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Review

Modern stored-product insect pest management

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Abstract: Stored-product entomologists have a variety of new monitoring, decision-making, biological, chemical, and physical pest management tools available to them. Two types of stored-product insect populations are of interest: insects of immediate economic importance infesting commodities, and insects that live in food residues in equipment and facilities. The sampling and control methods change as grain and grain products move from field to consumer. There are also some changes in the major insect pest species to take into consideration. In this review, we list the primary insect pests at each point of the marketing system, and indicate which sampling methods and control strategies are most appropriate. Economic thresholds for insect infestation levels developed for raw commodity storage, processing plants, and retail business allow sampling-based pest management to be done before insect infestations cause economic injury. Taking enough samples to have a representative sample (20–30 samples) will generally provide enough information to classify a population as above or below an economic threshold.

Key words: decision making, economic threshold, marketing chain, monitoring

Introduction

Modern stored-product entomologists have many tools that were not available to the pioneers of stored product protection (Hagstrum and Subramanyam 2006; Hagstrum *et al*. 2013). A variety of new decision-making, monitoring as well as biological, chemical, and physical pest management tools are available. Choosing the best sampling and pest control method for each point of the marketing chain provides the most cost-effective pest management program. Pest management is most cost-effective when managers monitor insect levels to determine whether infestation levels have reached a threshold insect-density level at which pest management is needed to prevent economic losses. If insects are allowed to reach high numbers, this can have greater effects later on in the marketing chain. The reason is that larger amounts of commodity are involved, which, have correspondingly higher pest management costs. Also, commodity damage is cumulative and can only increase over time. Flinn and Hagstrum (1990) and Hagstrum and Flinn (1990) illustrated how computer simulations with insect population growth models can be used to optimise the timing of pest management. Predictive computer models are available for 14 stored product pest species and four natural enemy species (Hagstrum and Subramanyam 2006).

Insect populations

Two types of stored-product insect populations are of interest: insects of immediate economic importance infesting commodities, and insects that live in food residues in equipment and facilities. Insects leaving commodities may sustain the residual population and insects from residual populations may infest commodities. Commodity samples can be used to estimate insect populations of economic importance. Residual populations, however, are often smaller and more difficult to estimate. Sanitary removal of residues can reduce the residual insect population and the likelihood that insects from the residual population will infest commodities. Pitfall probe traps have been used in stored grain to determine whether insect pest management is needed in commodities. Pheromone-baited sticky traps have been used to determine whether pest management of residual populations is needed to keep insects from infesting commodities.

Marketing system

The sampling and control methods change as grain and grain products move from field to consumer. There are also some changes in the major insect pest species. Using wheat and wheat products as an example, we will discuss the major insect pests, sampling methods, and treatment options that are available as wheat moves from the farm to regional elevator and then to flour mills, and as wheat products move from the processing facility to distribution warehouses and then to retail stores.

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Farm storage

After wheat is harvested, it is either sold directly to the elevator or mill or can be stored by the farmer who later sells it to the elevator. Metal bins are normally used for farm storage. These range in size from a 1,000 bu to over a 10,000 bu capacity (27–270 metric tons). Hard red winter wheat is normally harvested from early June up until August, depending on the latitude in the USA.

The main insect pests on stored wheat in the USA are: *Rhyzopertha dominica* (F.), *Cryptolestes ferrugineus* (Stephens), *Sitophilus oryzae* (L.), and *Tribolium castaneum* (Herbst). Grain can be sampled one or two months after storage. A grain trier and a sieve are used to separate insects from the grain. If more than 1 or 2 insects/kg that are injurious to grain are found, the grain should be fumigated. Insect pitfall probe traps can also be used for monitoring. These traps should be pushed into the grain so the top of a trap is below the surface. A trap should be left in place for 3 to 5 days. Insect traps do not catch insects when the grain temperature is below 20°C and they only sample near the grain surface, so they should be used with caution.

Ideally, the grain would also be aerated using an aeration controller to run fans during the night to cool the grain only when ambient air is cooler than the average grain temperature (Flinn *et al*. 1997; Reed and Harner 1998a, b). This process can be started soon after harvest in some geographical regions. Once all of the grain mass is below 20°C, aeration can stop and sampling is not necessary because the insects will not develop and will eventually die at that temperature. Aeration can be more effective if bins are cleaned prior to filling with wheat. The grain can also be treated with an insecticide before it is loaded into the bin. The problems with this approach are that it may be an unnecessary expense and may select for insecticide resistant insects. However, if aeration is not possible, this may be a good alternative.

Elevator storage

Elevator storage is usually composed of large upright concrete bins. Grain is moved from bin to bin using horizontal conveyor belts below the bins, a vertical bucket elevator to raise grain to the top of the elevator, and spouting or another horizontal conveyor belt to carry grain to the new bin. The insect species that are major pests on wheat stored in elevators in the USA are *S. oryzae*, *R. dominica*, *T. castaneum*, and *C. ferrugineus*. Sampling these insect pests is very difficult because the bins may be over 30 m tall. Low sampling rates result in few infestations being discovered. Sometimes, insect hotspots are detected by thermocouple cables in the grain. However, insect density is way above the 2/kg threshold by the time grain heating occurs. Cleaning bins prior to filling and removal of residual grain are as important at the elevator as it is on the farms (Reed *et al*. 2003; Arthur *et al*. 2006).

The grain can be sampled as it is moved from one bin to another by using an automatic sampler or by manually taking samples off the conveyor belt. Elevator managers routinely segregate grain by test weight, moisture and protein content. Grains are then blended from several bins to have a more uniform quality. The cost to move the grain is high, and the cost of adding phosphine pellets to fumigate the grain as it is moved is low. The consequence is that the elevator manager may frequently add phosphine tablets when moving the grain from bin to bin without sampling first to see if treatment is necessary. Another option is to use a vacuum probe sampler in combination with an inclined sieve to sample insects as deep as 12 m into the grain mass (Flinn *et al*. 2007). Once all of the bins at an elevator have been sampled, the manager can fumigate only those bins that have infestations above a certain threshold. In the USA, this is normally done when insect density is equal to or greater than 2 insects/kg of wheat.

A method to treat grain without having to move it or probe the phosphine tablets into the grain is recirculation or closed loop fumigation. This method was developed in Europe in the early 1900's to more evenly distribute the fumigant through the grain mass (Monro 1956). Closed loop fumigation has more recently been investigated in the USA (Lindgren and Vincent 1962; Cook 1984). Ideally the grain would be sampled about six weeks after it has been put into storage. Closed loop fumigation (Jones *et al*. 2011) could then be used to treat the grain if insect density is equal to or greater than 2/kg. After the grain is fumigated, controlled aeration using cool nighttime air could be used to cool the grain to below 20°C. Once the grain temperature is below 20°C, additional sampling and fumigation should not be necessary if the grain is sold before it warms in the spring.

Food processors

Flour mills purchase wheat from elevators or may have contracts to purchase grain directly from farmers. The main insect pest species at mills are *T. castaneum* and *Plodia interpunctella* (Hübner). It has been found that *Sitophilus* spp. is a problem for pasta at food processors (Chapman 1923; Babarinde *et al*. 2013). Insect monitoring methods include pheromone traps, tailings samples, and inspection of facilities and incoming ingredients. Inspections and grids of pheromone-baited sticky traps can be used to locate infested areas of the processing plant. Then, pest control can be focused on these areas.

Many insects are removed from wheat by cleaning before milling. Impact machines are used for dry wheat to release insects from the kernels before cleaning with a scourer-aspirator which removes the insects (Anonymous 1952). Impact machines are also used throughout mills: for tempered wheat ahead of first break roll, on screenings, on blending stocks, on returned goods, on flour stream, on tailings from flour rebolters, on feed stream, and on flour out of storage. Chemical pesticides cannot be applied directly to processed foods or surfaces that contact food so processors depend more on physical control methods such as building and equipment design, sanitation, stock rotation, packaging, impact machines, and heat treatments. Sanitation alone, is generally not effective, but can improve the effectiveness of other pest management methods. Reduced risk pesticides such as juvenile hormones and spinosad are replacing those chemicals which have a higher mammalian toxicity. Aerosols are used to combat residual insect infestations, but these treatments are not very penetrating and they kill only the insects that are moving around during treatment (Boina and Subramanyam 2012). Aerosols have been improved by adding insect growth regulators that are effective against immature stages and provide longer protection as a result of their slow degradation. Heat treatments which were used in flour mills in the early 1900's (Hansen *et al*. 2011; Subramanyam *et al*. 2011) and were replaced by methyl bromide fumigation are now replacing methyl bromide again since methyl bromide fumigation is being banned as an ozone depleter.

Distribution warehouses and retail stores

Wheat products such as flour, pasta, cereal, and pet food from food processors are shipped to distribution warehouses and then retail stores. The major pest species in distribution warehouses and retail stores are *P. interpunctella* and *T. castaneum*. For pet food at retail stores, *Sitophilus* spp. have been shown to be a problem (Toews *et al*. 2003). Inspection and pheromone-baited sticky traps are the primary methods of monitoring for insect pests in retail stores. Insect resistant packaging is the primary method by which processors can protect their product from insect pests during shipping and in retail stores. Package damage can be quite prevalent (Karitas 1964) and reduces the effectiveness of the packaging for preventing insect infestation. Sanitation and removal of infested products are the primary pest management methods used by retail store managers. Retailers may have contracts with pest control companies to use residual pesticides. Recently, biological control has been used in bakeries and organic food stores in Europe (Prozell and Schöller 2003). Pheromones can also be used for insect control as attracticides, for mass trapping and for mating disruption (Savoldelli and Trematerra 2011; Campos and Phillips 2014).

Transportation of commodites

Insects are moved through the marketing systems with wheat and wheat products, but low sampling rates can result in few insect infestations being discovered. Using un-infested combines to harvest wheat, and cleaning wheat handling equipment to remove insects and grain residues can help to reduce insect infestation of commodities. The vehicles transporting commodities from one point in a marketing system to another can be a source of infestation. Inspection of transport vehicles for insects, and removing insects and food residues or using chemicals to eliminate residual insect populations can help to prevent contamination of the commodities transported. Vehicles could be designed to make removal of insects and food residues easier. Use of containerised shipping as well as making sure pallets of processed commodities are wrapped with plastic wrap can reduce cross infestation when more than one commodity is transported.

Decision thresholds

Economic thresholds for insect infestation levels have been developed for raw commodity storage, processing plants and retail business (Table 1). The threshold for traps is higher than for commodity samples because traps catch insects over time while commodity samples do not. The threshold is generally lower for processed commodities than for raw commodities because of tighter regulation. The thresholds are generally lower for insects like

Table 1. Economic thresholds for stored-product insect infestation levels

Raw commodities			
Acanthoscelides obtectus (Say)	bean farm	4% bean damage	Baier and Webster 1992
Cryptolestes ferrugineus (Stephens)	wheat farm	2 insects/kg wheat	Subramayam *et al*. 1997
Prostephanus truncatus (Horn)	maize farm	0.2–1 insect/ear of maize	Meikle *et al*. 2000
Rhyzopertha dominica (F.)	grain elevator	2 insects/kg wheat	Flinn *et al*. 2007
Sitophilus zeamais Motschulsky	maize farm	10–20 insects/ear of maize	Meikle *et al*. 2000
Tribolium castaneum (Herbst)	rice warehouse	40 insects/food bait trap	Hodges *et al*. 1997
Processing plant			
Sitophilus oryzae (L.)	rice mill	0.5 insects/trap	Carvalho *et al*. 2013
Lasioderma serricorne (F.)	tobacco processor	5 insects/trap/week	Carvalho *et al*. 2006
Tribolium castaneum (Herbst)	flour mill	2.5 insects/trap/2 weeks	Campbell *et al*. 2010
Retail businesses			
Plodia interpunctella (Hübner)	warehouse	2 insects/trap/day	Arthur *et al*. 2013
Sitophilus spp.	pet store	0.62 insects/trap/week	Toews *et al*. 2003
Sitophilus zeamais Motschulsky	maize trader	5–6% damage	Compton *et al*. 1998

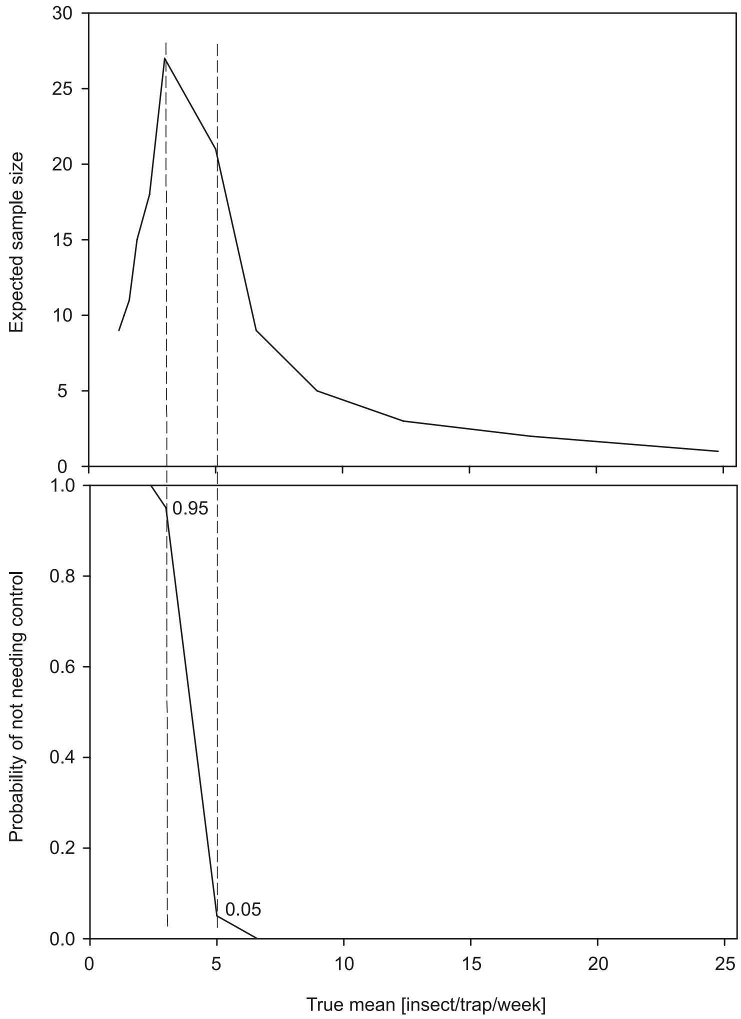

Fig. 1. Average sample number and curves of operating characteristics for *L. serricorne* in a cigarette factory redrawn from Carvalho *et al*. 2006. The vertical dashed lines show the insect density range for which sampling later may be recommended, instead of taking more samples

Sitophilus spp. and *R. dominica* that cause more damage than *Tribolium* spp. Also, thresholds are lower for high value commodities like tobacco than for lower value commodities like wheat.

Sampling

Economic thresholds allow sampling-based pest management to be done before insect infestations cause economic injury. The insect infestation level causing economic injury is not fixed but depends upon the cost of the pest management method used and the market value of the infested commodity. Thus, a less-expensive pest management method or an increase in the market value of a commodity lowers the economic threshold. Operating characteristics and average sample number curves (Fig. 1) can be used to describe the characteristics of a sampling plan that can classify insect populations as above or below a threshold insect density or damage level (Carvalho *et al*. 2006). These curves can explain how sampling can be done cost effectively. Taking enough samples to have a representative sample (20–30 samples in figure 1) will generally provide enough information to classify a population as above or below an economic threshold of 5 insects/trap. A manager only needs to check enough of the 20–30 samples to make a decision. Too many samples are required when the infestation levels are near the threshold, i.e. between the dashed line in figure 1 at 95% probability that no treatment is needed and the dashed line at 5% probability that no treatment is needed. So all insect populations with ≥ 5 insects per trap could be fumigated. The other populations with < 5 insects per trap could be sampled again later. Sampling must be done again before a growing insect population can cause economic losses. Computer simulation models can forecast when to sample again.

Example of using thresholds

The sampling of wheat at 10 rural elevators and one terminal elevator in Kansas, USA, and a similar group in Oklahoma, USA, every six weeks, provided a good example of using economic thresholds and sampling-based fumigation (Flinn *et al*. 2007). A vacuum-probe sampler was used to take ten 3-kg grain samples in the top 12 m of each wheat-containing elevator bin. Each of the ten

3-kg samples was taken over a 1.2 m of grain depth to provide a representative vertical profile of insect density. A computer model was used to predict future risk, based on current insect density, grain temperature, and grain moisture. For the majority of bins (71–80%), safe insect infestations (< 2 insects/kg sample) or high risk of dense infestation (> 2 insects/kg sample) and grain damage was correctly predicted. Fumigation was recommended for high risk bins. Resampling 6-weeks later was recommended for the untreated bins. Damaging insect densities were not predicted in only two out of 399 Kansas bins (0.5%) and in none of the 114 bins in Oklahoma. Only less than 20% of the bins had economically important insect infestations. The numbers of insects at elevators decreased with the depth below the surface as they did on farms. Generally, the bins with high insect densities were close to other highly infested bins (Hagstrum *et al*. 2010). Fumigation was recommended for only those bins with high insect densities instead of fumigating all the bins at a facility. Insect pest management would be more cost-effective if only the bins in which insect densities exceeded an economic threshold because treating only the bins that required fumigation minimised the risk of economic losses from insects, reduced the cost of pest management, and reduced the use of grain fumigant.

Conclusion

Modern stored-product, insect pest management methods can provide better pest monitoring and management at a lower cost while also maintaining high product quality during storage.

References

Anonymous 1952. Mechanical insect control introduced a dozen years ago. Am. Miller 80 (1): 90.

Arthur F.H., Campbell J.F., Toews M.D. 2013. Distribution, abundance, and seasonal patterns of *Plodia interpunctella* (Hübner) in a commercial food storage facility. J. Stored Prod. Res. 53: 7–14.

Arthur F.H., Hagstrum D.W., Flinn P. W., Reed C.R., Phillips T.W. 2006. Insect populations in grain residues associated with commercial Kansas grain elevators. J. Stored Prod. Res. 42 (2): 226–239.

Babarinde G.O., Babarinde S.A., Ogunsola S.O. 2013. Effect of maize weevil (*Sitophilus zeamais* Motschulsky 1855) infestation on the quality of three commercial pastas. Food Sci. Quality Manage. 21 (1): 1–11.

Baier A.H., Webster B.D. 1992. Control of *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae) in *Phaseolus vulgaris* L. seed stored on small farms. I. Evaluation of damage. J. Stored Prod. Res. 28 (4): 289–293.

Boina D., Subramanyam B. 2012. Insect management with aerosols in food-processing facilities. p. 195–212. In: "Insecticides – Advances in Integrated Pest Management" (F. Perveen, ed.). InTech Europe, Rijeka, Croatia. http://www.intechopen.com/books/insecticides-advances-in-integratedpest-management/insect-management-with-aerosols-in-food-processing-facilities [Accessed: August 15, 2013].

Campbell J.F., Toews M.D., Arthur F.H., Arbogast R.T. 2010. Long-term monitoring of *Tribolium castaneum* populations in two flour mills: rebound after fumigation. J. Econ. Entomol. 103 (3): 1002–1011.

Campos M., Phillips T.W. 2014. Attract-and-kill and other pheromone-based methods to suppress populations of the Indian meal moth (Lepidoptera: Pyralidae). J. Econ. Entomol. 107 (1): 473–480.

Carvalho M.O., Passos de Carvalho J., Torres L.M., Mexia A. 2006. Developing sequential sampling plans for classifying *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae) status in a cigarette factory. J. Stored Prod. Res. 42 (1): 42–50.

Carvalho M.O., Faro A., Subramanyam B. 2013. Insect population distribution and density estimates in a large rice mill in Portugal – A pilot study. J. Stored Prod. Res. 52: 48–56.

Chapman R.N. 1923. The possibility of transmitting a *Calendra* infestation from wheat to macaroni thru the processes of milling and manufacturing. J. Econ. Entomol. 16 (4): 341–348.

Compton J.A.F., Floyd S., Magrath P.A., Addo S., Gbedevi S.R., Agbo B., Bokor G., Amekupe S., Motey Z., Penni H., Kumi S. 1998. Involving grain traders in determining the effect of postharvest insect damage on the price of maize in African markets. Crop Prot. 17 (6): 483–489.

Cook J.S. 1984. Use of controlled air to increase the effectiveness of fumigation of stationary grain storages. p. 419–424. In: Proc. Int. Conference on Controlled Atmosphere and Fumigation in Grain Storages (B.E. Ripp, ed.), Perth, Australia, 11–22 April 1983. Elsevier, Amsterdam, 798 pp.

Flinn P.W., Hagstrum D.W. 1990. Simulations comparing the effectiveness of various stored-grain management practices used to control *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Environ. Entomol. 19 (3): 725–729.

Flinn P.W., Hagstrum D.W., Muir W.E. 1997. Effects of time of aeration, bin size, and latitude on insect populations in stored wheat: A simulation study. J. Econ. Entomol. 90 (2): 646–651.

Flinn P.W., Hagstrum D.W., Reed C.R., Phillips T.W. 2007. Stored Grain Advisor Pro: Decision support system for insect management in commercial grain elevators. J. Stored Prod. Res. 43 (4): 375–383.

Hagstrum D.W., Flinn P.W., Reed C.R., Phillips T.W. 2010. Ecology and IPM of insects at grain elevators and flat storages. Biopestic. Int. 6 (1): 1–20.

Hagstrum D.W., Klejdysz T.Z., Subramanyam Bh., Nawrot J. 2013. Atlas of Stored-Product Insects and Mites. Am. Assn. Cereal Chem. (AACC) Int., St. Paul, Minnesota, USA, 599 pp.

Hagstrum D.W., Subramanyam Bh. 2006. Fundamentals of Stored Product Entomology. Am. Assn. Cereal Chem. (AACC) Int., St. Paul, Minnesota, USA, 323 pp.

Hansen J.D., Johnson J.A., Winter D.A. 2011. History and use of heat in pest control: a review. Int. J. Pest Manage. 57 (4): 267–289.

Hodges R.J., Smith M., Madden A., Russell D., Gudrups I., Halid H. 1997. Development of a decision support system for the fumigation of milled-rice bag-stacks in the tropics. p. 425–434. In: Proc. Int. Conference on Controlled Atmosphere and Fumigation in Stored Products (E.J. Donahaye, S. Navarro, A. Varnava, eds.), Cyprus, April 1996. Printco Ltd., Nicosia, Cyprus, 700 pp.

Jones C., Hardin J., Bonjour E. 2011. Design of closed-loop fumigation systems for grain storage structures. Oklahoma Cooperative Extension Fact Sheet BAE-1111. http://osufacts.okstate.edu [Accessed: August 15, 2013].

Karitas J.J. 1964. Breakage and damage in grocery warehouses and retail food stores. United States Department of Agriculture (USDA) – Agriculture Research Service (ARS), Agricultural Market Service, Marketing Research Report No. 652, Washington, USA, 63 pp.

Lindgren D.L., Vincent L.E. 1962. Fumigation of food commodities for insect control. p. 85–152. In: "Advances in Pest Control Research" Vol. 5 (R.L. Metcalf, ed.). John Wiley & Sons, New York, USA, 326 pp.

Meikle W.G., Holst N., Degbey P., Oussou B. 2000. Evaluation of sequential sampling plans for the larger grain borer (Coleoptera: Bostrichidae) and the maize weevil (Coleoptera: Curculionidae) and of visual grain assessment in West Africa. J. Econ. Entomol. 93 (6): 1822–1831.

Monro H.A. 1956. History of the use of the recirculation method for applying fumigants in grain storage. Down to Earth 11 (4): 19–21.

Prozell S., Schöller M. 2003. Five years of biological control of stored-product moths in Germany. Advances in stored product protection. p. 322–324. In: Proc. 8th Int. Working Conference on Stored Product Protection (P.F. Credland, D.M. Armitage, C.H. Bell, P.M. Cogan, E. Highley, eds.), York, UK, 22–26 July 2002, 1071 pp.

Reed C.R., Hagstrum D.W., Flinn P.W., Allen R.F. 2003. Wheat in bins and discharge spouts, and grain residues on floors of empty bins in concrete grain elevators as habitats for stored-grain beetles and their natural enemies. J. Econ. Entomol. 96 (3): 996–1004.

Reed C., Harner J. 1998a. Cooling of stored wheat in multiple or single cycles using automatic aeration controllers. Appl. Eng. Agric. 14 (5): 497–500.

Reed C., Harner J. 1998b. Thermostatically controlled aeration for insect control in stored hard red winter wheat. Appl. Eng. Agric. 14 (5): 501–505.

Savoldelli S., Trematerra P. 2011. Mass-trapping, mating-disruption and attracticide methods for managing stored-product insects: success stories and research needs. Stewart Postharvest Review 3: 7. DOI: 10.2212/spr.2011.3.7 http://www.stewartpostharvest.com/Archives/Archives_Issue3_December_2011.htm [Accessed: August 15, 2013].

Subramanyam B., Mahroof R., Brijwani M. 2011. Heat treatment of grain-processing facilities for insect management: a historical overview and recent advances, Postharvest Review 3: 10. DOI: 10.2212/spr.2011.3.10 http://www.stewartpostharvest.com/Archives/Archives_Issue3_December_2011.htm [Accessed: August 15, 2013].

Subramanyam B., Hagstrum D.W., Meagher R.L., Burkness E.C., Hutchinson W.D., Naranjo S.E. 1997. Development and evaluation of sequential sampling plans for *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) infesting farm-stored wheat. J. Stored Prod. Res. 33 (4): 321–329.

Toews M., Subramanyam Bh., Roesli R. 2003. Development and validation of sequential sampling plans for *Sitophilus* species associated with pet specialty stores. p. 115–120. In: "Advances in Stored Product Protection" (P.F. Credland, D.M. Armitage, C.H. Bell, P.M. Cogan, E. Highley, eds.). Proc. 8th Int. Working Conference on Stored Product Protection, York, UK, 22–26 July 2002. CABI International, Wallingford, UK, 1071 pp.