9 Chemical Control in Stored Products

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This chapter covers insecticides used as sprays in empty bins before storing new grain, as direct grain protectants in bulk-stored grains, and as surface treatments and aerosols in grain storage structures and grain products. Discussion of fumigants and fumigations, modified atmospheres, and extreme temperatures for insect management are covered in chapters 14, 15, and 16, respectively. Sampling and insect monitoring, which are essential for evaluating effectiveness of chemical treatments, are covered in chapters 18, 19 and 21.

Insecticides Used in Bulk Grains

Structural sprays

Storage hygiene or sanitation is a mandatory component of insect pest management for storage facilities. Residual grain or grain debris in and around storage environments is an important source of infestation (Reed et al. 2003, Arthur et al. 2006). All trash should be removed from the storage structure and immediate surroundings before insecticide treatments are applied as pre-binning or structural sprays. There are a limited number of chemicals for such uses and the label requirements of these products often can be confusing. Application details described here relate to those with approved U.S. Environmental Protection Agency (EPA) registrations at the time of publication. Chlorpyrifos-methyl + deltamethrin (Storicide II) can only be used to disinfest empty structures if the structure is intended for storage of the five commodities listed on the label (barley, oats, sorghum, rice, and wheat). Also, the label specifies that empty grain bins should be treated by the applicator from outside the bin, applying the spray or dust from the top opening. Pirimiphos-methyl (Actellic 5E) is labeled for direct application to stored corn and stored sorghum but is not labeled for treating empty structures. In the United States, Cyfluthrin (Tempo SC Ultra) is an effective spray for treating structures but not the commodity. This new product replaced the wettable powder formulation. Diatomaceous earth is a natural product, with or without synergized pyrethrins, composed of fossilized skeletons of diatoms from fresh or salt water. Diatomaceous earth powders, or dusts, kill insects by absorbing the protective water-proofing compounds from the exoskeleton, leading to death by desiccation (Glenn et al. 1999; Subramanyam and Roesli 2000). Several diatomaceous earth dusts are available worldwide. Insecticidal efficacy varies among formulations, product sources, and insect species (Korunic 1998, Subramanyam and Roesli 2000).

Grain protectants

Protectants are chemical or nonchemical materials applied directly to raw commodities as they are loaded into a storage structure. They can be applied to farm-stored grain or small-scale commercial storages using a small tank sprayer (Figure 1) as grain is transferred to an elevating screw auger (Figure 2). Grain loaded into large-scale commercial structures is treated as it moves along a conveyer belt or where the grain is diverted into a storage bin. Generally,

chemical protectants that are subject to regulated residue tolerances should be applied once during the storage period to uninfested commodity. Protectants that are exempt from a residue tolerance, such as diatomaceous earth, can be applied multiple times, but it is rare to find commodities treated repeatedly with protectants. Several protectants are registered in the United States. Some of the older protectants have been cancelled due to regulation (1996 Food Quality Protection Act). Others that are legally registered for use are no longer recommended because insects have developed high levels of resistance.

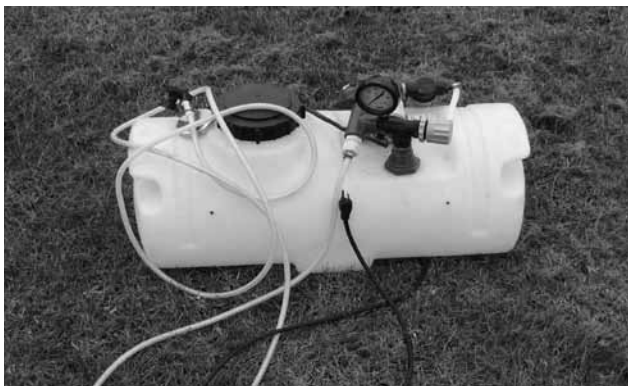

Figure 1. *Small tank sprayer for applying grain protectants (photo courtesy of F. H. Arthur, USDA-ARS-CGAHR).*

Figure 2. *Wheat being loaded into a small bin. The protectant insecticide is often applied as the grain is falling into the auger boot (photo courtesy of F. H. Arthur, USDA-ARS-CGAHR).*

There have also been changes in the way protectants should be applied to commodities. Before 1997 it was acceptable to use any suitable handheld sprayer. Some current labels require closed systems for mixing chemicals for applicator safety. Check labels for specific products and application instructions.

Storicide II is labeled for direct application to barley, oats, sorghum, rice, and wheat. It contains 3 parts per million (ppm) chlorpyrifos-methyl and 0.5 ppm deltamethrin. In the United States, Storicide II replaced chlorpyrifos-methyl, which was labeled at 6 ppm on these commodities. Tolerances for chlorpyrifos-methyl applied at 6 ppm were revoked in 2004. Chlorpyrifos-methyl is not effective against the lesser grain borer, *Rhyzopertha dominica* (F.), but the addition of deltamethrin to chlorpyrifos-methyl makes the formulation effective against this species and many other species, at least in the United States where resistance to deltamethrin has not been detected.

Actellic 5E is labeled for use on corn and sorghum at 6 to 8 ppm. The insect growth regulator (IGR) methoprene (Diacon II), is labeled at 1 to 2.5, and 5 ppm for all stored grain. In general, methoprene is effective against externally feeding stored-product insects and the lesser grain borer (Athanassiou et al. 2011a,b) but is less effective against internal feeders, particularly weevils (Arthur and Throne 2003). Methoprene is not effective against psocids (Athanassiou et al. 2010). There are a number of commercial formulations of diatomaceous dusts than can be applied directly to stored grains at varying label rates. Generally, the efficacy of most of these formulations decreases as grain moisture content or relative humidity increases (Subramanyam and Roesli 2000). Although diatomaceous earth is a food-safe material among compounds considered generally regarded as safe, application of effective concentrations of diatomaceous earth to entire grain masses can reduce the bulk density, or test weight, of the grain and reduce its value at the time of sale. In some countries (e.g., Australia) grain intended for export cannot be treated with diatomaceous earth, because it alters physical properties of the grain.

Several insecticides should be mentioned, which are rarely used today as structural sprays or grain protectants. Malathion, first registered in the United States in 1958, received extensive use as a structural spray and grain protectant. During the 1990s many agricultural chemical companies removed malathion formulations from the stored-product market. These products are being replaced with the insecticides previously mentioned because of widespread resistance in major stored-product insect species.

Synergized pyrethrins are a mixture of natural pyrethrins, derived from chrysanthemum flowers, plus the enzyme-suppressing synergist piperonyl butoxide, PBO. Although there are several active labels for commercial formulations of synergized pyrethrins for treating structures and commodity, these prod-

ucts are rarely used. To date, stored-product insects have not shown signs of resistance to synergized pyrethrins. *Bacillus thuringiensis* (*Bt*) (Dipel), is a naturally occurring pathogen that produces a parasporal crystal, which is toxic on ingestion by moth larvae. It is labeled as a surface application to the top of a grain mass primarily to control the Indianmeal moth, *Plodia interpunctella* (Hübner). This product is also effective against other moth pests found in grain. A total of 36 isolates of *B. thuringiensis* specific for beetles tested on the lesser grain borer provided less than satisfactory control (Beegle 1996). Dipel is exempt from a residue tolerance. Grain manager surveys indicate that this product is not used extensively to control moths in grain. Moths can develop high levels of resistance within a few generations of exposure to *Bt* (McGaughey and Beeman 1988). There are no *Bt* formulations registered in the United States to control stored-product beetles.

Concerns about human safety, insect resistance, and environmental impacts require a grain protectant that is highly effective against insects but safe to humans and the environment (Hertlein et al. 2011). One such product is Spinosad, which is derived via fermentation from a naturally occurring soil actinomycete, *Saccharopolyspora spinosa* Mertz and Yao. Spinosad is extremely effective against the lesser grain borer. This insecticide is registered in the United States for use on all grains at 1 ppm, but commercial formulations have not been released pending acceptance of international tolerances (Codex 1 ppm; U.S. 1.5 ppm) by Japan and Australia (Hertlien et al. 2011). The widespread global launch of Spinosad as a grain protectant is anticipated in the near future. Once released, the commercial formulation will be called Contain.

General surface treatments

Surface treatments are insecticides that can be applied over a wide surface area as liquid contact insecticides. Most of the commonly used surface treatments discussed below also can be used as spot or crack and crevice treatments to limited areas. A number of less common insecticides can be used on a limited basis as spot or crevice treatments. These minor use compounds will not be discussed in this chapter. The present discussion is limited to general surface treatments. Perhaps the most common conventional insecticide used as a general surface treatment is cyfluthrin (Tempo SC Ultra). Most of the previous research with this insecticide has been with either emulsifiable concentrate (EC) or wettable powder (WP) formulations (Arthur 2000). In general the red flour beetle, *Tribolium castaneum* (Herbst), and the confused flour beetle, *Tribolium confusum* (Jacquelin duVal), are more difficult to kill than other stored-product beetles (Arthur 2000, 2008). The order of susceptibility varies among insecticides, within the same or different classes of insecticides (Arthur 2008). The neonicotenoid chlorfenapyr (Phantom) was originally labeled for termites, cockroaches, and nuisance ants. Recently the label was expanded to include stored-product insects (Arthur 2009).

Efficacy of surface treatments can be adversely affected by the presence of a food source. When adult red flour beetles were provided with a flour food source either during or after exposure to cyfluthrin WP, survival increased relative to the survival that occurred when beetles were not given food (Arthur 1998). Similar results occurred in studies with chlorfenapyr (Arthur 2008). In other studies in which red flour beetles were placed on whole wheat kernels, dirt, or sawdust after they were exposed to cyfluthrin WP, survival increased then as well compared to survival without extraneous material (Arthur 2000). The presence of food and trash may provide harborage sites where adult beetles can escape exposure to insecticides, in addition to providing a nutritional or physical means to increase their tolerance to exposure (Toews et al. 2009, 2010).

The insect growth regulators hydroprene (Gentrol), methoprene, and pyriproxyfen (NyGard) are currently labeled in the United States as general surface treatments for controlling stored-product insects. Insect growth regulators normally do not give control of adults, although there is evidence of sublethal effects such as reduced fecundity after exposure (Daglish and Pulvirenti 1998). Hydroprene is the most volatile of the labeled insect growth regulators and gives less residual control than either methoprene or pyriproxyfen (Arthur et al. 2009).

Aerosols

These insecticides are liquid formulations that are atomized and dispensed as fine particles ranging from 5 to 50 microns in size, and often resemble a dense fog (Figure 3). Aerosols do not penetrate through packaging materials, bulk food products, or deep into machinery, and should not be confused

Figure 3. *Dispersion of pyrethrin aerosol inside a food storage facility. The aerosol was dispensed from an application system installed in the ceiling, and the insecticide was dispensed outward from the nozzles. (Photo courtesy of F. H. Arthur, USDA-ARS-CGAHR.)*

with fumigants, which are toxic gases that have excellent penetrating ability. There are several insecticides that are labeled in the United States for aerosol applications.

Dichlorvos (Vapona or DDVP) is an organophosphate insecticide that has been used since the 1970s. It has excellent vapor toxicity for exposed insects but little residual activity. Pyrethrins or pyrethroids, used either alone or in combination with insect growth regulators, are also used in pest management programs. Several field studies have shown increased survival of adult confused flour beetles when given food either during or after exposure to pyrethrins (Arthur 2010), hence, sanitation and cleaning are also important aspects of pest control programs when aerosols are used. Species differences between insects also must be taken into account when using aerosols. For example, the Indianmeal moth is a common pest in milling and retail environments. Mature larvae can be difficult to control with insecticides (Mohandass et al. 2007), including aerosol formulations of pyrethrin or pyrethroids (Jensen et al 2010ab). Inclusion of an insect growth regulator such as methoprene may give increased control of larvae compared to using a pyrethroid alone (Jenson et al. 2009, 2010ab). Incorporation of an insect growth regulator into the aerosol mixture will also give residual efficacy for beetle control (Arthur 2010). Methoprene also can be used to fog space above the stored grain to control flying insects.

Conclusions

Insecticides are important components of insect pest management programs for stored grains, mills, processing plants, and retail stores. Sanitation can help improve insecticidal efficacy and reduce economic costs associated with pesticide applications. Biological and environmental factors such as insect species and life stage, environmental temperatures, formulation type, coverage, and application method can influence efficacy of an insecticide.

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publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by Kansas State University or the U.S. Department of Agriculture (USDA). The USDA is an equal opportunity provider and employer. Consult pesticide labels for specific requirements and current uses of the particular insecticide formulation.

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