green, and brown lateral stripes. They are distinguished from other armyworms by a relatively larger head with two straight dark bands over the top, and a slender body. The worms hide around the base of the plants during the day. The adult moth has a dark streak running the length of the forewing. The dark streak is interrupted near the middle of the wing and then continues to the outer wing margin.

This insect spends the winter as a pupa in the soil. Moths emerge to lay eggs in the spring, and larvae can be found in wheat by June. There are two generations of wheat head armyworm per year in northern regions. A second moth flight occurs in late August.

Plant Response and Damage

First generation wheat head armyworm larvae feed on foliage, and later feed on the ripening seed head. They feed on a variety of grasses and cereal crops and seem to prefer the heads. Timothy is considered to be a preferred host. Damage to wheat kernels is similar in appearance to damage by stored grain weevils, with kernels appearing hollowed out.

Management Approaches

No chemical control data or economic threshold studies are available for this insect. Infestations are often limited to field margins. If an outbreak were to occur, the insecticide listed for armyworm (see Armyworm chapter) (/HPIPM:Small_Grains_Armyworm) should be effective against this insect.

This page was last modified 20:15, 8 April 2016 by Bilal Bush (/User:Bkbush). Based on work by Frank Peairs (/index.php?title=User:Fbpeairs&action=edit&redlink=1) and Allison Tiffany (/index.php?title=User:Trebeltrouble&action=edit&redlink=1) and others (/index.php?title=HPIPM:Wheat_Head_Armyworm&action=credits).

(http://www.bugwood.org)

A PACIFIC NORTHWEST EXTENSION PUBLICATION

Washington State University
Oregon State University
University of Idaho

INTEGRATED PEST MANAGEMENT FOR THE WHEAT HEAD ARMYWORM COMPLEX IN THE PACIFIC NORTHWEST

By
Diana Roberts, Professor and Regional Extension Specialist, WSU Extension, **Silvia I. Rondon,** Professor and Extension Entomologist, Oregon State University Extension, **Peter J. Landolt,** Entomologist, USDA ARS.

PNW PEER REVIEWED
PNW696

Integrated Pest Management for the Wheat Head Armyworm Complex in the Pacific Northwest

Abstract

The wheat head armyworm complex (WHAC) is comprised of two armyworm species, *Dargida diffusa* (Walker) and *Dargida terrapictalis* (Buckett), which caused recent, intermittent damage to cereal crops in the Pacific Northwest (PNW). This was the first record of *D. diffusa* as a pest in the PNW. While *D. terrapictalis* is native to the region, it has not been recorded previously as a pest.

This publication covers identification, biology, and integrated pest management for WHAC. We emphasize pest monitoring and field scouting methods, and also discuss natural insecticides.

Introduction

The wheat head armyworm complex is comprised of two armyworm species, *Dargida diffusa* (Walker) and *Dargida terrapictalis* (Buckett), which caused recent and sporadic damage to cereal crops in the Pacific Northwest (PNW). Genetic sequencing studies indicated that the two species are closely related. For this reason, we refer to them as the wheat head armyworm complex (WHAC).

Idaho first reported WHAC damage in 2005 in Bonneville County. The same species were responsible for damaged grain at harvest in Lincoln County, Washington, in 2007 (Figure 1). An infestation of WHAC in 2008, also between Reardan and Davenport, resulted in 10,000 acres of grain being sprayed with insecticide. The WHAC also caused crop damage in Umatilla County, Oregon, in 2007.

Researchers noted a 35% yield loss due to the insect in 2007 and 2008 in spring wheat trials conducted by Washington State University (WSU) near Davenport, Washington. These losses were likely intensified by the variety trials being located away from commercial fields; moths hatching from pupae in surrounding fallow ground congregated on the nearest green plants (Roberts 2008, 2009a, and 2009b).

Following the initial occurrences, crop damage was not seen for several years, although adult moths of WHAC were found in pheromone (sex attractants specific to the species involved) traps across eastern Washington and Umatilla County, Oregon (Landolt et al. 2011). Outbreaks occurred in the lower Columbia Basin (Oregon) in 2012 and 2014. In 2013 and 2014, WHAC infested about 10,000 acres of cereal grains near Edwall, Washington. This area is south of the portion of Lincoln County that was affected previously.

It is unclear why the pest has occurred in certain areas but not others. No-till (direct seed) farming has been blamed in Lincoln County, Washington. However, where the pest was found in Umatilla County, Oregon, farmers used a mix of conventional and minimum tillage. The outbreak in Bonnevillle County, Idaho, was on conventionally tilled farms.

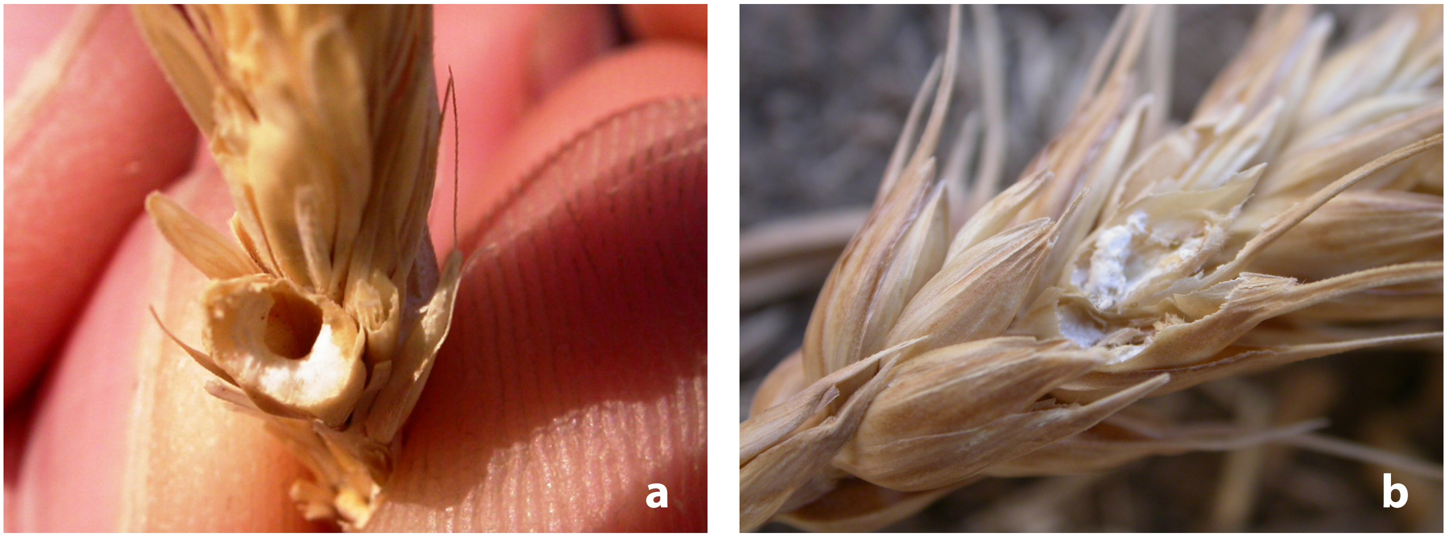

Figure 1 (a) and (b). Wheat head armyworm damage in mature wheat heads. (a) Photo by John Burns, WSU Extension and (b) Photo by Diana Roberts, WSU Extension.

With the recent confirmation of the pest status of *D. terrapictalis*, the question also arises as to why it took over 100 years of wheat farming in the region for this insect to cause noticeable yield loss. Possible reasons include climate variability, increased frequency of spring wheat in crop rotations, fewer frost events in late spring, or changes in soil health and cropping systems.

The Insect Species Involved

Two insect species have been implicated in WHAC infestations reported in the PNW. *D. diffusa* (Figure 2a) is found throughout the United States and Canada, but is more common in high-producing wheat areas including Kansas, Nebraska, Oklahoma, and Colorado (Michaud et al. 2007). The unpredictable and sporadic nature of infestations there has made the pest challenging to study.

We report here the first incidences of *D. diffusa* as a pest in the PNW, and local scientists referred to it initially as the “true” wheat head armyworm (Figure 2a). The second species, *D. terrapictalis*, is native to the western United States (Figure 2b). Its host range and pest status were not previously known (Michaud et al. 2007), and we referred to the pest locally as the “false” wheat head armyworm. Adult moths of the native species, *D. terrapictalis*, were by far the greatest catches in pheromone traps located across eastern Washington and northeastern Oregon in 2009 and 2010 (Landolt et al. 2011). Similar results were obtained from an insect pest survey in eastern Washington in 2015 (Crowder et al. 2015).

Attempts to rear field-collected larvae through to the adult moth in order to confirm the pest status of D. terrapictalis have not yet been successful. While the adult moths have obvious differences, it is not possible to distinguish between the larvae of the two species.

We collected larvae from WHAC-infested fields in Lincoln County, Washington, in 2014 and conducted sequencing studies to determine genetic differences among them for the COI (cytochrome oxidase I) region. However, the two species proved to be virtually identical for this genetic marker. These results indicate that *D. diffusa* and *D. terrapictalis* are recently divergent species (Wanner 2015). This finding suggests that *D. terrapictalis* is also a pest of cereal crops and we recommend farmers manage it accordingly.

The term “armyworm” is used to describe many different moths, and refers to their typical numbers and movement across fields. They are known as pests of a wide variety of plants. It is noteworthy that many reports of armyworms in grain crops east of the Rocky Mountains do not refer to WHAC. The true armyworm *Pseudaletia unipuncta* (Haworth), and the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) both infest cereals and may be referred to as “armyworms” (Capinera 2006); however, neither has been reported as a pest in the PNW.

WHAC Biology, Lifecycle, and Behavior

The genus *Dargida* consists of several species within the family *Noctuidae*, which are so named because the adult moths are nocturnal. *Noctuidae* comprise the largest family in the order *Lepidoptera*, which includes moths, skippers, and butterflies. The family also includes numerous pest species such as cutworms and armyworms (Mickel 1932). Although several species of *Dargida* can be found, the only available references to its biology are for *D. diffusa* in the Midwest.

Both WHAC species have straw-colored forewings, which likely provide camouflage protection from predators against a background of dry grasses, including wheat. *D. terrapictalis* has somewhat darker forewings and substantially darker hind wings (Figure 2).

Lepidoptera have four life stages: egg, larva, pupa, and adult. Larvae of noctuids go through five instars, when

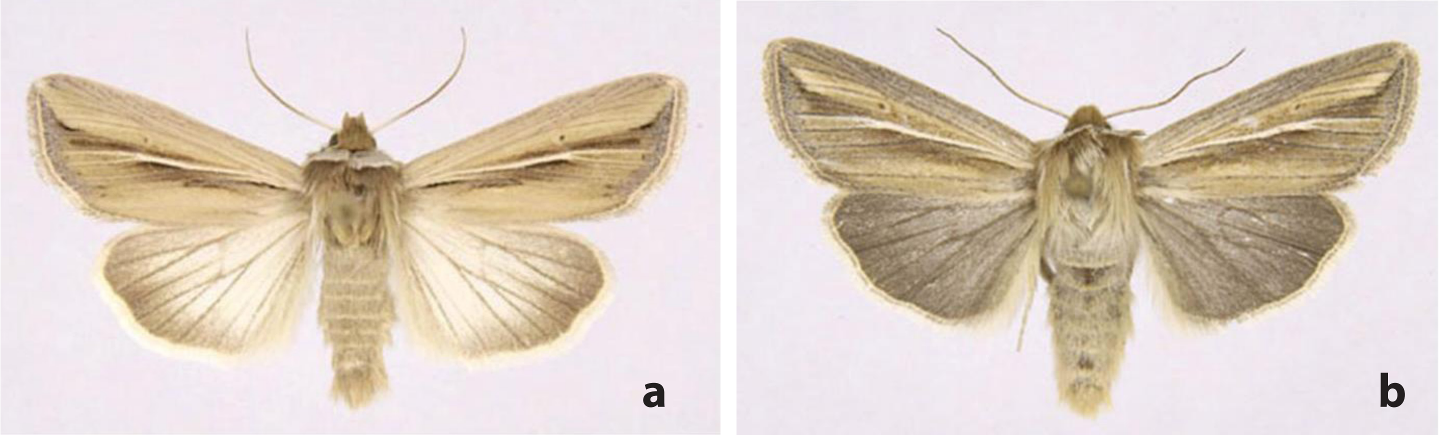

Figure 2. The two adult moths comprising the wheat head armyworm complex (a) *Dargida diffusa* and (b) *Dargida terrapictalis*. (Photos from the Canadian Biodiversity Information Facility, Moths of Canada website.)

they molt the exoskeleton and increase in size (Peairs 2006). The larvae vary in color but have been noted as gray, cream, or green with distinct yellow, white, and brown stripes along the length of the body (Figure 3). Michaud et al. (2007) described the adult moth as yellow-brown with a brown stripe running down the length of each of the forewings (Figure 2). The wingspan measures 1.2 to 1.5 inches.

The insect overwinters in the soil as a pupa. When spring arrives, moths emerge from the pupae. Within a few days, the moths lay eggs on wheat or barley crops (Peairs 2006). Larvae hatch and feed from late May through the remaining crop season, with maximum populations occurring around mid-June (Michaud et al. 2007). This late-spring timing coincides with wheat flag leaf development. Larvae feed on wheat heads, primarily at night, when ambient temperatures are cooler. During the heat of the day, larvae migrate towards the base of the plant (Michaud et al. 2007; Royer 2007).

Figure 3 (a) and (b). Wheat head armyworm complex larvae showing color variation and typical striping as they feed on wheat heads. (Photos by Diana Roberts, WSU Extension.)

WHAC in the Pacific Northwest

WHAC was first reported on wheat in Washington State in 2007, when grain harvested in Lincoln County was docked for broken kernels (Figure 4). A local crop consultant, suspecting armyworm damage, subsequently found pupae, corresponding to the description for WHAC (Figure 5), one inch down in the duff layer of an affected no-till field (K. Reed, personal communication).

Pheromone traps set up across eastern Washington and Umatilla County, Oregon, in 2009, attracted both species comprising WHAC. *D. diffusa* occurred only in Spokane, Lincoln, and Adams Counties, while *D. terrapictalis* was trapped (at low levels) in all the counties surveyed (Figure 6).

Figure 4. Wheat sample with broken kernels attributed to damage by the wheat head armyworm complex. (Photo by Diana Roberts, WSU Extension.)

Figure 5. Pupae of the wheat head armyworm complex collected in Lincoln County in 2007. (Photo by John Burns, WSU Extension.)

We set up this same system of traps in Lincoln and Spokane County, Washington, and Umatilla County, Oregon, in 2010 (Figure 7). Traps captured only *D. terrapictalis* moths in Umatilla County, with numbers peaking in mid-May. In Washington, moths of both species began to emerge in late May and populations peaked around the third week of June. *D. terrapictalis* moths comprised the bulk of the catch, versus the almost negligible numbers of *D. diffusa*. We expect there will be seasonal variations in these dates.

We recommend that in areas prone to WHAC infestations, crop consultants set out pheromone traps

Figure 6. Distribution of counties trapped (gray shading) and positive trap captures for *D. diffusa* (stippling) and *D. terrapictalis* (hash lines) moths in eastern Washington and Umatilla County Oregon, 2009. (Source: Landolt et al. 2011. Journal Kansas Entomological Society. Used by permission.)

as winter wheat enters the boot stage (Feekes Stage 10). This is approximately the last week of April in Umatilla County and mid-May in Spokane and Lincoln Counties. They should monitor moth catches on a weekly basis for the next month or until moth numbers are negligible. They should commence surveying adjacent fields for WHAC larvae about seven days after the peak occurrence of moths, or as soon as the wheat heads are half emerged from the boot (Feekes Stage 10.3). Catches of WHAC moths from the fall flight were negligible in both 2009 and 2010, so at this time we do not recommend monitoring populations in the fall.

WHAC moths lay eggs soon after emerging from pupae, and larvae are predicted to hatch about 10 days later, depending on heat and moisture conditions. In Lincoln County in 2008, newly hatched larvae, presumably of WHAC, were found on June 25 (Figure 8). It appeared that WHAC moths laid eggs on the flag leaf and the larvae fed on the upper layer of leaf tissue as they made their way down the leaf and into the boot to feed on the developing wheat head.

Holes chewed into the wheat floret are typical of WHAC damage (Figure 9), and feeding larvae leave telltale frass (feces) on the wheat head.

Feeding

WHAC larvae occur most commonly along field margins. The pest may feed on all parts of grass and cereal crops, but seems to prefer cereal heads. Larvae feed by inserting their mouthparts into the base of the floret, boring a small hole (Figure 10) through which

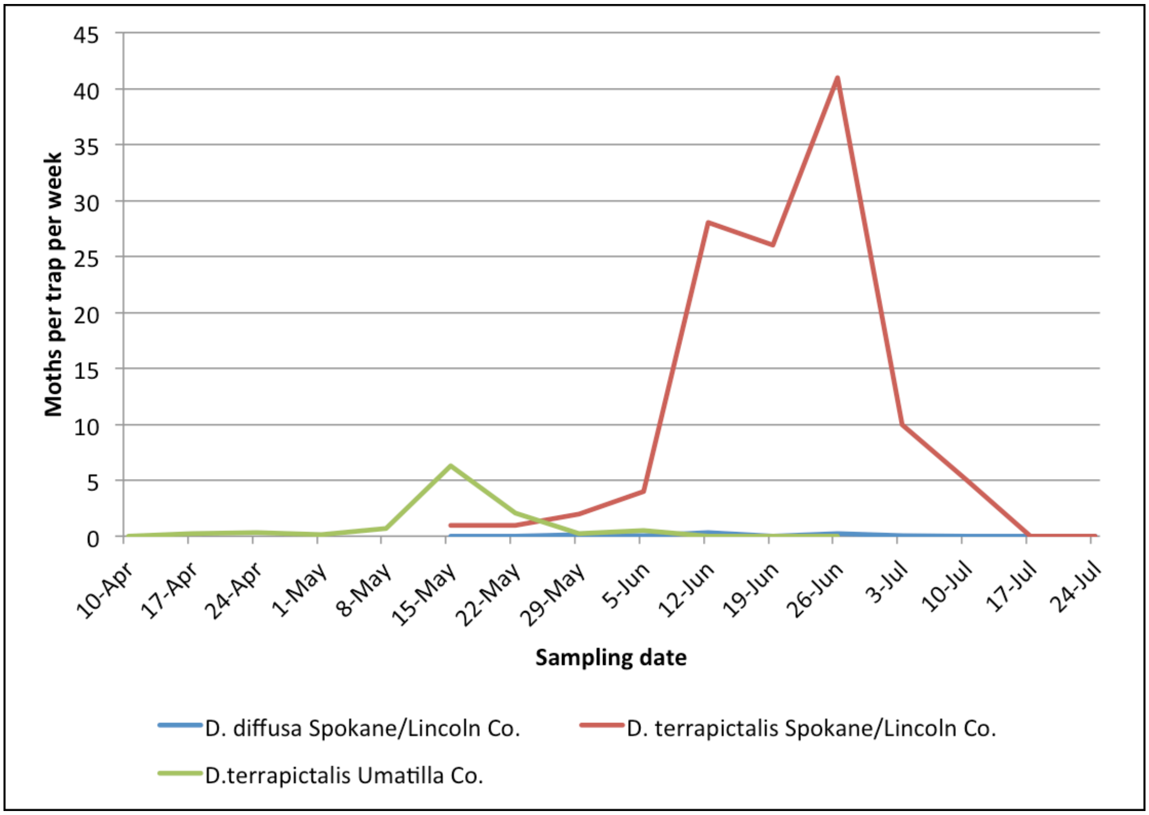

Figure 7. Mean weekly number of *D. diffusa* and *D. terrapictalis* moths caught in pheromone traps for 13 sites in Lincoln and Spokane Counties, Washington, and 25 sites in Umatilla County, Oregon, in 2010.

Figure 8. Newly hatched larvae of the wheat head armyworm complex showing their looper movement, moving down the flag leaf and into the boot of a wheat plant. (Photo by Diana Roberts, WSU Extension.)

Figure 9. Wheat head with feeding wheat head armyworm complex larva hanging upside down, leaving frass excrement, and holes bored in the florets. (Photo by Diana Roberts, WSU Extension.)

they eat out the developing grain. In stored grains, WHAC damage (Figure 1a) may appear very similar to that caused by weevils.

In the PNW, WHAC infests spring wheat fields primarily, although winter wheat and spring barley may also be affected. Michaud (2007) reported that Timothy grass (*Phleum pratense*) is also a host crop. The larvae generally feed at night and early in the morning. They hang upside down from the slender bristles on the head (awns) and hollow out the kernels.

WHAC Management

WHAC intermittently causes economic damage to cereal crops. The problem usually goes unnoticed until the crop is harvested and damaged kernels are found. Scouting for WHAC is unlikely to be justified unless it is part of an integrated pest management program or if infestations have occurred previously in a specific area. At present, control measures based on research are limited (see Chemical Control section), and scientifically tested economic thresholds for treatment are not available. We do not recommend growers spray at the first sign of the insect.

Monitoring the Pest

WHAC larvae cannot be identified to the species level based on appearance. Submit samples of moths, larvae, and damaged plants to your local county Extension office for identification.

Pheromone trapping and field scouting are helpful practices for monitoring WHAC populations in areas where the pest has caused damage in previous years.

Figure 10. Wheat head armyworm complex feeding damage on flag leaf, boot, and florets of wheat. (Photo by Diana Roberts, WSU Extension.)

Pheromone traps are useful for detecting the presence of WHAC moths in cereal grain fields and determining the optimum time to scout for larvae, but trap counts cannot be used directly to make management decisions, without additional scouting. The pheromone is a sex attractant, which in this case is specific to the male moths of *D. diffusa* and *D. terrapictalis*. The pheromone used is obtainable from commercial sources and is marketed as "wheat head armyworm pheromone."

The pheromone lure is placed in a basket at the top of a universal moth trap (Figure 11), which is mounted on a stake and located on the upwind side of a (spring) wheat field (Figure 12) to carry the pheromone molecules across the field. Male moths follow the scent into the trap, where they are killed by fumes of insecticide impregnated in a strip of tape (Vaportape) stapled to the inside of the bucket trap.

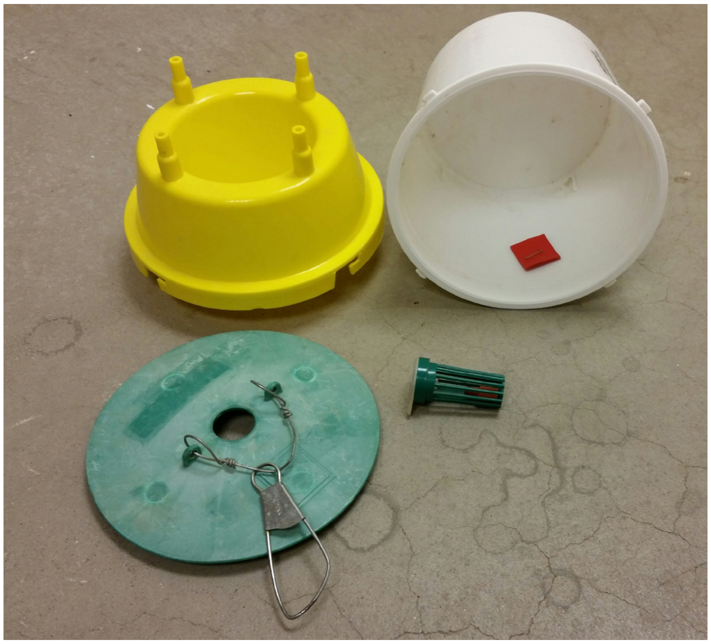

Figure 11. Components of a bucket trap showing lure in the top basket and Vaportape attached inside the lower bucket. (Photo by Diana Roberts, WSU Extension.)

Figure 12. Assembled bucket trap located at the upwind edge of a spring wheat field and suspended with the bottom of the trap level within the crop canopy. (Photo by Diana Roberts, WSU Extension.)

At least two traps (per hundred-acre field) should be set up as wheat enters the boot stage (Feekes Stage 10) and left in the field about four to five weeks until flowering is complete (at Feekes Stage 10.5.3). The pheromone plug and Vaportape should last this long. The trap height should be adjusted weekly as the plants grow so the bottom of the trap is level with the crop canopy (Figure 12). WHAC moths in the trap should be counted on a weekly basis and removed, along with other insects that were attracted to the bright colors of the trap.

Cost of wheat head armyworm complex trap and components for 2017, available at www.alphascents.com

Universal body trap:	$13.00 ea.	$262.50 for 25
Wheat head armyworm lure:	$2.75 ea.	$35.00 for 25
Vaportape (1” x 4” strip serves 4 traps):	$2.10 ea.	

This test is extremely sensitive because the pheromone attracts moths from at least 300 yards downwind. Consequently, the number of moths caught in the trap is not representative of the density of insects on a per plant basis, and management decisions should not be made based on these counts. We recommend sampling with a sweep net in fields where weekly moth counts exceed 25 to 30 per trap. In our experience, with lower weekly counts, we have typically not found WHAC larvae feeding on the crop. The weekly moth counts do indicate the peak flight time of the adult WHAC. The moths mate and lay eggs soon after they emerge from pupae, and the eggs hatch about 10 days later. Field scouting should start about one week following the peak moth count.

Field sampling for larvae is best done using a sweep net. It should be done in the cool hours of the morning and evening because WHAC larvae drop down in the canopy during the heat of the day. WHAC (and many other insect pests) are usually found along field borders, so it is important to sample transects well into the center of the field. Alternatively, take one set of sweeps along the field border and another within the field to enable making separate pest management decisions for each area. We recommend that each sample be a set of 50 sweeps, each 180 degrees, through the top of the crop canopy in a random zigzag motion from the edge towards the field center. Repeat the sample at several locations (minimum of three) across the field, and count the WHAC larvae in the net after each sample. Calculate the average number of larvae per sample for the final number.

Research-based economic thresholds have not been established for WHAC because the irregular occurrence of infestations make it a challenging insect to study. In Lincoln County, Washington, crop consultants have used a count of 15 WHAC larvae per 10 sweeps (75 larvae per 50 sweeps) as warranting treatment (J. Merkel, personal communication).

Environmental Factors

WHAC larvae are sensitive to cold temperatures. In Lincoln County, Washington, an unseasonal frost on July 10, 2008, reduced larval counts of WHAC in WSU variety trial plots by 90%. Insecticide treatment of commercial fields in the area was terminated for the same reason. Mid-season frost events do not occur frequently, but if a cold snap is predicted, it may be wise to postpone planned insecticide applications.

Biological Control

Ground beetles, spiders, birds, and rodents all prey on the true armyworm and the fall armyworm, which occur east of the Rocky Mountains. Several species of parasitic wasps and flies also manage their populations (Capinera 2005 and 2006). It is likely that similar predators and parasitoids control WHAC populations in the PNW and account for its inconsistent occurrence. In 2007, pupae of an unidentified parasitic wasp emerged from most of the 70 WHAC pupae collected after harvest in Lincoln County, Washington (Figure 13).

Chemical Control

While no insecticides are specifically labeled for control of WHAC in the PNW, pyrethroids have worked well in the field. They should be used with restraint since they kill natural enemies as well as the pest. For best results, spray early in the morning or late in the evening when the pest is exposed and feeding on the upper part of the plant. If the field is sprayed during the day, the treatment is likely to be less effective because the pest larvae are low down in the crop canopy.

Any registered contact insecticide labeled for cutworms and armyworms on wheat or barley should be effective against the pest. They are shown in the PNW Insect Management Handbook at http://insect.pnwhandbooks.org/agronomic/small-grain. While armyworms are listed on the labels of a number of chemicals, no currently available commercial insecticide specifically names WHAC.

While several chemicals are listed in the handbook, two commonly used insecticides that may be effective against the pest are Warrior II with Zeon Technology, from Syngenta, and Mustang Max EC, from FMC. Warrior has a signal word of warning, a re-entry interval of 24 hours, and a preharvest interval (PHI) of 30 days. This may pose a problem for growers if it is applied close

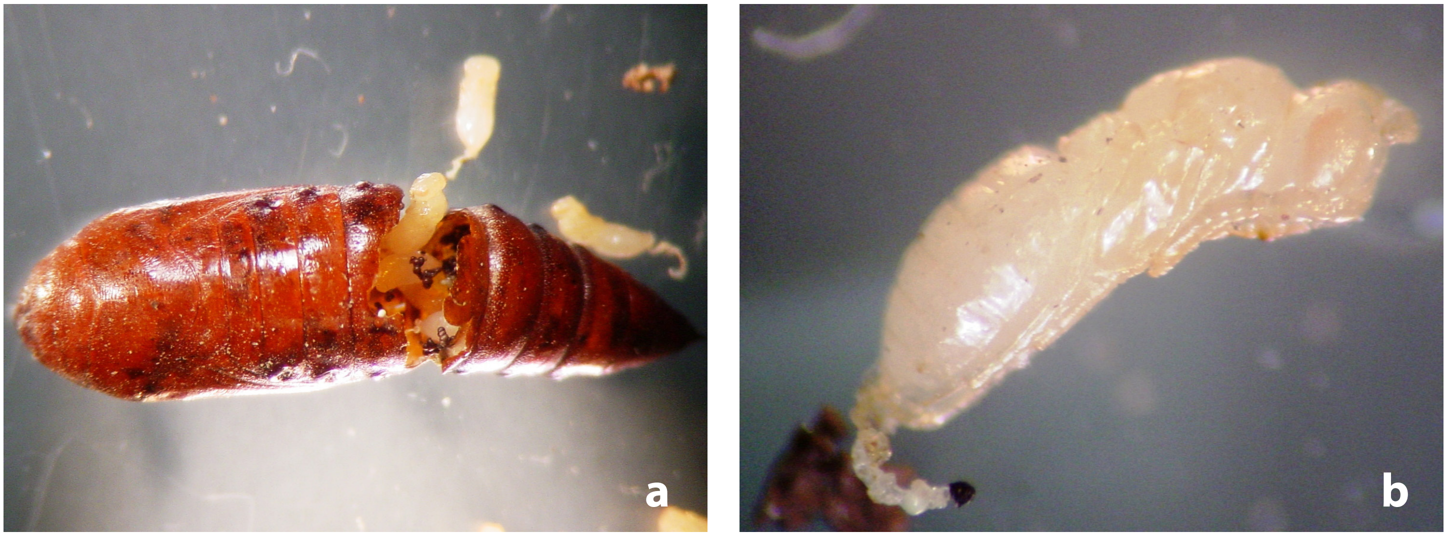

Figure 13. Parasitized wheat head armyworm complex pupa collected in Lincoln County, Washington, August 2007. (a) Wasp pupae emerging from wheat head armyworm complex pupa and (b) single wasp pupa. (Photos by Diana Roberts, WSU Extension.)

to harvest, in winter wheat especially. Mustang Max has a signal word of warning, a re-entry interval of 12 hours, and a PHI of 14 days; and it can only be applied to wheat.

Natural Insecticides

In testing natural insecticides on second instar larvae of *D. diffusa* under laboratory conditions, Reddy and Antwi (2016) found Entrust WP (spinosad 80%) to be effective and fast acting, resulting in close to 100% mortality within three days after application. Spinosad is toxic to many insect species, including bees. Under sunlight conditions, the product breaks down within seven days, so reapplication might be necessary if more WHAC larvae hatch in the field.

Spinosad is available in several formulations. Entrust (wettable powder; Dow Agrosciences) and Success (aqueous suspension; Dow Agrosciences) are labeled for managing armyworms in cereal grains. Entrust may be applied at 1 to 2 ounces per acre, not to exceed 5.6 ounces (0.28 lb active ingredient) spinosad per acre per year. Success may be applied at 3 to 6 fluid ounces per acre, not to exceed 19 fluid ounces (0.28 lb active ingredient) per acre per year. Both formulations have a preharvest interval of 21 days. It is recommended that no more than two applications be used successively to prevent insects from developing resistance to the pesticide.

In the same study, Reddy and Antwi (2016) also evaluated products containing the entomopathogenic (insect killing) fungus, *Beauveria bassiana*. Xpectro OD (*B. bassiana* GHA + pyrethrins) was faster acting than Mycotrol ESO (*B. bassiana* GHA), which took nine days to be fully effective. This was to be expected with a fungus that takes time to develop a lethal infection.

The law requires applicators to **always read and follow all pesticide label instructions when using chemical products**.

Conclusion

At this time, WHAC is an intermittent and localized pest in the PNW. We encourage growers and consultants to employ the scouting techniques described, and to use insecticides with restraint. Virtually all labeled products that help manage WHAC and other pests are also harmful to beneficial insects.

Acknowledgments

We appreciate the financial support of the Washington Grain Alliance and the Oregon Wheat Commission for this project on WHAC.

This study would not have been possible without the hard work of field technicians Kathleen Mayhan and Robin Garcia (WSU Extension).

Substantial material in this publication originally appeared in Wheat Head Armyworm True or False: A Tale from the Pacific Northwest (EM 9000), Oregon State University, by Silvia Rondon, Mary K. Corp, Diana Roberts, Keith S. Pike, Peter J. Landolt, and Dustin Keys.

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Toxicity of natural insecticides on the larvae of wheat head armyworm, *Dargida diffusa* (Lepidoptera: Noctuidae)

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ABSTRACT

The wheat head armyworm, *Dargida* (previously *Faronta*) *diffusa* (Walker) (Lepidoptera: Noctuidae), is widely distributed in North American grasslands and is most common on the Great Plains, where it is often a serious pest of corn and cereal crops. Six commercially available botanical or microbial insecticides used against *D. diffusa* were tested in the laboratory: Entrust® WP (spinosad 80%), Mycotrol® ESO (*Beauveria bassiana* GHA), Aza-Direct® (azadirachtin), Met52® EC (*Metarhizium brunneum* F52), Xpectro® OD (*Beauveria bassiana* GHA + pyrethrins), and Xpulse® OD (*Beauveria bassiana* GHA + azadirachtin). Concentrations of 0.1, 0.5, 1.0 and 2.0 fold the lowest labelled rates of formulated products were tested for all products, while for Entrust WP additional concentrations of 0.001 and 0.01 fold the label rates were also assessed. Survival rates were determined from larval mortality at 1–9 days post treatment application. We found that among the tested chemicals, Entrust® (spinosad) was the most effective, causing 83–100% mortality (0–17% survival rate) at day 3 across all concentrations. The others, in order of efficacy from most to least, were Xpectro® (*B. bassiana* GHA + pyrethrins), Xpulse® OD (*B. bassiana* GHA + azadirachtin), Aza-Direct® (azadirachtin), Met52® EC (*M. brunneum* F52), and Mycotrol® ESO (*B. bassiana* GHA). These products and entomopathogenic fungi caused 70–100% mortality (0–30% survivability) from days 7 to 9. The tested products and entomopathogenic fungi can be used in management of *D. diffusa*.

1. Introduction

The wheat head armyworm, *Dargida* (previously *Faronta*) *diffusa* (Walker) (Lepidoptera: Noctuidae), while usually a minor pest, can sporadically cause important crop damage (Peairs et al., 2010). This species is similar in appearance to its congener *Dargida terrapictalis* (Buckett) (Lepidoptera: Noctuidae), with which it is often confused (Rodriguez and Angulo, 2005). Both species were moved from *Faronta* to *Dargida* by Rodriguez and Angulo (2005). *Dargida diffusa* feeds on a range of grasses and cereal crops and appears to prefer seed heads (Watts and Bellotti, 1967), making it a pest of cereal grains throughout the Midwest and Great Plains of North America (Covell, 1984). Although its host range and pest status are not well studied (Michaud et al., 2007), crop damage seems to occur both in the field and during grain storage. There are currently no integrated pest management thresholds or recommended treatments for this pest due to its sporadic late season appearance (Peairs et al., 2010).

Dargida diffusa larvae pupate and overwinter in the soil, and adults mate within a few days of emerging. Females then lay eggs on developing wheat or barley (Powell and Opler, 2009). Larvae occur on wheat heads by June. Larvae and adults are typically nocturnal (Michaud et al., 2007; Royer, 2007). In more northern regions, *D. diffusa* has two generations per year and adults fly in late August. A 35% yield loss in spring wheat due to *D. diffusa* has been reported in Washington State (Roberts, 2009). Meanwhile, Rondon et al. (2011) found both *D. diffusa* and *D. terrapictalis* to cause crop damage in Idaho and Oregon.

Concern over this pest increased with the occurrence of increased percentages of insect-damaged kernels (IDK) in 2014 in wheat harvest in the Golden Triangle area of Montana. Underhill et al. (1977) reported that *D. diffusa* responds to lures baited with a combination of the sex attractant compounds Z11-16Ac and Z11-16Ald. Such pheromone lures are being used to detect and monitor adults in wheat fields (Landolt et al., 2011). However, the use of these lures is limited to monitoring, and control is based on use of insecticides, even though such applications may not be advisable near harvest.

Sustainable insect pest management (SIPM) products are intended to be safe alternatives to conventional insecticides, and some are both effective and harmless to the environment (Peshin

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Table 1
Insecticide treatments and concentrations used.

Treatments	Insecticide concentration[a]						
	0*X*	0.001*X*	0.01*X*	0.1*X*	0.5*X*	1*X*	2*X*
Mycotrol ESO[b]	0			0.072	0.36	0.72	1.44
Met52 EC[c]	0			0.072	0.36	0.72	1.44
Aza-Direct[d]	0			0.144	0.72	1.44	2.88
Xpulse OD[e]	0			0.072	0.36	0.72	1.44
Xpectro OD[f]	0			0.25	1.25	2.5	2.5
Entrust WP[g]	0	0.000091	0.00091	0.0091	0.0455	0.091	0.182

[a] Insecticide concentration: 0*X*, control (water); 0.001*X*, 0.01*X*, 0.1*X*, 0.5*X*, 1*X*, and 2*X* of the lowest label application rate.

[b] Mycotrol ESO: 0.1*X* = 0.072 ml/L (0.007848 g a.i./L); 0.5*X* = 0.36 ml/L (0.03924 g a. i./L); 1*X* = 0.72 ml/L (0.07848 g a.i./L); 2*X* = 1.44 ml/L (0.15696 g a.i./L).

[c] Met52 EC: 0.1*X* = 0.072 ml/L (0.00792 g a.i./L); 0.5*X* = 0.36 ml/L (0.0396 g a. i./L); 1*X* = 0.72 ml/L (0.0792 g a.i./L); 2*X* = 1.44 ml/L (0.1584 g a.i./L).

[d] Aza-Direct: 0.1*X* = 0.072 ml/L (0.01728 g a.i./L); 0.5*X* = 0.72 ml/L (0.0864 g a.i./L); 1*X* = 1.44 ml/L (0.1728 g a.i./L); 2*X* = 2.88 ml/L (0.03456 g a.i./L).

[e] Xpulse OD: 0.1*X* = 0.072 ml/L (0.0072432 g a.i./L); 0.5*X* = 0.36 ml/L (0.036216 g a.i./L); 1*X* = 0.72 ml/L (0.072432 g a.i./L); 2*X* = 1.44 ml/L (0.144864 g a.i./L).

[f] Xpectro OD: 0.1*X* = 0.25 ml/L (0.002025 g a.i./L); 0.5*X* = 1.25 ml/L (0.010125 g a.i./L); 1*X* = 2.5 ml/L (0.02025 g a.i./L); 2*X* = 5 ml/L (0.0405 g a.i./L).

[g] Entrust WP: 0.001*X* = 0.000091 ml/L (0.0000728 g a.i./L); 0.01*X* = 0.00091 ml/L (0.000728 g a.i./L); 0.1*X* = 0.0091 ml/L (0.00728 g a.i./L); 0.5*X* = 0.0455 ml/L (0.0364 g a.i./L); 1*X* = 0.091 ml/L (0.0728 g a.i./L); 2*X* = 0.182 ml/L (0.1456 g a.i./L).

and Dhawan, 2009; Murray et al., 2013; Bailey et al., 2013). To date, no attempt has been made to find materials with these attributes for use against *D. diffusa*. Here we present results from a laboratory bioassay to evaluate the efficacy of several commercially available biorational products against larvae of *D. diffusa*.

2. Materials and methods

2.1. Insects

Larvae of *D. diffusa* were collected from wheat fields near Valier, MT, USA, using sweep nets, in June and July, 2015. Larvae were taken to the laboratory and placed in collapsible cages (12 cm × 10 cm × 10 cm), where they were fed wheat seed heads, and held at 21 ± 2 °C, 70–80% relative humidity, and an approximately 14:10 h L:D photoperiod. Field-collected larvae were separated by instar and ranged from first to four instars. For all experiments, second instars were used for laboratory bioassays.

2.2. Insecticides

Insecticides used were commercial formulations of (1) Entrust WP (spinosad 80%, Dow AgroSciences Indianapolis, IN), (2) Mycotrol ESO (*Beauveria bassiana* GHA, Lam International, Butte, MT), (3) Aza-Direct (azadirachtin, Gowan Company, Yuma, AZ), (4) Met52 EC (*Metarhizium brunneum* F52, Novozymes Biologicals, Salem, VA), (5) Xpectro OD (*Beauveria bassiana* GHA + pyrethrins, Lam International, Butte, MT), and (6) Xpulse OD (*Beauveria bassiana* GHA + azadirachtin, Lam International, Butte, MT). Cultures of *M. brunneum* F52 (a commercialized isolate previously identified as *M. anisopliae*) conidial powders were stored dry at 4–5 °C until formulated for use. The concentrations tested were 0.1, 0.5, 1.0 and 2.0 fold lowest label rate, while for Entrust additional concentrations of 0.001 and 0.01 fold the label rate were also prepared (Table 1).

2.3. Laboratory tests

Laboratory tests were carried out from July and August of 2015 via contact application of various concentrations of the test materials (see Table 1 for exact concentrations tested). For each replicate, five second instar larvae were transferred onto a disk of Whatman No. 1 filter paper (9 cm diam, Whatman® quantitative filter paper, ashless, Sigma–Aldrich, St. Louis, MO, USA) in a 9 cm disposable Petri dish. Each Petri dish received three wheat stems about 5 cm long, each with 8–10 leaves as food for the larvae. Six replicate Petri dishes, containing a total of 30 larvae (5 per dish), were treated (using a 473 ml capacity Plant & Garden Sprayer, Sprayco, Livonia, MI) with 1 ml of the relevant test material (Reddy et al., 2014). Controls were sprayed with 1.0 ml tap water. Following application, dishes were held under the same laboratory conditions used for rearing, and larval mortality was assessed daily for 9 days.

2.4. Statistical analyses

The data were analyzed with SAS 9.4 (SAS Institute, 2015). Mortality rates were corrected using Abbott's formula (Abbott, 1925; Perry et al., 1998; Antwi et al., 2007a) to adjust for control mortality. Mortality rates were regressed on concentrations, days, with treatment as categorical variable using logistic function in the general linear model (GLM). Based on the logistic function the effect and significance of concentration, day, and treatment on mortality were assessed. Survival rates were also determined from the mortality rates and graphs of survival rate (%) against log concentration were plotted with Sigma Plot 13.0 (SPSS Inc., Chicago, IL). Survival rates were regressed on log concentration using PROC REG. Lethal values (LC_{50}) were determined with PROC PROBIT. Differences in lethal values between treatments were determined by comparison of the 95% confidence limits (Finney, 1971; Robertson et al., 2007; Antwi and Peterson, 2009). Poor fit models were accounted for by multiplying the variances by the heterogeneity factor ($\chi^2/k-2$), where k is the number of concentrations to account for extra binomial variations due to genetic and environmental influences that caused poor fit (SAS Institute, 2015; Antwi and Peterson, 2009).

3. Results

3.1. Mortality

The results of contact bioassays with tested materials against second instars of *D. diffusa*, shown in Table 2, and Fig. 1. Entrust caused high mortality to larvae, acting rapidly and reaching 83–100% mortality (0–17% survival rate) at day 3 across all concentrations (Table 2, Fig. 1.). Mortalities were 66.7–100% (0–33.3% survival rate) for Xpectro, 42.5–100% (0–57.5% survival rate) for Xpulse, 30.8–100% (0–69.2% survival rate) for Aza-Direct across all concentrations from days 4 to 9. Across all the concentrations from days 5 to 9 mortalities were 10–100% (0–90% survival rate) for Mycotrol, 30–100% (0–70% survival rate) for Met52 (Table 2, Fig. 1).

Effects of concentration, day and treatment on mortalities are shown in Tables 3 and 4. Concentration and day effects were significant (Table 3). Among the regression models that were fitted Eq. (2) was the best model (Table 3). Eq. (2) from Table 3 indicates that among the treatments Entrust was the most effective and this had

Table 2
Time–concentration–mortality response of *Dargida diffusa* larvae to reduced risk insecticides.

Treatments	DAT[a]	Insecticide concentration[b]						
		0*X*	0.001*X*	0.01*X*	0.1*X* % Mortality[c]	0.5*X*	1*X*	2*X*
Mycotrol ESO	1	0			0	0	0	0
Met52 EC	1	0			0	0	3.3	0
Aza-Direct	1	0			0	0	0	0
Entrust	1	0	26.7	36.7	90	96.7	100	100
Xpulse OD	1	0			0	0	0	0
Xpectro OD	1	0			0	0	6.7	36.7
Water	1	0	0	0	0	0	0	0
Mycotrol ESO	2	0			0	0	0	0
Met52 EC	2	0			0	0	3.3	0
Aza-Direct	2	0			0	0	6.7	16.7
Entrust	2	0	63.3	86.7	100	100	100	100
Xpulse OD	2	0			0	3.3	13.3	30
Xpectro OD	2	0			13.3	26.7	60	93.3
Water	2	0	0	0	0	0	0	0
Mycotrol ESO	3	0			0	0	0	0
Met52 EC	3	0			0	0	3.3	13.3
Aza-Direct	3	0			0	5.8	22.5	59.2
Entrust	3	0	83.3	93.3	100	100	100	100
Xpulse OD	3	0			10	26.7	60.8	96.7
Xpectro OD	3	0			43.3	80	90	100
Water	3	0	0	0	0	0	0	0
Mycotrol ESO	4	0			0	0	2.5	14.2
Met52 EC	4	0			0	12.5	26.7	69.2
Aza-Direct	4	0			30.8	44.17	66.7	100
Entrust	4	0	86.67	93.33	100	100	100	100
Xpulse OD	4	0			42.5	71.7	95.83	100
Xpectro OD	4	0			66.67	100	100	100
Water	4	0	0	0	0	0	0	0
Mycotrol ESO	5	0			22.5	10	40.8	52.5
Met52 EC	5	0			30	52.5	70	100
Aza-Direct	5	0			69.2	78.3	88.3	100
Entrust	5	0	86.7	93.3	100	100	100	100
Xpulse OD	5	0			90	96.7	100	100
Xpectro OD	5	0			90	100	100	100
Water	5	0	0	0	0	0	0	0
Mycotrol ESO	6	0			37.5	35.8	80	80
Met52 EC	6	0			59.2	77.5	95.8	100
Aza-Direct	6	0			100	100	100	100
Entrust	6	0	86.7	93.3	100	100	100	100
Xpulse OD	6	0			100	100	100	100
Xpectro OD	6	0			100	100	100	100
Water	6	0	0	0	0	0	0	0
Mycotrol ESO	7	0			73.3	84.2	100	91.7
Met52EC	7	0			88.9	100	100	100
Aza-Direct	7	0			100	100	100	100
Entrust	7	0	83.3	93.3	100	100	100	100
Xpulse OD	7	0			100	100	100	100
Xpectro OD	7	0			100	100	100	100
Water	7	0	0	0	0	0	0	0
Mycotrol ESO	8	0			91.1	100	100	91.7
Met52 EC	8	0			100	100	100	100
Aza-Direct	8	0			100	100	100	100
Entrust	8	0	83.3	91.7	100	100	100	100
Xpulse OD	8	0			100	100	100	100
Xpectro OD	8	0			100	100	100	100
Water	8	0	0	0	0	0	0	0
Mycotrol ESO	9	0			94.4	100	100	88.9
Met52 EC	9	0			100	100	100	100
Aza-Direct	9	0			100	100	100	100
Entrust	9	0	83.3	91.7	100	100	100	100
Xpulse OD	9	0			100	100	100	100
Xpectro OD	9	0			100	100	100	100
Water	9	0	0	0	0	0	0	0

[a] DAT, days after treatment.

[b] Insecticide concentration: 1*X* the lowest label application rate equals Mycotrol ESO, 0.72 ml/L; Met 52 EC, 0.72 ml/L; Aza-Direct, 1.44 ml/L; Entrust, 0.091 ml/L; Xpulse OD, 0.72 ml/L; Xpectro OD, 2.5 ml/L.

[c] Mortalities were adjusted for using the Abbott method (Abbott, 1925).

[d] Water, control.

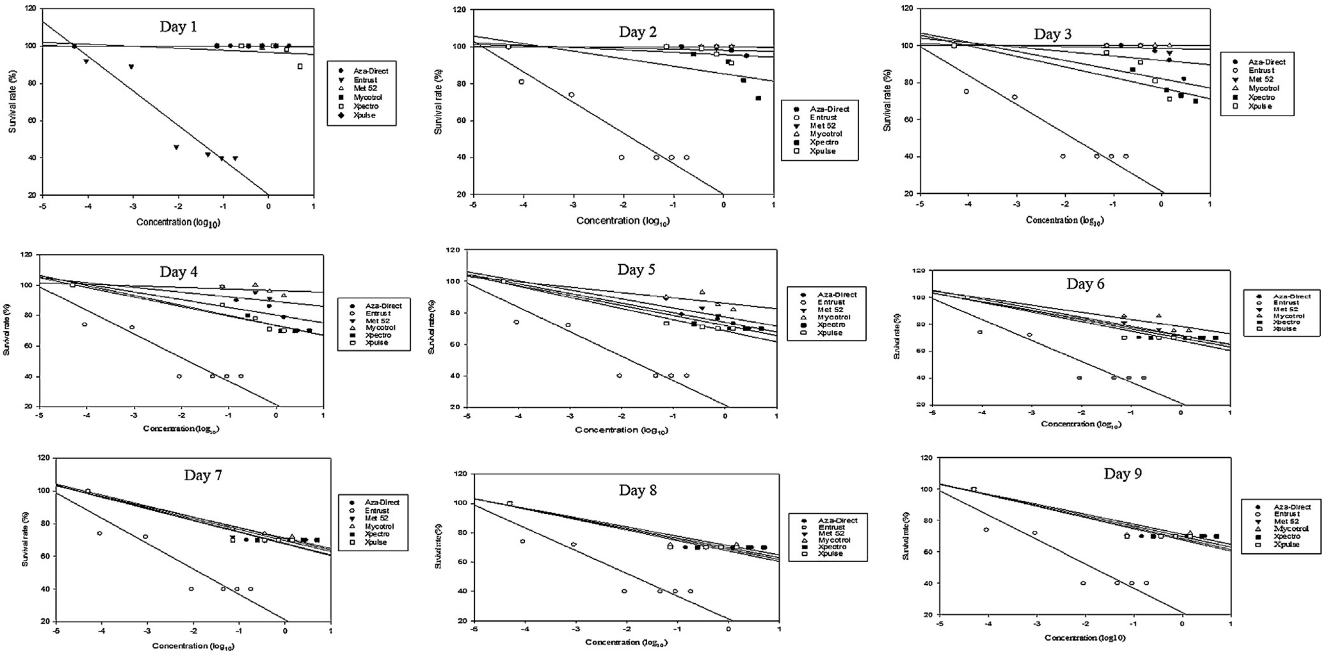

Fig. 1. Survival rate of *Dargida diffusa* larvae versus log concentration of Aza-Direct, Entrust, Met52, Mycotrol, Xpectro, and Xpulse at days 1–9.

Table 3
Effect of concentrations, days, and treatments on mortalities of *Dargida diffusa*.

Fitted equation	Logistic regression model[a,b,c]	Variables	S.E.[d]	*t* Value	*P*[e]
1	$Y = -2.42 + 1.57X_1 + 0.22X_2$[a]	Intercept	0.39221	−6.172	2.31×10^{-9}***
		Concentration	0.31581	4.971	1.15×10^{-6}***
		Day	0.06084	3.618	0.000351***
2	$Y = -1.16 + 1.47X_1 - 0.21X_2 - 0.45X_3 + 0.33X_4 + 0 \times .15X_5$[b]	Intercept	0.3373	−3.448	0.000652***
		Entrust	0.4104	3.582	0.000401***
		Met52	0.4929	−0.423	0.672928
		Mycotrol	0.5137	−0.869	0.385469
		Xpectro	0.4611	0.713	0.476385
		Xpulse	0.4698	0.311	0.756286
3	$Y = -2.03 \times 10^{15} + 8.79 \times 10^{14}X_1 + 2.51 \times 10^{14}X_2 + 3.30 \times 10^{14}X_3 + 1.82 \times 10^{14}X_4 + 1.56 \times 10^{14}X_5 - 2.82 \times 10^{14}X_6 + 4.60 \times 10^{14}X_7$[c]	Intercept	4.411×10^{14}	−4.598	6.47×10^{-6}***
		Concentration	1.764×10^{14}	4.985	1.09×10^{-6}***
		Day	5.244×10^{13}	4.786	2.76×10^{-6}***
		Entrust	4.431×10^{14}	0.744	0.457
		Met52	4.838×10^{14}	0.376	0.707
		Mycotrol	4.838×10^{14}	0.321	0.748
		Xpectro	4.862×10^{14}	−0.580	0.562
		Xpulse	4.838×10^{14}	0.952	0.342

[a] Logistic regression model: Y = mortality (%); X_1 = concentration (ml/L); X_2 = day.
[b] Logistic regression model: Y = mortality (%); X_1 = entrust; X_2 = Met52; X_3 = mycotrol; X_4 = Xpectro; X_5 = Xpulse.
[c] Logistic regression model: Y = mortality (%); X_1 = concentration (ml/L); X_2 = day; X_3 = entrust; X_4 = Met52; X_5 = mycotrol; X_6 = Xpectro; X_7 = Xpulse.
[d] S.E. = standard error.
[e] ***Highly significant effect at $P \leq 0.05$.

the most significant effect on *D. diffusa*. Concentration effects were significant for Mycotrol, Met52, Aza-Direct, and Xpulse (Table 4). Entrust had a *P* value of 1 for the concentration and intercept, due to the death rate being approximately close to 1 as most organisms were dead within day 1 (Table 4). Day effects were significant for Xpulse, and Entrust treatments (Table 4).

Lethal concentrations for each test material are presented in Table 5. Generally, there was a good fit to the model assumptions. Entrust was the most effective insecticide compared to Mycotrol, Met52, Aza-Direct, Xpulse, and Xpectro, since Entrust had a steep slope of mortality over time (i.e., it killed rapidly) (Fig. 1). Table 6, show the regression relationship between survival rates of *D. diffusa* and log concentration of tested materials (Mycotrol, Met52, Aza-Direct, Xpulse, Xpectro, and Entrust).

For Mycotrol the models explained 22.78–90.17% of the total survival rate variation for *D. diffusa* for days 1–9 (Table 6). The regression models explained 3.67–99.44% of the *D. diffusa* survival in the Met52 treatment from days 1 to 9 (Table 6), and 24.29–99.30% of the total survival rate response variation for days 1–9 in the Aza-Direct treatment (Table 6). Regression models explained 24.29–98.33% of the total survival rate of *D. diffusa* to Xpulse from days 1 to 9 (Table 6). Xpectro treatment to *D. diffusa*

Table 4
Effect of concentrations, and days for each treatment on mortalities of *Dargida diffusa.*

Treatment	Logistic regression model[ab]	Variables	S.E.[c]	*t* Value	*P*[d]
Mycotrol	$Y = -7.73 \times 10^{14} - 1.61 \times 10^{14} X_1$[a]	Intercept	5.782×10^{14}	−1.338	0.188
		Day	1.013×10^{14}	−1.586	0.120
	$Y = -2.41 + 2.16X_1$[b]	Intercept	0.4877	−4.932	1.27×10^{-5}***
		Concentration	0.6859	3.142	0.00303**
Met52	$Y = -7.45 \times 10^{14} + 6.23 \times 10^{13} X_1$[a]	Intercept	6.594×10^{14}	−1.131	0.265
		Day	1.155×10^{14}	0.539	0.593
	$Y = -2.28 + 2.64X_1$[b]	Intercept	0.4870	−4.688	2.79×10^{-5}***
		Concentration	0.7959	3.312	0.00188**
Aza-Direct	$Y = -5.57 \times 10^{13} - 4.29 \times 10^{13} X_1$[a]	Intercept	7.181×10^{14}	−0.078	0.938
		Day	1.263×10^{14}	−0.340	0.736
	$Y = -2.14 + 1.58X_1$[b]	Intercept	0.4897	−4.361	7.94×10^{-5}***
		Concentration	0.4949	3.189	0.00266**
Entrust	$Y = 2.45 \times 10^{15} - 4.03 \times 10^{14} X_1$[a]	Intercept	8.703×10^{14}	2.814	0.00658**
		Day	1.532×10^{14}	−2.629	0.01083*
	$Y = -1.63 + 1.05X_1 \times 10^3 X_1$[b]	Intercept	1.299×10^5	0	1[e]
		Concentration	2.964×10^8	0	1
Xpectro	$Y = -1.61 \times 10^{15} + 1.71 \times 10^{14} X_1$[a]	Intercept	8.250×10^{14}	−1.951	0.0576
		Day	1.445×10^{14}	1.184	0.2431
	$Y = -2.14 + 1.69X_1$[b]	Intercept	0.9591	−2.235	0.0307*
		Concentration	0.9780	1.726	0.0915
Xpulse	$Y = -3.21 \times 10^{15} + 3.34 \times 10^{14} X_1$[a]	Intercept	7.722×10^{14}	−4.159	0.00015***
		Day	1.352×10^{14}	2.472	0.01745*
	$Y = -2.07 + 3.74X_1$[b]	Intercept	0.5405	−3.827	0.000416***
		Concentration	1.3062	2.863	0.006460**

[a] Logistic regression model: $X_1{}^a$ = day; $X_1{}^b$ = concentration (ml/L).
[b] Logistic regression model: $X_1{}^a$ = day; $X_1{}^b$ = concentration (ml/L).
[c] S.E. = standard error.
[d] *Significant, **very significant, ***highly significant effect at $P \leq 0.05$.
[e] Due to most death within day 1, the death rate was close to one, the generalized linear model could not converge with fitted probabilities close to one.

Table 5
Lethal concentrations of *Dargida diffusa* larvae to reduced risk insecticides.

Treatment	Day	LC_{50} (g a.i./L)	C.I. (95%)	$P > \chi^2$
Mycotrol ESO[a]	5	0.10968	0.042–164.62	0.0834
Met52 EC[b]	5	0.01880	0.0094–0.029	0.0382
Aza-Direct	5	0.0004042	ND[c]	0.0100
Xpulse OD[d]	5	0.0007180	1.0733E-26–0.0035	0.7012
Xpectro OD	5	0.00177	0.0017–0.0019	1.0000
Entrust WP	5	8.11E-6[e]	1.70179E-8–0.000037	0.8477

[a] Weight estimate of 4.78×10^{-12} g/spore (2×10^{13} viable spores/quart).
[b] Contains 5.5×10^9 colony forming units (CFU)/g of product (5×10^{10} viable conidia/g of active ingredient.
[c] ND, no data as confidence interval could not be determined by statistical analysis.
[d] *Beauveria bassiana* Strain GHA (0.06%) contains not less than 1×10^{11} viable spores/quart.
[e] 8.11E-6 = 8.11×10^{-6}.

resulted in total survival rate response variation of 24.29–97.67% at days 1–9 (Table 6). Entrust treatment also resulted in the models explaining survival rate of *D. diffusa* variation from 35.02 to 61.09% at days 1–9 (Table 6).

For Mycotrol the slopes varied from −10.56 to 2.12 at days 1–9 (Table 6). For Met52 the slopes ranged from −17.70 to 2.12 at days 1–9 (Table 6). Aza-Direct treatment resulted in slopes ranging from −9.11 to 1.12 at days 1–9 (Table 6). Xpulse treatment resulted in slopes varying from −19.77 to 2.12 from days 1 to 9 (Table 6). At days 1 to 9 for Xpectro treatment the slopes varied from −5.49 to 0.67 (Table 6). From days 1 to 9 for Entrust treatment the slopes ranged from −275.06 to 16.51 (Table 6).

Lethal concentrations at 5 days post treatment were determined for Entrust (8.11×10^{-6} g a.i./L), Aza-Direct (0.0004042 g a.i./L), Xpulse (0.0007180 g a.i./L), Xpectro (0.00177 g a.i./L), Met52 (0.01880 g a.i./L), and Mycotrol (0.10968 g a.i./L) (Table 3). Based on the lethal concentrations Entrust was the most toxic among the treatments to *D. diffusa*.

4. Discussion

Of the six biological insecticides tested against *D. diffusa* in the laboratory, only Entrust (spinosad 80%), caused high rates of mortality to larvae, with 100% of larvae dying by 9 days after treatment. The other materials were virtually indistinguishable in final rates of mortality at day 9 but some acted more quickly, with Xpectro (*B. bassiana* GHA + pyrethrins) was the next most toxic followed by Xpulse, Aza-Direct, Met52 and Mycotrol. Spinosad, the active ingredient in Entrust, is a broad-spectrum insecticide, relatively fast acting and toxic to wide variety of insects (Salgado, 1998; Simon, 2009; Sparks et al., 1998). Studies by Cleveland et al. (2001) and Morandin et al. (2005) showed through acute oral and contact toxicity that spinosad is highly toxic to bees. During our study, Entrust caused lower survivability within 24 h after treatment, which may make this product advantageous to use whenever sudden pest outbreaks occur. On the other hand, repeated Entrust applications may be necessary, since spinosad loses its toxicity after 7 days

Table 6
Relationship between survival rate of *Dargida diffusa* and log concentration of Aza-Direct, Entrust, Met 52, Mycotrol, Xpectro, and Xpulse.

Treatment	Day	Regression model[a]	F	R^2	P
Mycotrol ESO	1	$Y = -2.27 + 2.12X$	2.67	0.4711	0.2007
	2	$Y = 100.00 + 0X$	ND[b]	ND	ND
	3	$Y = 100.00 + 0X$	ND	ND	ND
	4	$Y = 100.00 + 0X$	ND	ND	ND
	5	$Y = 100.15 - 4.93X$	27.51	0.9017	0.0135
	6	$Y = 95.26 - 10.15X$	7.71	0.7198	0.0692
	7	$Y = 91.75 - 14.18X$	5.67	0.6541	0.0975
	8	$Y = 85.15 - 12.63X$	1.75	0.3681	0.2779
	9	$Y = 82.27 - 10.56X$	0.88	0.2278	0.4163
Met52 EC	1	$Y = -2.27 + 2.12X$	2.67	0.4711	0.2007
	2	$Y = 99.88 - 0.15X$	0.11	0.0367	0.7575
	3	$Y = 99.88 - 0.15X$	0.11	0.0367	0.7575
	4	$Y = 100.46 - 2.81X$	30.63	0.9108	0.0116
	5	$Y = 100.27 - 14.41X$	530.11	0.9944	0.0002
	6	$Y = 93.18 - 17.70X$	16.10	0.8430	0.0278
	7	$Y = 87.55 - 15.34X$	3.59	0.5447	0.1545
	8	$Y = 82.56 - 11.89X$	1.16	0.2796	0.3595
	9	$Y = 81.83 - 11.24X$	0.96	0.2429	0.3989
Aza-Direct	1	$Y = -2.09 + 1.12X$	2.50	0.4550	0.2117
	2	$Y = 100.00 + 0X$	ND	ND	ND
	3	$Y = 100.48 - 1.81X$	52.20	0.9457	0.0055
	4	$Y = 100.84 - 6.41X$	423.48	0.9930	0.0003
	5	$Y = 94.45 - 9.11X$	26.06	0.8968	0.0145
	6	$Y = 87.07 - 7.20X$	3.09	0.5074	0.1770
	7	$Y = 81.83 - 5.62X$	0.96	0.2429	0.3989
	8	$Y = 81.83 - 5.62X$	0.96	0.2429	0.3989
	9	$Y = 81.83 - 5.62X$	0.96	0.2429	0.3989
Xpulse OD	1	$Y = -2.27 + 2.12X$	2.67	0.4711	0.2007
	2	$Y = 100.00 + 0X$	ND	ND	ND
	3	$Y = 100.55 - 6.47X$	176.49	0.9833	0.0009
	4	$Y = 98.05 - 19.77X$	114.71	0.9745	0.0017
	5	$Y = 90.27 - 17.50X$	6.26	0.6759	0.0876
	6	$Y = 83.19 - 12.33X$	1.35	0.3096	0.3300
	7	$Y = 81.83 - 11.24X$	0.96	0.2429	0.3989
	8	$Y = 81.83 - 11.24X$	0.96	0.2429	0.3989
	9	$Y = 81.83 - 11.24X$	0.96	0.2429	0.3989
Xpectro OD	1	$Y = -1.94 + 0.67X$	2.39	0.4437	0.2197
	2	$Y = 101.35 - 2.19X$	22.18	0.8808	0.0181
	3	$Y = 98.29 - 5.49X$	125.61	0.9767	0.0015
	4	$Y = 90.00 - 4.89X$	5.75	0.6573	0.0960
	5	$Y = 85.50 - 4.17X$	2.23	0.4260	0.2325
	6	$Y = 82.93 - 3.52X$	1.28	0.2984	0.3408
	7	$Y = 81.83 - 3.24X$	0.96	0.2429	0.3989
	8	$Y = 81.83 - 3.24X$	0.96	0.2429	0.3989
	9	$Y = 81.83 - 3.24X$	0.96	0.2429	0.3989
Entrust WP	1	$Y = -3.14 + 16.51X$	7.85	0.6109	0.0379
	2	$Y = 77.06 - 275.06X$	4.20	0.4563	0.0958
	3	$Y = 69.80 - 224.03X$	2.92	0.3683	0.1484
	4	$Y = 68.04 - 210.76X$	2.72	0.3525	0.1599
	5	$Y = 67.82 - 209.10X$	2.70	0.3502	0.1616
	6	$Y = 67.82 - 209.10X$	2.70	0.3502	0.1616
	7	$Y = 67.82 - 209.10X$	2.70	0.3502	0.1616
	8	$Y = 67.82 - 209.10X$	2.70	0.3502	0.1616
	9	$Y = 67.82 - 209.10X$	2.70	0.3502	0.1616

[a] Regression model: Y = survival rate (%); X = concentration ($\log_{10}$).
[b] ND = No data due to insufficient variation in the data to create a density plot.

and it may therefore be necessary to reapply if new larvae hatch. Rizk et al. (2014) suggested that this might be because the major route for spinosad degradation is photolysis. Several other reports (Brunner and Doerr, 1996; Liu et al., 1999; Antwi et al., 2007b) have found that Entrust (spinosad) applied to field crops largely loses activity after a week due to degradation when exposed to sunlight (Saunders and Bret, 1997). However, we found that none of the other treatments provided similar levels of control to that of the Entrust treatment (Fig. 1, Tables 5 and 6).

Aza-Direct (azadirachtin), while having no immediate knockdown effect on pests, has been found to reduce feeding and cause death within several days (Rizwan-Ul-Haq et al., 2009;Roy and Gurusubramanian, 2011). Foliar spray applications of commercial neem formulations have been found to persist for 5–7 days under field conditions (Schmutterer, 1990).

Met52 (*M. brunneum* F52) and Mycotrol (*B. bassiana* GHA), compared to spinosad, caused 73.3–100% (0–26.7 survival rate), and 88.9–100% (0–11.1% survival rate), respectively from days 8 to 9.

This is consistent with the mode of action of fungi, which require time for infections to develop and become lethal (Schapovaloff et al., 2014; Wu et al., 2014). While they act more slowly than spinosad, the data indicates that entomopathogenic fungi can be used in the management of *D. diffusa*. However, additional work is needed to determine the efficacy of these products under field conditions.

Conflict of interest

None declared.

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