PS3-4 - 6280

Performance of spinosad as a stored-grain protectant

Bh. Subramanyam

Abstract

Laboratory and field trials have shown that spinosad, a commercial insecticide based on the fermentation products of a bacterium, to be an effective grain protectant at the labeled rate of 1 mg (a.i.)/kg of grain based on laboratory and field studies in the United States, Kenya, and Australia. Of the stored-product insects tested, the lesser grain borer is highly susceptible to spinosad. Spinosad is not effective in killing adults of the red flour beetle and sawtoothed grain beetle, but neonates of these two species are susceptible to spinosad at 1 mg/kg. Susceptibility of rice weevils at 1 mg/kg increases with an increase in the exposure period. Spinosad is not effective against psocids, and it is toxic to stored-product insect parasitoids. The low mammalian toxicity of spinosad as well as its persistence on grain for a period of one year without loss of insecticidal activity makes it an appealing stored-grain protectant.

Key words: Spinosad, grain protectant, efficacy assessment.

Introduction

Grain protectants are liquids or dusts applied to newly-harvested grain intended for short or long term storage. These products in the United States include malathion dust, pirimiphos-methyl (Actellic®), methoprene (Diacon II®), chlorpyrifos-methyl (Reldan®) plus deltamethrin (Storcide II®), synergized pyrethrins, and several formulations of diatomaceous earth such as Insecto®, Diasource®, Dryacide®, Perma Guard®, and Protect-It®. Grain protectants should be applied only once to newly-harvested grain prior to storage in structures. Application of a protectant is a preventive method as one application ensures protection against insect infestation from several months to more than a year. Occasionally grain that is infested is treated with a protectant as the grain is moved from one storage structure into another, and such treatments are only partially effective in suppressing infestations because some stages, especially those developing inside the kernels, will not be exposed to the insecticide. Research has shown that protectants are not effective when applied to infested grain (Arthur and Throne, 2003), and it is imperative that infested grain be treated with a fumigant, such as phosphine. For this reason, all protectant labels contain language recommending that infested grain be fumigated prior to treatment with the protectant.

An effective protectant should have three basic requirements. First, it should have a broad spectrum of activity against insect pests associated with grain; second, it should be persistent on treated commodities with little loss

of insecticidal activity for at least one year; and third, it should have low mammalian toxicity. The labeled application rate is usually the tolerance level for protectants on grain, except in the case of diatomaceous earth and methoprene, as they are exempt from a residue tolerance. Protectants such as diatomaceous earth can be removed from grain before it is milled by cleaning and aspiration (Desmarchelier and Dines, 1987). However, residues of protectants such as pirimiphos-methyl, malathion, or Storcide II® persist on the grain and in grain fractions at levels well below the established tolerance levels.

Recently registered protectants

A majority of the grain on farms in the US is treated with protectants and treatment of the grain in the marketing channels is usually with the fumigant phosphine. The most commonly used grain protectants in the US include the organophosphorous insecticides malathion, chlorpyrifos-methyl and pirimiphos-methyl. However, under the 1996 Food Quality Protection Act, which set tougher standards for reviewing registered pesticides, the future of organophosphorous compounds in general and these three protectants in particular remained uncertain. The sale and distribution of chlorpyrifos-methyl (Reldan® at 6 mg (a.i.)/kg) ceased as of December 31, 2004, but chloropyrifos-methly (at 3 mg (a.i.)/kg) is available in Storcide II® in combination with deltamethrin. In addition, resistance in key stored-product insects has limited the effectiveness of these three protectants (Subramanyam and Hagstrum, 1995). Therefore, new chemistries or pest management strategies are constantly being explored as alternatives to the traditionally used organophosphates. Since passing of the Food Quality Protection Act, two new compounds have been registered as grain protectants. These include methoprene (this was registered in 1992 before the FQPA) or Diacon II®, an insect growth regulator (hormone mimic) that affects growth, development, and reproduction

of insects, and Storcide II®, a formulation that has half the labeled rate (3 mg (a.i.)/kg) of chlorpyrifos-methyl combined with 0.5 mg (a.i.)/kg of deltamethrin, a synthetic pyrethroid that has accepted international tolerances. In January 2005, spinosad received US Environmental Protection Agency's approval as a grain protectant at 1 mg (a.i.)/kg on barley, millets (foxtail, proso, and pearl), oats, rice, sorghum (milo), triticale, wheat, and birdseed (Federal Register 2005, Vol. 70: 1349-1357). The maximum residue limits for spinosad on grain were approved by The CODEX Committee on Pesticide Residues in 2005. The US tolerance for spinosad is 1.5 mg/kg and the CODEX tolerance is 1 mg/kg. The registrant of spinosad, Dow AgroSciences (Indianapolis, Indiana, USA), has been working with the grain industry and various countries for approval of spinosad tolerances on grain. Launch of commercial products will be delayed until international tolerances are in place. This article is therefore timely to educate grain managers in the world about a novel product that can be used in the future for effectively managing insect pests associated with stored grain.

Spinosad, a reduced-risk insecticide

Spinosad is a reduced-risk commercial insecticide used for management of many insect pest species on a variety of crops (Thompson et al., 2000). The activity of spinosad is attributed to the metabolites spinosyns A and D, which are fermentation products of the soil actinomycete bacterium, *Saccharopolyspora spinosa* (Mertz and Yao) (Mertz and Yao, 1990). Spinosad has low mammalian toxicity and it is environmentally benign (Bret et al., 1997). Spinosad is toxic to insects by ingestion or contact, and it acts on the insect nervous system at the nicotinic acetylcholine and gamma-aminobutyric acid (GABA) receptor sites (Sparks et al., 2001). Poisoned insects exhibit involuntary muscle contractions and tremors, followed by hyperexcitation and paralysis (Salgado, 1998).

Spectrum of activity of spinosad on stored-product insects

Laboratory and field trials in the US (Fang et al., 2002a,b; Toews and Subramanyam, 2003; Toews et al., 2003; Flinn et al., 2004; Huang et al., 2004), Kenya (Mutambuki et al., 2002), and Australia (Nayak et al., 2005; Daglish and Nayak, 2006) have shown spinosad to be an effective compound against a wide variety of insect species associated with stored grain at a low rate of 1 mg/kg. Tests have been conducted on corn, wheat, and sorghum and also with liquid and dry formulations (Getchell, 2006). Effectiveness is measured based on adult mortality and failure to produce the next generation (progeny) on spinosad-treated grain (Fang et al., 2002a). As with any insecticide, there is variation in how different insect species and stages of insects respond to spinosad-some are highly susceptible while others are less susceptible. For instance, the lesser grain borer, a devastating pest of stored wheat worldwide, is highly susceptible to spinosad, even at rates as low as 0.1 mg/kg, one-tenth the approved label rate (Fang et al., 2002b). The larger grain borer, a species in the same family (Bostrichidae) as the lesser grain borer, which is a serious pest of stored corn in East and West Africa, is also highly susceptible to very low rates of spinosad (Mutambuki et al., 2002). The adults of the red flour beetle and sawtoothed grain beetle are less susceptible to spinosad (Fang et al., 2002a,b; Flinn et al., 2004). However, the young larvae of these species are highly susceptible to spinosad, because on spinosad-treated grain populations of these two species fail to develop (Toews and Subramanyam, 2003). Spinosad is also not very effective against book lice or psocids (Nayak et al., 2005; Subramanyam, unpublished data), which have recently emerged as economically important pests in Australian stored grain because of their resistance to phosphine. On all other economically important species of beetles and moth pests associated with grain, spinosad is effective at 1 mg/kg in killing adults and/or preventing population growth. Spinosad is not as fast acting on the rice weevil as it is on the lesser grain borer (Fang et al., 2002a; Getchell, 2006), and the adults of the former, therefore, have a chance to lay eggs inside the grain. Exposure of weevils to spinosad-treated grain for 14 days provides complete mortality, however. The maize weevils are more susceptible to spinosad than the rice weevils (Subramanyam, unpublished data). Larvae of the moth pests (Indian meal moth, almond moth, rice moth that was tolerant to pirimiphos-methyl, and Angoumois grain moth) we have tested so far are also highly susceptible to spinosad (Flinn et al., 2004; Huang and Subramanyam, 2004; Subramanyam, unpublished data). In all tests, spinosad performed better on wheat against insects when compared with performance on other grains (Getchell, 2006), and there are difference in responses of insects (except lesser grain borer) on different wheat classes treated with 1 mg/kg of spinosad (Fang et al., 2002a). Laboratory tests, however, showed that the responses of stored-grain insect species to be similar on different varieties of a wheat class (Getchell, 2006). Research from Australia showed that key stored-grain insects resistant to traditionally used grain protectants were susceptible to spinosad at 1 mg/kg (Nayak et al., 2005), and this could be attributed to the unique mode of action of spinosad. As expected, in tests with spinosad-treated whole grain, cracked grain, and grain dust at 1 mg/kg, the insecticide consistently performed better against insects on whole grain than on cracked grain or grain dust (Toews and Subramanyam, 2003). Therefore, applying spinosad to clean grain is important to improve its performance against insects.

## Peformance of spinosad in field trials

Field trials were conducted in Kansas on stored wheat and Indiana on stored corn using farm-size bins (60-125 metric ton capacity). At the application rate of 1 mg/kg, there was about 25-30 % loss of the insecticide during application, resulting in 0.70-0.75 mg/kg spinosad deposition on grain (Subramanyam et al., 2006; Daglish and Nayak, 2006). This

percentage of loss of applied insecticide can be expected with any grain protectant due to the heterogeneous nature of the grain. Although spinosad breaks down within a week when exposed to sunlight, in grain storage environments, spinosad residues persisted for a period of 6 months to a year with minimal loss in insecticidal activity (Figure 1). The absence of sunlight in storage environments possibly prevented degradation of spinosad on stored grains. Trials in Indiana on stored corn revealed that spinosad is stable on grain with minimal loss in insecticidal activity against maize weevils for a period of two years (Dirk Maier, unpublished data). In small bin tests in Oklahoma, Thomas Phillips (unpublished data) showed that spinosad at 1 mg/kg persisted on hard red winter wheat for a period of two years and the residues at the end of two years were still effective in killing and preventing progeny production of the lesser grain borer.

In field trials, very low densities of live adults or no live adults were found in grain samples in bins receiving spinosad treatments, when compared with large number of insects founds in untreated grain samples (Flinn et al., 2004). Grain samples collected monthly from farm bins were exposed to insects in the laboratory to determine insect mortality and production of progeny on treated grain. The species tested included the lesser grain borer, red flour beetle, rusty grain beetle, maize weevils, and Indian meal moth. Spinosad at 1 mg/kg provided excellent control of adults of all of these species during the six months to one year test period, with the exception of the red flour beetle, which is less susceptible (Figures 2 and 3). However, progeny production of all of these species was greatly suppressed, including that of the red flour beetle (Subramanyam et al., 2006).
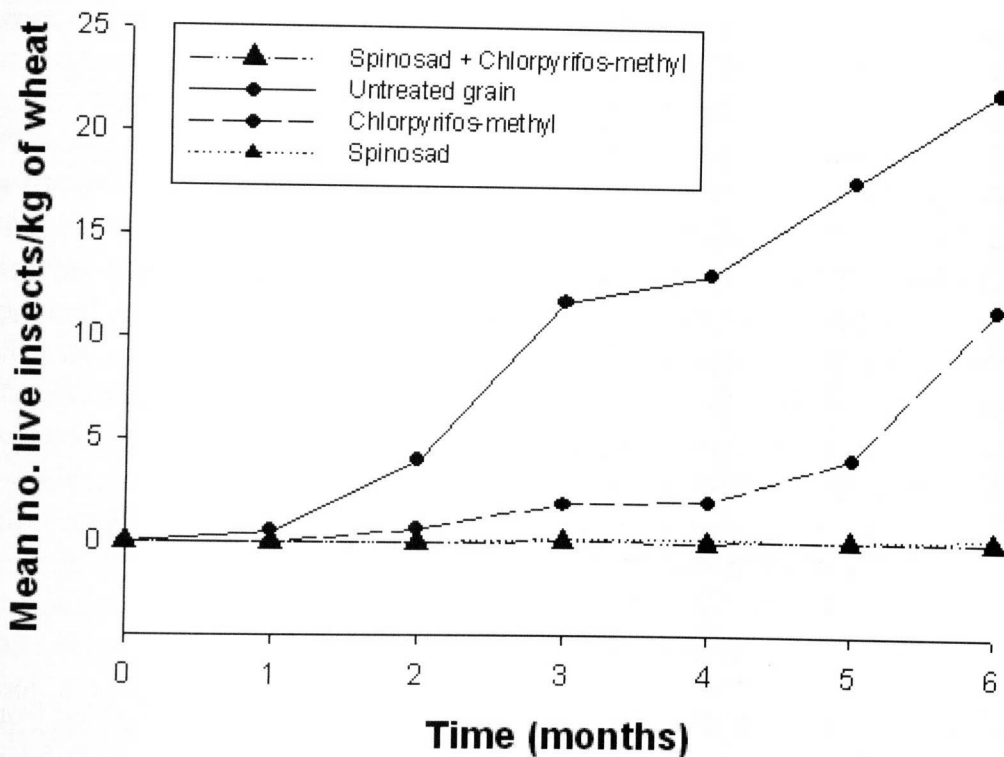
Figure 1. Live insects from grain samples collected from farm bins in Kansas during July 2002-January 2003 receiving no treatment (untreated), chlorpyrifos-methyl at 3 mg/kg (half the labeled rate), spinosad at 1 mg/kg, and spinosad at 1 mg/kg combined with chlorpyrifos-methyl at 3 mg/kg. The data presented are based on three replications (farm bins) (Subramanyam et al., 2006).
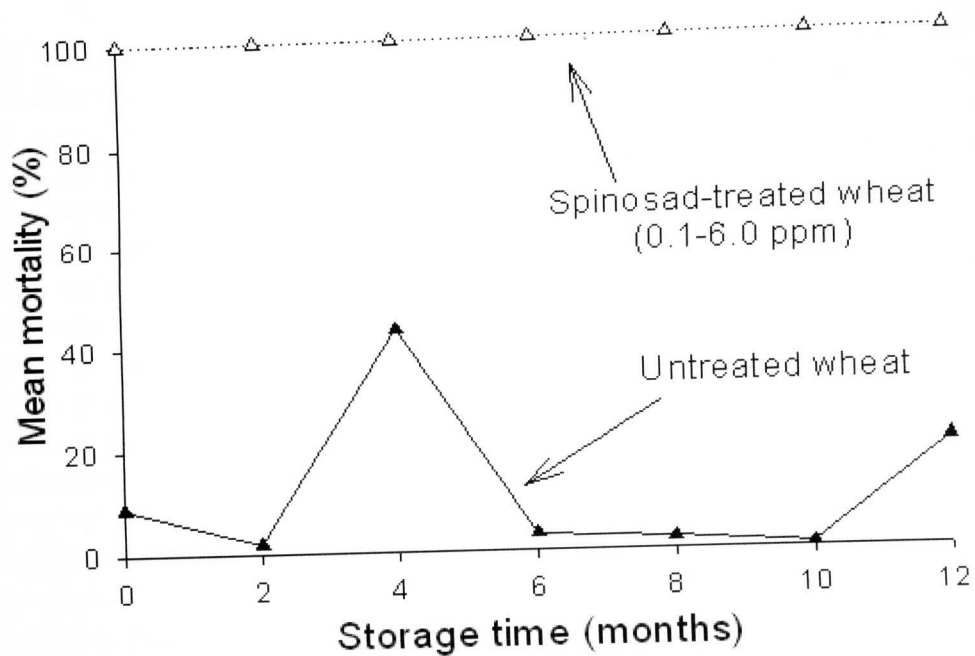
Figure 2. Mortality of adults of lesser grain borer exposed for 14 days to untreated wheat and wheat treated with 0.1, 0.5, 1, 3, and 6 mg/kg of spinosad. The wheat samples from farm bins were collected monthly over a period of 12 months. The data presented are based on three replications (farm bins) (Fang et al., 2002b).
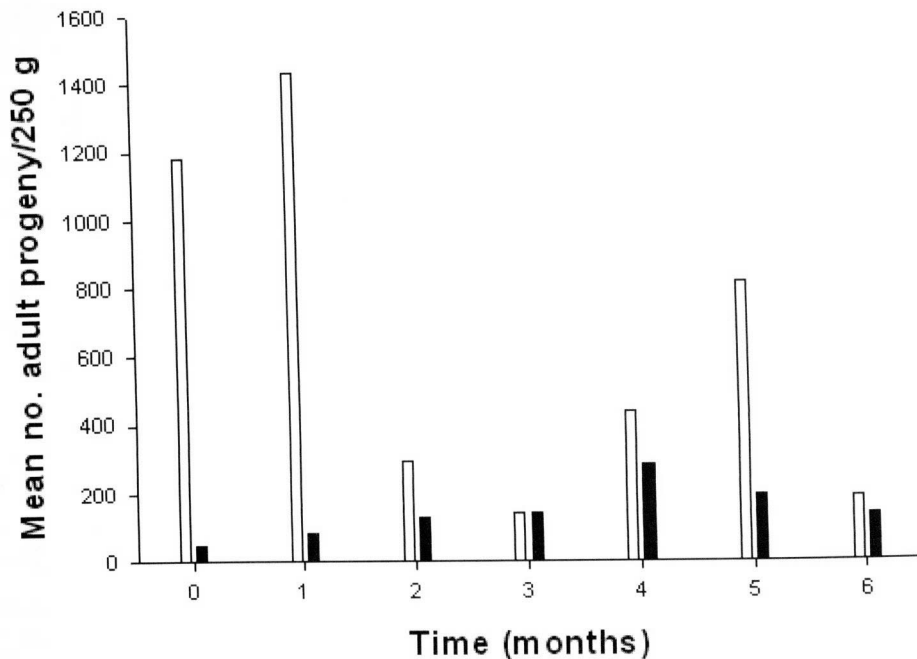
Figure 3. Adult progeny of lesser grain borer produced on wheat samples collected from Kansas farm bins during July 2002-January 2003. Each sample (250 g) was infested with 50 adults and these samples were examined 8 weeks later to count adult progeny produced. The data presented are based on three replications (farms). The clear bars represent progeny numbers in the control treatment and the solid black bars represent numbers in the chlorpyrifos-methyl treatment. There were no progeny in the spinosad or spinosad + chlorpyrifos-methyl treatment (Subramanyam et al., 2006).

In Kenya, Mutambuki et al. (2002) reported that spinosad dust formulation at 0.35, 0.70, and 1.44 mg/kg applied once to stored corn provided effective control of larger grain borer and maize weevils for a period of 24 weeks (6 months).

Compatibility with natural enemies

In laboratory tests, Toews and Subramanyam (2004) reported that spinosad is toxic to parasitoids at the labeled rate. The warehouse pirate bug (predator), however, survived spinosad treatment. Field studies are needed to study the additional benefit accrued from releasing predators in grain treated with spinosad for suppression of stored-grain insects.

Commercial product availability

Commercial products of spinosad for use on stored grain will not become available until international tolerances are accepted by countries importing US grains. Two companies, Bayer CropScience and Agriliance, will be marketing commercial spinosad formulations for use on stored grain. Grain protectants are usually available in liquid and dry formulations, and there are plans for spinosad to be made available in both formulations. In situations where there is no electrical hook up, the use of dry formulations may be preferable. Recent research at K-State showed that the spinosad dry formulation at 1 mg/kg was as effective as the liquid spinosad against several insect species on wheat, corn, and sorghum (Getchell, 2006). In addition, a formulation with spinosad plus pirimiphos-methyl may be available primarily for use on stored corn and sorghum. The spinosad active ingredient is organic certified by the United States Department of Agriculture's National Organics Standard Board, and the prospects of an organic formulation for use on organic grains looks promising.

Spinosad will be another viable product that grain managers can use in the future along with existing protectants. However, it is important to use existing and any new grain protectants by keeping integrated pest management practices in mind. Some of these practices include sanitation and treatment of empty storage facilities prior to storing grain, disinfesting grain handling equipment, grain cleaning, aeration, temperature and insect monitoring, grain turning, and use of fumigants as needed.

Acknowledgments

References

Arthur, F.H., Throne, J.E., 2003. Efficacy of diatomaceous earth to control internal infestations of rice weevil and maize weevil (Coleoptera: Curculionidae).

Journal of Economic Entomology 96, 510-518.

Bret, B.L., Larson, L.L., Schoonover, J.R., Sparks, T.C., Thompson, G.D., 1997. Biological properties of spinosad. Down to Earth 52, 6-13.

Daglish, G.J., Nayak, M.K., 2006. Long-term persistence and efficacy of spinosad against *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in wheat. Pest Management Science 62, 148-152.

Desmarchelier, J., Dines, J.C., 1987. Dryacide treatment of stored wheat: its efficacy against insects, and after processing. Australian Journal of Experimental Agriculture 27, 309-312.

Fang, L., Subramanyam, Bh., Arthur, F.H., 2002a. Effectiveness of spinosad on four classes of wheat against five stored-product insects. Journal of Economic Entomology 95, 640-650.

Fang, L., Subramanyam, Bh., Dolder, S., 2002b. Persistence and efficacy of spinosad residues in farm-stored wheat. Journal of Economic Entomology 95, 1102-1109.

Flinn, P.W., Subramanyam, Bh., Arthur, F.H., 2004. Comparison of aeration and spinosad for suppressing insects in stored wheat. Journal of Economic Entomology 97, 1465-1473.

Getchell, A.I., 2006. Efficacy of two spinosad formulations on various commodities against stored-product insects. M. S. thesis, Kansas State University, Manhattan, 76 pp.

Huang, F., Subramanyam, Bh., 2004. Responses of *Corcyra cephalonica* (Stainton) to pirimiphos-methyl, spinosad, and combinations of pirimiphos-methyl and synergized pyrethrins. Pest

Management Science 60, 191-198.

Huang, F., Subramanyam, Bh., Toews, M.D., 2004. Susceptibility of laboratory and field strains of four stored-product insect species to spinosad. Journal of Economic Entomology 97, 2154-2159.

Mertz, E.P., Yao, R.C., 1990. *Saccharopolyspora spinosa* sp. nov. isolated from soil collected in a sugar rum still. International Journal of Systematic Bacteriology 40, 34-39.

Mutambuki, K., Ngatia, C.M., Mbugua, J.N., Likhayo, P., 2002. Evaluation of the efficacy of spinosad dust against major stored insect pests, pp. 888-891. In: Credland, P. F., Armitage, D.M., Bell, C.H., Cogan, P.M., Highley, E. (eds.). Proceedings of the 8th International Working Conference on Stored Product Protection, York 22-26 July 2002. CAB International, Wallingford, United Kingdom.

Nayak, M.K., Daglish, G.J., Byrne, V.S., 2005. Effectiveness of spinosad as a grain protectant against resistant beetle and psocid pests of stored grain in Australia. Journal of Stored Products Research 41, 455-467.

Salgado, V.L., 1998. Studies on the mode of action of spinosad: Insect symptoms and physiological correlates. Pesticide Biochemistry and Physiology 60, 91-102.

Sparks, T.C., Crouse, G.D., Durst, G., 2001. Natural products as insecticides: the biology, biochemistry, and quantitative structure-activity relationships of spinosyns and spinosoids. Pest Management Science 57, 896-905.

Subramanyam, Bh., Hagstrum, D.W., 1995. Resistance measurement and management,

pp. 331-397. In: Subramanyam, Bh., Hagstrum, D.W. (eds.). Integrated management of insects in stored products. Marcel Dekker, Inc., New York.

Subramanyam, Bh., Toews, M., Ileleji, K.E., Maier D.E., Thompson G.D., Pitts, T.J., 2006. Evaluation of spinosad as a grain protectant on three Kansas farms. Crop Protection (in review).

Thompson, G.D., Dutton, R., Sparks, T.C., 2000. Spinosad-a case study: an example from a natural products discovery programme. Pest Management Science 56, 696-702.

Toews, M.D., Subramanyam, Bh., 2003. Contribution of contact toxicity and wheat condition to mortality of stored-product insects exposed to spinosad. Pest Management Science 59, 538-544.

Toews, M.D., Subramanyam, Bh., 2004. Survival of stored product insect natural enemies in spinosad-treated wheat. Journal of Economic Entomology 97, 1174-1180.

Toews, M.D., Subramanyam, Bh., Rowan, J., 2003. Knockdown and mortality of adults of eight species of stored-product beetles exposed to four surfaces treated with spinosad. Journal of Economic Entomology 96, 1967-1973.