

Organic Approaches and Regulations for Stored Product Pest Management

Matthew J. Grieshop

Ted Rogers

Frank H. Arthur

The management of pests in organic systems or Organic Pest Management (OPM) has received an increasing amount of attention over the past decade. OPM is similar to Integrated Pest Management (IPM) in that it stresses the use of sampling and thresholds to make pest management decisions, integration of multiple pest management tactics, and the use of less disruptive pest management tactics such as sanitation, aeration, and biological control before turning to chemically based pest management. The primary difference between these two management approaches are the types of tools available to the manager. In the case of IPM in the United States, managers are allowed to use pest management products labeled by the U.S. Environmental Protection Agency (EPA) for their crop, pest, and situation. In OPM, available products and approaches must also meet the more stringent standards of the USDA National Organic Program (NOP).

The Organic Materials Review Institute (OMRI) is a private nongovernmental organization that provides third-party certification to organic inputs. Products that OMRI finds to be in compliance with the NOP carry the OMRI seal and typically are allowed in organic production or handling situations. Organic certifiers — accredited organic certifying agents or USDA-approved state organic programs — determine whether a particular product is allowed. They should be contacted before using any new pest management product. A list of OMRI certified compounds is maintained at www.omri.org.

In agricultural production systems, OPM is typically based upon the development of a healthy soil

and agroecosystem and the use of insect- or disease-resistant cultivars. Stored products represent a special case for OPM because there is limited potential for plant regrowth. The same regulatory standards that apply to agricultural production also apply to products as they move further through the food system.

The national organic rules were fully implemented on Oct. 21, 2002. Since then, producers and handlers must be certified by a USDA accredited organic certifying agent or a USDA-approved state organic program to sell, label, or represent their products as “100 percent organic,” “organic,” or “made with organic (specified ingredients or food group(s)).” The certification agency used by a particular producer or handler need not be in the same state, although state governments may require that the certifier be licensed by the state department of agriculture. The organic rules (7 CFR Part 205) are easily accessed at the National Organic Program website: <http://www.ams.usda.gov/nop/>.

Before October 2002, there were no national standards for organic claims. A few states had requirements for certification and standards for food labeled as organic, and private organizations. For example, California Certified Organic (CCOF) or Oregon Tilth certified products to their own standards or to a particular customer’s standards. The USDA Agricultural Marketing Service (AMS) administers the national standards, but there is no federal inspection or certification. The National Organic Program uses accredited private certifiers or approved state organic programs. State authorities may also act as accredited certifiers using the national standards. The national

organic rules undergo regular review to ensure compatibility with normal operations of organic producers and handlers as well as consumer expectations of the organic label.

Definitions and Procedures

A handler, in the national organic rules, is an inclusive term for anyone who stores, processes or otherwise handles organic products or ingredients, except for final retailers. Retailers are exempt from the certification requirements unless they are processing organic products. Those handling organic products or providing pest management services for a handler of organic products will need to establish a clear, strong, professional relationship with the USDA Accredited Organic Certifying Agent (USDA-AOCA) or the USDA Approved State Organic Program (USDA-ASOP).

The USDA Agricultural Marketing Service National Organic Program has promulgated the final rules and implemented the program. The AMS Administrator and the NOP are the primary interpreters of the rules. The National Organic Standards Board (NOSB) is an advisory committee that functions in accordance with the Federal Advisory Committee Act (5 U.S.C. app. 2 et seq.). The board has specific responsibilities when it comes to the approval of substances to be used in organic production and handling operations as regulated by that part of the rules referred to as the National List. However, the NOSB is also called on by the NOP for advice on a wide variety of issues related to the rules and the program.

Those who work on pest management in an organic handling operation and find difficulties complying with the rules, or if there is a particular input that is thought to be compatible with organic handling, should discuss these issues with the NOP staff and with the NOSB. A process is specified in the national organic rules (§ 205.607 Amending the National List) to petition the NOSB to review new inputs to appear on the National List. These inputs would be approved synthetic materials or classified as a natural (nonsynthetic) substance unless specifically prohibited on the National List. NOSB meetings, as required by the Federal Advisory Committee Act, are public meetings. Opportunities for public comment are always part of meeting agendas.

When working with products that are to be ingredients in organic foods or with organic foods it is wise to be familiar with the entire organic regulation 7 CFR Part 205, but sections of the rule most directly applicable to pest management in organic handling operations are discussed.

- 205.103 Recordkeeping by certified operations.
- 205.201 Organic production and handling system plan.
- 205.271 Facility pest management practice standard.
- 205.272 Commingling and contact with prohibited substance prevention practice standard.

And from the National List:

- 205.601 Synthetic substances allowed for use in organic crop production.
- 205.602 Nonsynthetic substances prohibited for use in organic crop production.
- 205.605 Nonagricultural (nonorganic) substances allowed as ingredients in or on processed products labeled as “organic” or “made with organic (specified ingredients or food group(s)).”

Other sections of the rule may need to be consulted, but these provide a basic understanding of pest management activities that are or are not approved and how to document them.

Section 205.103 – Recordkeeping by certified operators

Records addressed under this section include transactional records that are not dealt with by pest managers. Records of pest management inputs used — whether baits and traps or pesticides — are required. Transactions for lease or contracting for heating or chilling equipment are other examples of non-chemical records required that might support and verify the organic handling plan.

Section 205.201 – Organic production and handling system plan

This section lists the regulatory requirements of an organic plan. The purpose of an organic plan is to describe the details of an organic system, and could be extensive for large facilities or simple for small operators. Plans must be agreed to by both the

organic handler and the USDA Accredited Organic Certifying Agent or Approved State Organic Program, which emphasizes the importance of the relationship with those programs. The organic plan must reflect all practices and procedures used for pest management, plus a list of all inputs that may be used including sources, composition, and locations where used. The plan would also include descriptions of the monitoring practices instituted in the handling facility and the frequency with which they will be performed. Monitoring refers to pest monitoring and also refers to the process of monitoring for compliance with the plan.

Recordkeeping practices must also be covered and include requirements described in section 205.103. Practices ensuring that no organic product comes in contact with prohibited substances must also be addressed in the organic plan. In working with the USDA certifying agent and state organic program, additional information may be required in the plan for a particular facility.

Section 205.271 – Facility pest management practice standard

The facility pest management practice standard as expressed in section 205.271 is based on intensive preventative management. Hermetic sealing to generate a low-oxygen condition, vacuum sealing to generate a low oxygen condition, chilling practices, and heat treatments are acceptable. The use of carbon dioxide or nitrogen to generate a low-oxygen atmosphere is also acceptable practice. Carbon dioxide is registered as a fumigant and is listed in section 205.605(b). Nitrogen, oil free grade, is listed in 205.605(a) as an allowed nonsynthetic in this form in processed products as a processing aid. Ozone is another gas of interest to organic handlers but is only registered as an antimicrobial (disinfectant) and could not currently be used as a fumigant regardless of any organic status.

The rule specifies preventive management as a first line of defense, followed by mechanical or physical control methods. These methods are briefly described in more detail later in the chapter, and many are described in detail in other chapters of this volume. Mechanical or physical methods include traps, light, and sound. They also include lures and repellents using natural or synthetic substances consistent with the National List. Physical or mechanical method-

ologies other than those listed in the standard also may be acceptable. In accordance with the Organic Hierarchy of Pest Management — Section-205.206, the use of a pesticide consistent with the National list is available for use only after preventative management, mechanical controls, or physical control methods have proved ineffective.

Section 205.272 – Commingling and contact with prohibited substance prevention practice standard

Section 205.272 paragraph (a) is a simple statement prohibiting the commingling of organic and nonorganic products. Additionally, any contact of organic products with prohibited substances is not allowed and requires that any handler have in place measures to prevent any such occurrence. Paragraph (b) contains a pair of specific prohibitions directly required by the Organic Food Production Act of 1990. The first specific prohibition in subparagraph (b)(1) denies the use of any packaging materials and storage containers, including bins, that contain a synthetic fungicide, preservative, or fumigant. The second prohibition in subparagraph (b)(2) is intended to prevent the inadvertent contact of organic products with a prohibited substance that might be in any bag or container used or reused for the storage or packaging of organic products or ingredients.

The National List (Sections 205.601 - 205.606 – The List)

This list is derived from an interpretation of the language in the Organic Food Production Act of 1990, which is the statutory basis for the NOP rules. In approaching the list, the first consideration is that any natural (nonsynthetic) substance is considered approved for use in organic production or handling unless it is specifically prohibited on the list. Any natural substance that is registered with EPA for use on stored grains, other raw agricultural commodities, or in food storage facilities or food processing plants is by definition approved for use in organic handling operations. Likewise, all synthetic substances are prohibited for use in organic handling operations unless they appear on the list.

Pesticide Formulations and Their Relationship to The List

Section 205.601 – Synthetic substances allowed for use in organic crop production

This section covers the synthetic substances that are active and inert ingredients in any pesticide formulation used for pest control in stored products. Any such substance must be labeled and registered for such use by the U.S. Environmental Protection Agency (EPA). In section 205.601(m)(1), synthetic inert pesticide ingredients used in formulations of pesticides in organic production and handling operations are limited only to those registered inert ingredients classified by EPA as List 4 – Inerts of Minimal Concern. Unfortunately List 4 is no longer used by EPA; it exists as an obsolete artifact and has not been used to classify inerts for several years. More information about this appears later in this chapter. This places any pest manager in a difficult and uncertain situation because inert ingredients do not appear on pesticide labels and are not generally published. These inert ingredients often are considered proprietary and are covered by confidential business information regulations where the contents cannot be revealed even by regulators.

OMRI provides independent and confidential review of input formulations. OMRI listing does not guarantee that a particular pesticide is certified for use in organic systems. The final decision on any input remains in the hands of the certifier (USDA-AOCA or ASOP) although many certifiers will list accepted commonly used inputs, and typically they do allow the use of OMRI listed products.

The EPA is also proceeding to review all new inerts and inerts for which there was not enough data to make safety decisions. The result of these reviews is that those with adequate safety data are classified as not needing any tolerance in foods (no tolerance required). Neither the National Organic Program nor the National Organic Standards Board have developed an inerts policy that reflects the EPA process. The board is also intent on reviewing some of the more critical inert ingredients not appearing on the out-of-date List 4 and then placing them on the National List if they are deemed appropriate for use

in pesticide formulations used in organic production and handling operations.

The pest manager has to be circumspect in making choices among pesticide formulations, even those with natural or allowed synthetic active ingredients. This is another reason to establish a strong professional relationship with federal and state certifying officials. What follows is a list of the pesticide active ingredients and methodologies that appear to be acceptable for use as pest control agents or techniques in pest management systems in facilities handling organic labeled ingredients or finished products. This list is rendered from a reading of the regulations appearing as 7 CFR Part 205. The previous discussion of inert ingredients is a necessary preface to this list.

Over the years, some products will be removed from the National List (205.601- 205.606) and other products will be added, so this list cannot be projected as accurate beyond a few months to a year after the publication date of this chapter. It does illustrate the extent of the pest management tools available to the pest manager faced with the responsibility of management in a facility handling organic products. Any product used as a pesticide must have EPA pesticide registrations and labels for the specific use intended.

Nonsynthetic substances such as pyrethrum, neem, diatomaceous earth (DE), or spinosad (recently reviewed by the NOSB) are designated as nonsynthetic substances and not prohibited from use in organic production and handling. Registered and labeled products containing these ingredients for use in storage and processing applications may be used in or around organic products or commodities so long as they have OMRI or certifier approval. Pyganic® (MGK) has recently received such a label and may be used in organic systems. Dow Agrosciences is in the late stages of gaining a stored product use label for Entrust®, its OMRI approved formulation of spinosyn. The common synergist piperonyl butoxide, a derivative of a plant extract, was classified as a synthetic substance and by definition prohibited in organic production and handling. As a result, any substance containing piperonyl butoxide is prohibited.

Insecticides Approved for Organic Use But Not Currently Labeled for Stored Products

Neem – The active ingredient in neem, azadirachtin, is a terpenoid derived from the Indian neem tree, *Azadirachta indica*. It produces direct toxicological effects on larvae and adult insects, and its effects are similar to insect growth regulators on the immature stages (Immaraju 1998). Extensive tests have been conducted with neem against agricultural pests. Reviews have been published during the last 10 to 15 years (Trisyono and Whalen 1999), but very little published research has been reported for insect pests of stored grains or food warehouses.

One recent report (Makanjuola 1989) describes laboratory and field tests with neem from seed and leaf extracts for control of stored-product beetles. More research data are needed to determine the effectiveness and practicality of neem for postharvest markets. Currently, the production of azadirachtin is labor-intensive and expensive compared to synthetic insecticides, and may be restricted to high-value markets (Immaraju 1998). Although there are several registrations in the United States for neem (Immaraju 1998), at this time there are no commercial products labeled for use on stored commodities or as surface or aerosol treatments in food warehouses. Pest managers must keep current on such neem labeling as changes occur.

Spinosad – This is a broad-spectrum biological pesticide that has been evaluated against a variety of insect orders, and is labeled for more than 100 crops in the United States (Thompson et al. 2000, Hertlien et al. 2011). It is highly effective at low label rates against insect pests in stored grains (Fang et al. 2002). In May 2002, spinosad received an experimental use permit (EUP) for direct application to wheat. Additional trials have been conducted on stored grain with great success against both beetles and moths (Toews et al. 2003, Flinn et al. 2004, Huang et al. 2004, Getchall et al. 2008, Huang and Subramanyam 2007, Subramanyam et al. 2007). The registrant (DowAgrosciences) has also tested spinosad for use in processing, structural, and stored product applications. Entrust® was found to be highly toxic to many stored product pest natural enemies (Toews and Subramanyan 2004).

Spinosad received a label by the US-EPA in 2005 for application to stored grains and also received allowable international residue tolerances. Spinosad has not been marketed in the United States because some countries will not allow spinosad residues on imported wheat. This matter had not been resolved as of press time. A registration of Entrust®, Dow's organic formulation of spinosad on stored products is expected sometime in the near future.

Insecticides Approved for Organic Use and Currently Labeled for Stored Products

Boric acid – This dust is one of the oldest registered insecticides. It is strictly limited to structural pest control, and is not labeled for direct contact with organic food or crops. It is used for void treatments in dry areas against insects that may use these sites as harborages.

Pyrethrins – Pure pyrethrum and mixtures without any synergist are approved for use, but without a synergist, the pyrethrum is less effective. Pyrethrins without a synergist may not give sufficient control at economical application rates when used in pest management programs for stored products. Pyganic® was not found to be effective at managing psocids in wheat, rice, or corn (Guedes et al. 2008, Athanassiou et al. 2009), but little work has been published regarding its effect on major internal and external feeding stored product beetles or moths.

Diatomaceous earth – This is an inert dust composed of fossilized skeletons from microscopic single-celled plants called diatoms. It kills insects through interference with the lipid layer in the exocuticle and through desiccation (Glenn et al. 1999). Commercial diatomaceous earth formulations can be manufactured from marine or freshwater sources, and there are many products currently available in the United States and throughout the world for direct application to grains and for structural applications inside mills, warehouses, and processing plants (Quarles and Winn 1994, Subramanyam and Roesli 2000). The physical characteristics of the individual particles, origin of the deposits, and presence of added material can all affect insecticidal efficacy of commercial diatomaceous earth formu-

lations (Korunic 1997, Fields and Korunic 2000). Insect species also vary in their response to diatomaceous earth. Small mobile beetles and immature stages are particularly vulnerable (Mewis and Ulrichs 2001), while less-mobile species and larger beetles are often more tolerant in comparison (Arthur 2001, 2002). Most diatomaceous earth formulations tend to lose effectiveness with increases in grain moisture content or relative humidity (Golob 1997, Korunic 1998, Arthur 2000, Athanassiou et al. 2005). Some formulations contain added ingredients such as food attractants, silica, and other products to enhance toxicity. It is essential that the use of a particular diatomaceous earth formulation be discussed in advance as part of the management plan and be approved for use by federal and state certifying officials.

Physical Control Treatments for Organic Use

Bulk Grains

Hermetic sealing – Hermetic sealing to create low-oxygen conditions for pest control has been used for more than 2,500 years (Adler et al. 2000). The time required for oxygen depletion depends on many factors, including the specific commodity, moisture content, temperature, volume, and storage structure (Hill et al. 1983). Most of the research conducted in this area has been with underground bunker-type storage of raw grains in low-moisture environments, particularly in the middle East and in Australia (Adler et al. 2000). Little current research in the United States exists on hermetic sealing for insect control in bulk grains. The use of carbon dioxide or nitrogen to generate a low-oxygen atmosphere is also acceptable practice. Carbon dioxide is registered as a fumigant and is listed in section 205.605(b). Nitrogen, oil-free grade is listed in 205.605(a) as an allowed nonsynthetic in this form in processed products as a processing aid. Ozone is another gas of interest to organic handlers but is only registered as an antimicrobial (disinfectant) and could not currently be used as a fumigant regardless of any organic status.

Vacuum sealing – Over the past several years a system of low pressure application, or vacuum sealing has been developed which circumvents some of the obvious problems of vacuum sealing of stored products, both bulk and packaged. The system can

be applied to bulk product in bags or to packaged products in packages that will withstand the external pressures from vacuum sealing of the products. The system utilizes large heavy gauge flexible polyvinyl chloride (PVC) bags, known commercially as “cocoon,” which can be used to create a container for bagged or otherwise packaged products. These “cocoon” are sealed and evacuated with a vacuum pump creating a low pressure environment with an atmosphere very low in oxygen. Oxygen levels of 1 to 2% prove insecticidal to all live stages of major stored product insect pests when applied at common room temperatures for 1 to 4 days. (Mbata et al., 2001, 2004, 2005; Phillips 2006, Phillips et al. 2007). Commercial scale vacuum treatment will take longer than traditional fumigation (e.g., 4 hours for methyl bromide), but it can be done in buildings while workers are present and poses no risk because there is no chemical input, simply removal of air from the cocoon.

Aeration for cooling bulk grains – Aeration is generally defined as the practice of using low-volume ambient air to cool bulk grains, and is an important component of grain management in temperate climates throughout the world (Armitage et al. 1994, Mason et al. 1997, Arthur et al. 1998, 2001, Arthur and Casada 2005, 2010). This process utilizes fans that either draw air into the bottom of the grain bins and forces a cooling front upward in the bin, or air can be brought into the bin from the top to force the front downward through the grain mass. The purpose of aeration is not to kill insects, but instead to cool the grain below levels that support insect population growth and development. Growth and reproduction of most stored-product insects ceases at 60°F (15°C) (Howe 1965, Fields 1992), so this temperature is commonly used as an initial threshold in management plans (Arthur et al. 2001, Arthur and Flinn 2000). Airflow rates are usually specified in the United States as 0.1 to 0.5 cubic feet per minute (cfm) per bushel, or 0.0013 to 0.0065 m³/s/m³. It is important to differentiate aeration from grain drying, which often utilizes rates of much greater magnitude to dry grain immediately after harvest, and also can involve specialized heating equipment (Reed and Arthur 2000).

Grain chilling – Chilling treatments in stored raw commodities are accomplished using commercial refrigerating equipment designed to quickly cool large bulk bins and elevator silos (Mason et al. 1997,

Maier et al. 1997). Commodities are usually cooled to 10 to 15°C, so there is very little mortality of insect pests even when using chilling technology (Burks et al. 2000). If commodities are held for long periods of time, chilling could eventually eliminate pests. Initial costs for chilling equipment are high, but long-term costs when amortized over time can be compatible with other pest management strategies such as fumigation or aeration with ambient air (Mason et al. 1997, Roulon et al. 1999).

Heat treatments – Heating systems for bulk grains have been devised using fluidized beds, radiation, or microwave technology (Burks et al. 2000). Although high temperatures can kill insects, the costs of older equipment and technology used for heating whole grains often were prohibitive compared to other methods. The ability of insects to acclimate to lethal temperatures or the difficulties involved in heating a bulk grain mass must also be considered when discussing heat as a control method for bulk grains. Grains can crack, harden, and become brittle if heating is introduced too quickly or if excessive temperatures occur during the process (Burks et al. 2000), and the germ could also be damaged by extreme heat. In addition, milling characteristics and baking quality can also be affected by extreme temperatures (Lupano and Anon 1986, 1987, Guerrieri and Cerletti 1996). Although new equipment and technologies may reduce the costs of heating for disinfestation of bulk grains, the concerns regarding effects on product quality may limit the use of heat to kill insects in bulk grain.

Mills, Processing Plants, and Warehouses

Cold treatments – Cold treatments have been tried as a whole-plant disinfestation strategy in flour mills in western Canada (Worden 1987). In one case, the mill was opened during the winter, and the outside air was used to lower the temperature to levels that would be lethal to insects. This method is not very practical, given the ability of insects to acclimate to cold temperatures, the effects of extreme temperatures on milling and processing equipment, and the processes required to distribute these temperatures equally throughout the mill (Burks et al. 2000). Also, the plant may need to be shut down for several days while the cold temperatures are maintained, causing losses in production and income. Cold treatments are more likely to be used as chamber treatments

to disinfest bagged or packaged commodities. Even when used in this manner, the time required to bring the core temperature in the center of the room to the desired level could be several days (Mullen and Arbogast 1979). The same difficulties will occur when chilling bulk commodities in chambers.

Heat treatments – The use of heat to kill insects dates back to the early 20th century (Dean 1911, 1913). New technologies and advances in heating equipment and design are contributing to renewed interest in using heat for insect control (Dowdy and Fields 2002, Wright et al. 2002). Thermal requirements for mortality are known for most of the economically important stored product insects (Howe 1965, Fields 1992), and several private companies are actively using heat as a part of their management strategies. Treatments of heat combined with diatomaceous earth appear to be effective and can reduce lethal temperatures or time intervals required for complete kill of exposed insects (Dowdy 1999, Dowdy and Fields 1992). Heat treatments also can be used in small-scale chamber or vacuum fumigations. The procedures, difficulties in transferring heat, and the ability of insects to partially acclimate would be similar to challenges for using cold treatments in small chambers.

Additional Control Measures

Section 205.271(d) allows for a situation in which all the previously discussed approaches have failed. In that situation, use of any registered pesticide (this would include fumigants and rodenticides) might be used; however, *contact of these prohibited substances with organic ingredients or products must be prevented*. Such a treatment must be agreed on by the handler and the USDA-Accredited Organic Certifying Agent or Approved State Organic Program, and methods of application and measures to prevent contact with organic products must be included in the agreement. Paragraph (f) makes a similar allowance for treatment required by federal, state or local authorities, with the same stipulation about contact with organic products. While these allowances provide for emergency treatment of infested facilities, they would not allow the treatment of organic products that were themselves infested. In that situation, the products or their approval for the organic label would be sacrificed. Any application of

a nonsynthetic or synthetic substance to control or prevent pest infestations would require an update of the facility's organic plan. The update would have to include the substance used, method of application, and measures to assure that contact with organic products or ingredients was prevented (Section 205.271(e)). Organic stored product management includes rules requiring strict segregation of organic ingredients and products from commingling with nonorganic ingredients or products. A repetition of the requirement of prevention of contact of any organic ingredient or product with prohibited substances is stated in Section 205.272 .

Commingling and Contact with Prohibited Substance Prevention Practice Standard

Details are not included here because they are only marginally relevant to organic stored product pest management. Stored product managers in general may be interested in this section of the rule.

Conclusion

The rules for handling organic products, particularly pest management in storage and processing facilities, are unquestionably challenging. Many tools are available to help the modern pest manager meet the requirements specified for handling organic products. Intensive integrated pest management techniques can eliminate much of the need for pesticides. The rules (7 CFR Part 205) emphasize an intensive approach to pest management. Personnel with high levels of management skill and training will be needed to successfully carry out such approaches.

To deliver pest management for organic stored products, either for a company or a client, the regulations as described and explained in this chapter must be followed. It is most important to establish a strong professional relationship with the USDA Accredited Organic Certifying Agent or the state authority certifying under a USDA-approved state organic program. This relationship will be immensely important in solving problems before they arise. Vigilance and circumspection from those responsible for pest management decisions will be required not only in managing the system but in the changing regulatory

environment as new pesticides and approved inert ingredients become part of the equation. *When in doubt about the use of a pesticide, whether synthetic or nonsynthetic, do not use it until clarification is received from the USDA-Accredited Organic Certifying Agent or USDA-Approved State Organic Program.*

As national organic standards evolve, participate in discussions among the National Organic Program, National Organic Standards Board, USDA-AOCA or USDA-ASOP, and the public. Involvement will help the practical evolution of the program and regulatory framework.

Acknowledgments and Disclaimer

This paper reports the results of research only. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by Kansas State University, Michigan State University, or the U.S. Department of Agriculture (USDA). The USDA is an equal opportunity provider and employer.

References

- Adler, C., H. Corinth, and C. Reichmuth. 2000. Modified Atmospheres. pp. 105-146 *In* Bh. Subramanyam and D. W. Hagstrum, (eds.). Alternatives to pesticides in stored product IPM, Kluwer Academic Publishers, Boston, MA.
- Armitage, D.M., P.M. Cogan, and D.R. Wilkin. 1994. Integrated pest management in stored grain: Combining surface insecticide treatments with aeration. *J. Stored Prod. Res.* 30: 303-319.
- Arthur, F.H. 2000. Toxicity of diatomaceous earth to red flour beetles and confused flour beetles: Effects of temperature and relative humidity. *J. Econ. Entomol.* 93: 526-532.
- Arthur, F.H. 2001. Immediate and delayed mortality of *Oryzaephilus surinamensis* (L.) exposed on wheat treated with diatomaceous earth: Effects of temperature, relative humidity, and exposure interval. *J. Stored Prod. Res.* 37: 13-21.
- Arthur, F.H. 2002. Survival of *Sitophilus oryzae* (L.) on wheat treated with diatomaceous earth: Impact of biological and environmental parameters on product efficacy. *J. Stored Prod. Res.* 38: 305-313.
- Arthur, F. H. and Casada, M. 2005. Feasibility of summer aeration for management of wheat stored in Kansas. *Appl. Eng. Agric.* 21: 1027-1038.
- Arthur, F.H. and Casada, M.E. 2010. Directional Flow of summer aeration to manage Insect pests in stored wheat. *Appl. Eng. Agric.* 26: 115-122.

- Arthur, F. H. and P.W. Flinn. 2000. Aeration management for stored hard red winter wheat: simulated impact on rusty grain beetle (Coleoptera: Cucujidae) populations. *J. Econ. Entomol.* 93: 1364-1372.
- Arthur, F.H., J.E. Throne, D.E. Maier and M.D. Montross. 1998. Initial cooling cycles for corn stored in the southern United States: Aeration strategies based on weather data. *Am. Entomol.* 44: 118-123.
- Arthur, F.H., J.E. Throne, D.E. Maier, and M.D. Montross. 2001. Impact of aeration on maize weevil (Coleoptera: Curculionidae) populations in corn stored in the northern United States: simulation studies. *Am. Entomol.* 47: 104-110.
- Athanassiou, C.G., F.H. Arthur, and J.E. Throne. 2009. Efficacy of grain protectants against four psocid species on maize, rice and wheat. *Pest Man. Sci.* 65: 1140-1146.
- Athanassiou, C.G., B.J. Vayias, C.B. Dimizas, N.G. Kavallieratos, A.S. Papagregoriou, and C. T. Buchelos. 2005. Insecticidal efficacy of diatomaceous earth against *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Tribolium confusum* du Val (Coleoptera: Tenebrionidae) on stored wheat: influence of dose rate, temperature and exposure interval. *J. Stored Prod. Res.* 41: 47-55.
- Boina, D., Bh. Subramanyam, S. Alavi. 2008. Dynamic model for predicting survival of mature larvae of *Tribolium confusum* during facility heat treatments. *J. Econ. Entomol.* 101: 989-997.
- Burks, C.S., J.A. Johnson, D.E. Maier, and J.W. Heaps. 2000. Temperature. pp. 73-104 *In* Bh. Subramanyam and D.W. Hagstrum, (Eds.). *Alternatives to pesticides in stored-product IPM*. Kluwer Academic Publishers, Boston, MA.
- Dean, D.A. 1911. Heat as a means of controlling mill insects. *J. Econ. Entomol.* 4: 142-158.
- Dean, D.A. 1913. Further data on heat as a means of controlling mill insects. *J. Econ. Entomol.* 6: 40-53.
- Dowdy, A.K. 1999. Mortality of red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae) exposed to high temperature and diatomaceous earth combination. *J. Stored Prod. Res.* 35: 175-182.
- Dowdy, A.K. and P.G. Fields. 2002. Heat combined with diatomaceous earth to control the confused flour beetle (Coleoptera: Tenebrionidae) in a flour mill. *J. Stored Prod. Res.* 38: 11-22.
- Flinn, P.W., Bh. Subramanyam, and F. H. Arthur. 2004. Comparison of aeration and spinosad for suppressing insects in stored wheat. *J. Econ. Entomol.* 97: 1465-1473.
- Fang, L., Bh. Subramanyam, and F. H. Arthur. 2002. Evaluation of spinosad on four classes of wheat against 5 stored-product insects. *J. Econ. Entomol.* 95: 640-650.
- Fields, P. and Z. Korunic. 2000. The effect of grain moisture content and temperature on the efficacy of diatomaceous earths from different geographical locations against stored-product beetles. *J. Stored. Prod. Res.* 36: 1-13.
- Fields, P.G. 1992. The control of stored-product insects and mites with extreme temperatures. *J. Stored Products Res.* 28: 89-118.
- Flinn, P.W., Bh. Subramanyam, and F. H. Arthur. 2004. Comparison of aeration and spinosad for suppressing insects in stored wheat. *J. Econ. Entomol.* 97: 1465-1473.
- Getchall, A. and Bh. Subramanyam. 2008. Immediate and delayed mortality of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) and *Sitophilus oryzae* (Coleoptera Curculionidae) adults exposed to spinosad-treated commodities. *J. Econ. Entomol.* 101: 1022-1027.
- Glenn, D.M., G.J. Puterka, T. Vanderwet, R.E. Byers, and C. Feldhake. 1999. Hydrophobic particle films, a new paradigm for suppression of arthropod pests and plant diseases. *J. Econ. Entomol.* 92: 759-771.
- Golob, P. 1997. Current status and future perspectives for inert dusts for control of stored product insects. *J. Stored Prod. Res.* 33: 69-79.
- Guedes, R.N.C., J. F. Campbell, F.H. Arthur, G.P. Opit, K.Y. Zhu, and J.E. Throne. 2008. Acute lethal and behavioral sublethal responses of two stored-product psocids to surface insecticides. *Pest Man. Sci.* 64: 1314-1332.
- Guerrieri, N. and P. Cerletti. 1996. Effect of high-temperature short-time treatment of wheat flour on gluten vitality and structure. *Cereal Chem.* 73: 375-378.
- Hertlein, M.B., G.D. Thompson, B. Subramanyam, and C. G. Athanassiou. 2011. Spinosad: a new natural product for stored grain protection. *J. Stored Prod. Res.* (In Press)
- Hill, R.A., J. Lacey, and P.J. Reynolds. 1983. Storage of barley grain in iron age type underground pits. *J. Stored Prod. Res.* 19: 163-171.
- Howe, R.W. 1965. A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. *J. Stored Products Res.* 1: 177-184.
- Huang, F., and Bh. Subramanyam. 2007. Effectiveness of spinosad against seven major stored-grain insects on corn. *Insect Sci.* 14 (3): 225-230.
- Huang, F., Bh. Subramanyam, and M.D. Toews. 2004. Susceptibility of laboratory and field strains of four stored-product insect species to spinosad. *J. Econ. Ent.* 97: 2154-2159.
- Immaraju, J.A. 1998. The commercial use of azadirachtin and its integration into viable pest control programmes. *Pestic. Sci.* 54: 285-289.
- Korunic, Z. 1997. Rapid assessment of the insecticidal value of diatomaceous earths without conducting bioassays. *J. Stored Prod. Res.* 33: 219-229.
- Korunic, Z. 1998. Diatomaceous earths, a group of natural insecticides. *J. Stored Prod. Res.* 34: 87-97.
- Lupano, C.E. and M.C. Anon. 1986. Denaturation of wheat germ proteins during drying. *Cereal Chem.* 63: 259-262.
- Lupano, C.E. and M.C. Anon. 1987. Denaturation of wheat endosperm proteins during drying. *Cereal Chem.* 64: 437-442.
- Maier, D.E., R.A. Rulon, and L.J. Mason. 1997. Chilled versus ambient aeration and fumigation of stored popcorn Part 1: temperature management. *J. Stored Prod. Res.* 33: 39-49.

- Mahroof, R. and Bh. Subramanyam. 2007. Susceptibility of *Plodia interpunctella*. (Hubner)(Lepidoptera: Pyralidae) to high temperatures used during structural heat treatments. Mahroof, R. and Bh. Subramanyam. Bull. Entomol. Res. 97: 539-545.
- Makanjuola, W.A. 1989. Evaluation of extracts of neem (*Azadirachta indica* A. Juss) for the control of some stored product pests. J. Stored Prod. Res 25: 231-237.
- Mason, L.J., R.A. Rulon, and D.E. Maier. 1997. Chilled versus ambient aeration and fumigation of stored popcorn Part 2: pest management. J. Stored Prod. Res. 33: 51-58.
- Mbata, G.N., T.W. Phillips, and M. Payton. 2004. Mortality of eggs of stored-product insects held under vacuum: effects of pressure, temperature, and exposure time. J. Econ. Entomol. 97: 695-702.
- Mbata, G.N., and T.W. Phillips. 2001. Effects of temperature and exposure time on mortality of stored-product insects exposed to low pressure. J. Econ. Entomol. 94: 1302-1307
- Mbata, G.N., M. Johnson, T.W. Phillips, and M. Payton. 2005. Mortality of life stages of cowpea weevil (Coleoptera: Bruchidae) exposed to low pressure at different temperatures. J. Econ. Entomol. 98: 1070-1075.
- Mewis, I. and Ch. Ulrichs. 2001. Action of amorphous diatomaceous earth against different stages of the stored product pests *Tribolium confusum*, *Tenebrio molitor*, *Sitophilus granarius* and *Plodia interpunctella*. J. Stored. Prod. Res. 37: 153-164.
- Mullen, M.A. and R.T. Arbogast. 1979. Time-temperature-mortality relationships for various stored-product insect eggs and chilling times for selected commodities. J. Econ. Entomol. 72: 476-478.
- Phillips, T.W. 2006. The Science and Technology of Postharvest Insect Control: Challenges, Accomplishments and Future Directions. Chapter 18 pp. 211-222, In J. Heaps, (ed.), Insect Management for Food Storage and Processing, 2nd Ed. Am. Assoc. Cereal Chem.
- Phillips, T.W., R. Hulasare, S. Liu and G.J. Hallman. 2007. Vacuum as a methyl bromide alternative for disinfestation of durable and fresh commodities. pp. 557-566, In Donahaye, E.J., S. Navarro, C. Bell, D. Jayas, R. Noyes, T.W. Phillips. (eds.). Proceedings of the International Conference of Controlled Atmosphere and Fumigation in Stored Products, Gold Coast Australia 8-13th August 2004. FTIC Ltd. Publishing. Israel.
- Quarles, W. and P. S. Winn. 1994. Diatomaceous earth and stored product pests. IPM Practitioner 18: 1-10.
- Reed, C. and F. H. Arthur. 2000. Aeration. pp. 51 - 72, In Bh. Subramanyam and D.W. Hagstrum, (eds.). Alternatives to pesticides in stored-product IPM, Kluwer Academic Publishers, Boston, MA.
- Roulon, R.A., D.E. Maier, and M.D. Boehlje. 1999. A postharvest economic model to evaluate grain chilling as an IPM technology. J. Stored Prod. Res. 35: 369-383.
- Subramanyam, B., M.D. Toews, K.E. Ileleji, D.E. Maier, G.D. Thompson, and T.J. Pitts. 2007. Evaluation of spinosad as a grain protectant on three Kansas farms. Crop Prot. 26 : 1021-1030.
- Subramanyam, Bh. and R. Roesli. 2000. Inert Dusts, pp. 321 to 379, In Bh. Subramanyam and D.W. Hagstrum, (eds.). Alternatives to pesticides in stored-product IPM. Kluwer Academic Publishers, Boston, MA.
- Thompson, G.D., R. Dutton, and T.C. Sparks. 2000. Spinosad – a case study: an example from a natural products discovery programme. Pest Manag. Sci. 56: 696-702.
- Toews, M. D., and Bh. Subramanyam. 2004. Survival of stored-product insect natural enemies in spinosad-treated wheat. J. Econ. Ent. 97: 1174-1180.
- Toews, M.D., Bh. Subramanyam, and J.M. Rowan. 2003. Knockdown and mortality of adults of eight species of stored-product beetles exposed to four surfaces treated with spinosad. J. Econ. Ent. 96: 1967-1973.
- Trisyono, A. and M.E. Whalon. 1999. Toxicity of neem applied alone and in combinations with *Bacillus thuringiensis* to Colorado Potato Beetle (Coleoptera: Chrysomelidae). J. Econ. Entomol. 92: 1281-1288.
- Worden, G.C. 1987. Freeze-outs for insect control. Bulletin 4903-4904, Association of Operative Millers, Minneapolis, MN.
- Wright, E.J., E.A. Sinclair, and P.C. Annis 2002. Laboratory determination of the requirements for control of *Trogoderma variabile* (Coleoptera: Dermestidae) by heat. J. Stored. Prod. Res.38: 147-155



Publications from Kansas State University are available at: www.ksre.ksu.edu

Publications are reviewed or revised annually by appropriate faculty to reflect current research and practice. Date shown is that of publication or last revision. Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. In each case, credit the authors, Stored Product Protection, Kansas State University, March 2012.

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, Gary Pierzynski, Interim Director.

S156 – 20 March 2012