In: Beetles: Biodiversity, Ecology and Role in the Environment ISBN: 978-1-63463-380-2
Editor: Camilla Stack

Chapter 5

BIOLOGY, ECOLOGY AND STRATEGIES FOR CONTROL OF STORED-GRAIN BEETLES: A REVIEW

Thiago H. Napoleão, Afonso C. Agra-Neto, Bernardo R. Belmonte, Emmanuel V. Pontual and Patrícia M.G. Paiva*

Departamento de Bioquímica, Centro de Ciências Biológicas, Universidade Federal de Pernambuco, Cidade Universitária, Recife, Pernambuco, Brazil

ABSTRACT

Beetle species belonging to the coleopteran families Bruchidae, Curculionidae, Laemophoeidae, Silvanidae and Tenebrionidae, as well as beetle-like insects from the psocopteran family Liposcelidae, are responsible for serious damages to agricultural products and resources. These beetles can be primary and/or secondary pests, feeding on integral and healthy grains or attacking those already damaged. The affected grains lose weight and germination power, are decreased in nutritive value and vigor, and are impaired by hygiene and sanitary conditions. This chapter summarizes information on biological and ecological aspects of stored product pests such as life cycle, fecundity, longevity, growth rate, voracity, natural habitats and hosts, and infestation focuses of beetles. These aspects are important for the development and choice of control measures. Classic strategies include mechanical methods, biological control, and the use of insecticide formulations such as powders, emulsions, aerosols, and microcapsules. Fumigation with phosphine has been the main strategy for control but this insecticide is highly volatile and toxic and increasingly there are reports of insect resistance to it. In this sense, natural insecticides, such as plant extracts, secondary metabolites, essential oils and lectins, have been investigated for insecticidal activity on destructive beetles. In summary, this chapter provides a brief and updated view of the state of the art on beetles that act as stored grain pests.

[*]Correponding author: E-mail: ppaivaufpe@yahoo.com.br Tel: +55 81 21268540; fax: +55 81 21268576.

1. DAMAGES TO AGRICULTURE CAUSED BY STORED-GRAIN PESTS

Grains such as sorghum, maize, rice and wheat are the main components of basic food in many countries. Since the harvest of grains occurs seasonally while the market demand is relatively unceasing, the storage step has a critical role in the global economy (FAO, 1994; Bilia et al., 2004). In this sense, the deterioration of stored products is a problem for agriculture, mainly in tropical regions, where the seeds are often subjected to high temperatures and humidity. In addition to physical and chemical factors, the stored grains can also be damaged by biological agents such as insect pests (Tavares and Vendramim, 2005; Silveira et al., 2006; Alencar et al., 2011). The insects belonging to the orders Coleoptera (beetles) and Psocoptera (booklice and barklice, also referred as beetle-like) cause most of the damage to stored grains. Figure 1 shows representative drawings of important species of the coleopteran families such as Bruchidae, Curculionidae, Laemophoeidae, Silvanidae and Tenebrionidae, and the psocopteran family, Liposcelidae.

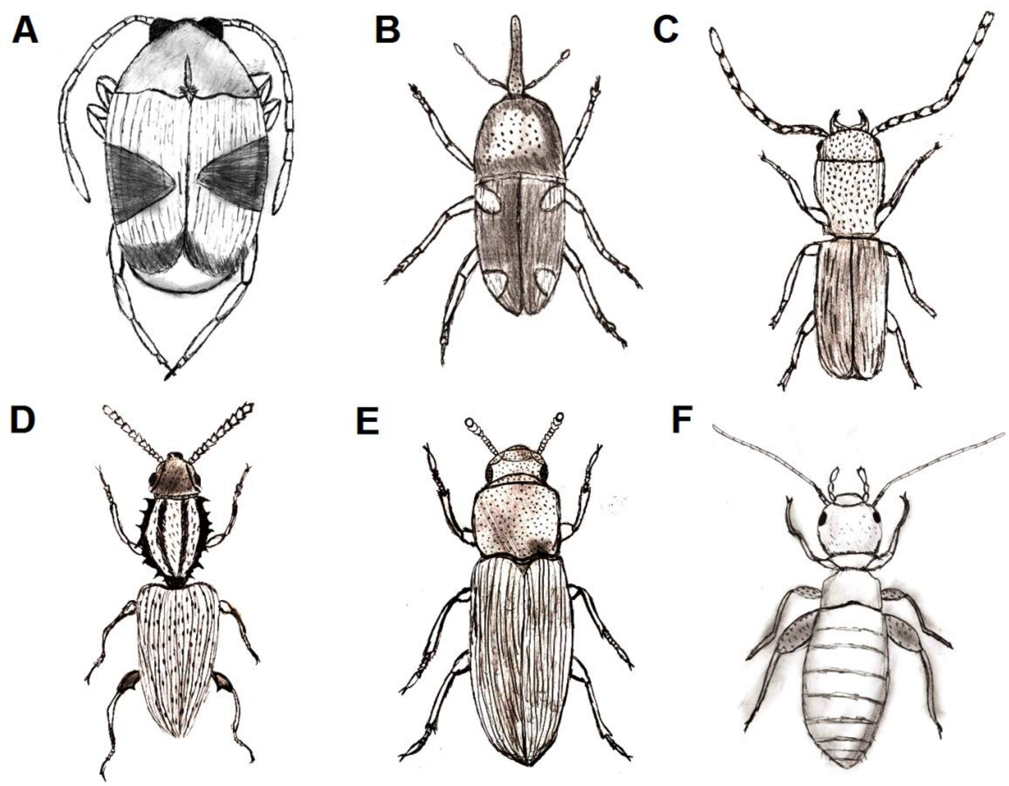

Figure 1. Representative drawings of stored-grain pests belonging to the respective families and species: (A)Bruchidae, *Callosobruchus maculatus*; (B) Curculionidae, *Sitophilus zeamais*; (C) Laemophoeidae, *Cryptolestes ferrugineus*; (D) Silvanidae, *Oryzaephilus surinamensis*; (E) Tenebrionidae, *Tribolium castaneum*; (F) Liposcelidae, *Liposceles* sp.

The insects that attack grains can be considered primary pests, which attack healthy grains throughout their development, and secondary pests, which are only able to attack grains that had been previously damaged (Silveira et al., 2006). The density of the insect population, the exposure time and the coexistence of primary and secondary pests dramatically increase the deterioration (Antunes et al., 2011; Tefera et al., 2011; Copatti et al., 2013). Alencar et al. (2011) assessed the effects of *Sitophilus zeamais* and *Tribolium castaneum* on maize and verified that the coexistence of these species during infestation promoted damage 20 times higher than that detected when these species infested the seeds separately. Similarly, Copatti et al. (2013) found more significant losses (91.48%) in rice grains concurrently attacked by *S. zeamais* and *Laemophloeus minutes*.

In general, insect pests usually feed on the endosperm because of its high nutritional content (Faroni, 1992; Nawrocka et al., 2010) and the most prevalent characteristics of damaged grains include reduction of dry matter, nutrient content and germination power. Caneppele et al. (2003) detected a loss of dry matter around 0.36% per day in maize grains infested during 150 days by *S. zeamais*. Mutungi et al. (2014) evaluated the effects of *Callosobruchus maculatus* on maize after six months of storage and found that 95% of the grains had their germination power reduced by more than 50%. This same pest also reduced the content of lipids and carbohydrates of beans by over 50% (Akintunde, 2012). Wheat grains infested by *Liposcelis bostrychophila* showed weight reduction of approximately 15% after 90 days of exposure (Kucerova, 2002).

The affected grains also have impaired hygiene and sanitary conditions. The water generated by the respiratory metabolism of insects leads to increased moisture in the storage environment, which leads to the multiplication of other deteriorating agents such as fungi (FAO, 1985; Puzzi, 1986; Jayas and White, 2003) and fungi that develop in storage conditions can produce mycotoxins that are harmful to the human health (Moreno-Martinez et al., 2011; Smith et al., 2012; Suleiman et al., 2013). Ahmedani et al. (2011) observed a strong correlation between the increase of moisture content and weight loss of wheat infested by the beetle *Trogoderma granarium*.

2. Biology and Ecology of Beetles and Beetle-Like Insects That Attack Stored Grains

2.1. Bruchidae (Coleoptera)

The insects from Bruchidae family (approximately 1,300 species) are cosmopolitan and develop in the seeds of several plants, mainly leguminous, cultivated in almost all parts of the world. Some authors classify this family as a subfamily of the Crysomelidae family called Bruchinae. The bruchids are usually classified in two groups: the species that lay the eggs in the fruits of host plants and whose larvae feed on the seeds; and the species that lay the eggs directly on the seeds and thus act as stored-grain pests (Lima, 1952; Gallo et al., 2002; Buzzi, 2010).

Adult bruchids are usually less than 10 mm in length and the body has an oval shape (Figure 1A). Some of the characteristics of Bruchidae family were described by Lima (1952), Athié and de Paula (2002), Gallo et al. (2002), Kingsolver (2004) and Buzzi (2010) are: the head is free with a short and flat rostrum as well as serrated or pectinate antennae with 11 segments; the elytra are striated and do not cover all the abdomen, leading the last tergum (called pygidium) exposed; and the posterior legs are more robust than the others. The larvae are white or yellow and have a robust body, with a tiny and curved head that can retract into the thorax. After oviposition, the newly-hatched larvae penetrate into the grains and build a chamber consuming the entire cotyledon. The larva passes through four molts and remains feeding until the end of the last instar, after which it enters the pupa stage. The pupation may occur completely inside the larval chamber, may start within and complete out of the chamber, or may occur completely out of the seed where the larva developed.

Some of the most relevant pests from Bruchidae are *Acanthoscelides obtectus, Bruchus pisorum, Callosobruchus maculatus, Callosobruchus phaseoli* and *Zabrotes subfasciatus* (Athié and de Paula, 2002; Gallo et al., 2002). *A. obtectus* is a primary pest and the eggs may be laid on the pods in the field or directly on the stored seeds. The optimal conditions for development of larvae are ca. 30°C and 70% relative humidity. Although the period of adult life is short, this species has great infestation ability because the adults are good fliers and the life cycle is quickly completed (approximately 23 days) (Lorini, 2010). *C. maculatus* is native from Africa but distributed along all the tropics and subtropics. The most important hosts of *C. maculatus* are the beans from the *Vigna* genus and this beetle has a high ability for cross-infestation, attacking the tillage and the storage environment (Athié and de Paula, 2002; Gallo et al., 2002). An interesting study conducted by Cope and Fox (2003) revealed that the *C. maculatus* females distributed the eggs during oviposition according to the size of the seeds, aiming to optimize the use of resources. The oviposition of this species is stimulated by the alkanes present on the surface wax that cover the attacked seeds (Parr et al., 1998; Adhikary et al., 2014).

2.2. Curculionidae (Coleoptera)

The family Curculionidae represents the more numerous in the Animal Kingdom, with approximately 50,000 species described (Gallo et al., 2002; Buzzi, 2012) and about 30 species of this family are pests of stored products around the world. The curculionids attack mainly fruits and seeds and a few subfamilies and the genus feed on dead vegetable materials. The most economically important species are *Sitophilus zeamais* (Figure 1B), *Sitophilus oryzae* and *Sitophilus granarium*, which can be found in storages of wheat, oat, rye, rice and maize and are also able to deteriorate beans, nuts, birdseeds, sunflower seeds and processed foods such as pasta.

According to Lima (1952), Athié and de Paula (2002), Gallo et al. (2002) and Buzzi (2010), the adults have a fairly elongated rostrum, straight or bent, which contains the chewing mouthparts at the end. The antennae are geniculate-capitate or geniculate-clavate with the scape inside a groove. The elytra are associated with the pro-thorax, usually cover the entire abdomen and can be glabrous, hairy and scaled. The scales may confer metallic coloration (green, blue, violet and golden). The posterior wings can be well-developed, rudimentary, obsolete or absent. The curculioniform larvae, which are apodal, robust, slightly bent and with a darker head, develop within the fruits, stems and seeds, consuming all the content present in these tissues. The pupae have a whitish color.

S. zeamais is found in all the warm and tropical regions. They are one of the major pests in stored grains in Brazil. This species possess a large number of hosts, including maize, wheat, sorghum and rice. It may also develop in processed cereals and food (Athié and de Paula, 2002; Gallo et al., 2002). *S. zeamais* have also been found attacking fruits such as apples, peaches and grapes (Botton et al., 2005). A remarkable characteristic of *S. zeamais* is the presence of reddish spots on the elytra and the curved rostrum present in the head is shorter and thicker in males. The adults are able to fly, quickly infesting the grains in the field and storage and are able to easily penetrate in the grains, and have a high potential for cross-infestation (Antunes and Dionello, 2010).

Danho et al. (2002) reported that the proportion of grains infected by *S. zeamais* is greater with decreasing in the amount of grains available. The females can live up to 140 days, 104 of these corresponding to oviposition period, and the average number of eggs per female is 282 (Botton et al., 2005). The females seal the hole made in the grain with a protein-rich secretion so that it is not possible to view the place of oviposition**.**

2.3. Laemophoeidae (Coleoptera)

The genus (*Cryptolestes*) is unique in the family Laemophoeidae that has importance as stored-grain pest. The *Cryptolestes* species feed on cereals, oleaginous seeds, nuts and dry fruits, and their presence is an indicator of very inadequate conditions in storage since these beetles develop in places already infested by other insects and fungi. The adults (Figure 1C) have a reddish-brown color, about 1.5–3.0 mm in length with a dorsoventral flattening. The antennae are filiform with 11 segments. The larvae penetrate grains with damaged or imperfect coats but the breaks only need to be microscopic to allow the entering of the larva. The eggs are elongated and more tapered at one of the ends. Each female is capable of laying 200 to 500 eggs and the oviposition occurs in the debris of plant material (Rillet, 1949; Athié and de Paula, 2002).

The species *Cryptolestes ferrugineus* is distributed at tropical, subtropical and temperate regions. It usually appears after an infestation by *Sitophilus* or *Rhyzopertha* and is able to develop in the grains of rye, wheat, maize, rice, oats, barley, corn, sunflower, flax, and soybeans (Rillet, 1949). *C. ferrugineus* also feeds on several types of fungi (mycophagous habit) found in storage. During cold seasons, they tend to move to the inner region of the grain mass (warmer region), and are present in the peripheral regions in warmer seasons (Athié & Cesar de Paula, 2002).

2.4. Silvanidae (Coleoptera)

The Silvanidae family includes about 500 species. The body of these insects is narrowed, brownish and densely punctured, with variable dimensions (1–15 mm in length), and the dorsoventral region is flattened (Figure 1D). Their antennae are clavate with 11 segments and their elytra entirely cover the abdomen. Several species are mycophagous and some are important pests of grain products (Athié and de Paula, 2002).

The species *Oryzaephilus surinamensis* (sawtoothed grain beetle) has a cosmopolitan distribution and is found infesting cereals, flour, spices, dry fruits, pasta, chocolate and even jerky beef. These beetles did not develop well in oleaginous seeds. It is a major pest of stored barley and is classified as a secondary pest because it is only able to cause scratches or scars on healthy and whole grains; however it quickly develops in broken grains. The adults have limited flight ability and thus the infestations are usually resulting from residual populations present in the storage or previous contamination of grains (Athié and de Paula, 2002; Gallo et al., 2002; Beckel et al., 2002, 2007). Each female lays 37 eggs on average (Beckel et al., 2007).

2.5. Tenebrionidae (Coleoptera)

The family Tenebrionidae (darkling beetles) is present in tropical and temperate regions. About 15,000 species are described, commonly xerophiles with nocturnal habits. About 80 species are reported to act as stored-grain pests and are found attacking cereals and flours. The most important species that act as pests belong to the genus *Tribolium*, *Gnatocerus*, *Alphitobius*, *Tenebrio*, and *Latheticus*; all these beetles possess thoracic and abdominal glands of defense that secrete benzoquinones and hydroquinones. In addition to storage pests, in this family other crop pests are present such as mycetophagous, coprophagous, predators, myrmecophilous and polyphagous species (Lima, 1952; Athié and de Paula, 2002; Buzzi, 2010).

The adults have a variable coloration (black, brown, reddish-brown, cinereous) and body size (3–10 mm in length, with species that can reach 18 mm). The head is very small and narrower than the prothorax (Figure 1E). The antennae are filiform, moniliform or serrated (more common) with 11 segments. The exoskeleton is remarkably thick and stiff, shiny and glabrous. The elytra cover the entire abdomen and the wings are often stunted. The legs are ambulatorial (cursorial) or less frequently fossorial (adapted for digging). The larvae are elateriform (worm-like) with sclerotic, glabrous and shiny integument and have short legs (Lima, 1952; Athié and de Paula, 2002; Gallo et al., 2002; Buzzi, 2010).

Tenebrio mollitor (mealworm) is considered a pest because the larvae are able to feed on stored grains (Siemianowska et al., 2013). The species *Tribolium castaneum* is supposed to have an Indian origin and is distributed in tropical and subtropical regions being very tolerant to arid conditions. It attacks all kinds of ground cereals and is an important secondary pest that infests cereals, coffee, cocoa, soybeans, dried fruits, nuts, cotton seed and also stored milk powder. Occasionally, *T. castaneum* may attack stored peas and beans (Athié and de Paula, 2002).

2.6. Liposcelidae (Psocoptera)

The insects belonging to this family are known as booklice or barklice. Although they comprise a taxonomically distinct group, sometimes these insects are referred as “beetle-like”. They often live under dead bark, leaves and grass, in the nests of birds and mammals, on shelves, inside cracks of steps and furniture, and dusty places, among other locations. It grows easily in environments with relatively high temperature and humidity. Liposcelidae species can feed on fungi, algae, lichens, and pollen as well as on eggs and fragments of dead insects. Only a few species behave as pests of grain, for example, *Liposcelis bostrychophila*, which is able to damage rice. They are easily attracted by the presence of flour as well as moldy or wet food. Since these beetles are apterous the auto-dispersion is limited (Turner, 1998; Athié and de Paula, 2002; Buzzi, 2010; Chin et al., 2010).

The short (1–10 mm in length) body of these insects is tiny, flat and fragile (Figure 1F), with a yellowish or pale gray color and a semi-transparent appearance. The head is relatively large with a long and filiform (thread-like) antenna with 15 segments. The thorax is small and the abdomen is bigger than the rest of the body. Although the egg is approximately 1/3 of the female size, about 3-4 eggs are laid daily per female, resulting in a mean of 100 eggs in three weeks in the summer season. The metamorphosis is incomplete, being the nymphal stages (4 for females and 3 for males) and adult forms are very similar only differing in size and color (Turner, 2002; Athié and Cesar de Paula, 2002; Buzzi, 2010).

3. Current Strategies for Control of Stored-Grain Beetles

According to Gallo et al. (2002), three main techniques are usually applied to control pests in stored grains: fumigation, pulverizing and spraying. Other methods listed by Bond (1984) are sanitation, refrigeration, aeration, heating, drying, gamma radiation, microwaves, and infra-red radiation, as well as the use of insect growth regulators, predators, and pathogens. It also includes the use of insect resistant packaging.

Fumigation is the method most often used and can be applied to bulk or bagged products. It consists of the use of chemical compounds that are volatile at storage temperatures and toxic to the insect pests. However, only these characteristics are not enough to indicate the use of a substance. The compound should not be corrosive to containers or other materials in storage, should not react with the products originating irreversible residues and should not cause damage to the grains (Bond, 1984; Gallo et al., 2002). The fumigation technique is effective in eliminating insects in different stages of their life cycle.

The most used compounds in fumigation are methyl bromide and phosphine (aluminum phosphate and magnesium phosphate), which target the respiratory system of the insect. However, these substances are strongly toxic to non-target organisms, including humans (Gallo et al., 2002). Methyl bromide is acutely very toxic, mainly affecting the central nervous system, and intoxication may lead to death (Yang et al., 1995). Symptoms of methyl bromide poisoning are vomiting, headache, vertigo, imbalance while walking, slurred speech, and tremulousness of the upper limbs (Balogabal et al., 2011). Epidemiological evidence indicates that occupational exposure to methyl bromide is linked to incidence of human prostate cancer (Budnik et al., 2012). Phosphine is also toxic to non-target invertebrates and vertebrates disrupting the sympathetic nervous system, energy metabolism and the redox state of the cell (Nath et al., 2011). Exposure to high levels of phosphine causes acute respiratory problems, cough, headaches, dizziness, numbness, general fatigue and gastrointestinal disturbance. The chronic exposure results in anemia, bronchitis, gastrointestinal disorders, speech and motor disturbances, toothache, weakness, weight loss, mandible necrosis and spontaneous fractures (Takamiya, 2007).

The pulverizing method consists of mixing chemical powders with the grains and is recommended for treatment of small amounts of grains. Examples of chemicals used are bifenthrin, deltamethrin, fenitrothion, and pirimiphos (Gallo et al., 2002). The spraying method is achieved by micro pulverizations using an atomizer unit.

The excessive use of an insecticide inevitably results in a great selection pressure, which favors the proliferation of resistant individuals. Resistance of *S. zeamais* populations to the insecticides malathion, lindane, deltamethrin and phosphine has been described (Perez-Mendoza, 1999) and the development of strong resistance to phosphine by booklice has contributed to increase the importance of this species as a stored-grain pest (Collins et al., 2001). Opit et al. (2012) reported the detection in Oklahoma of a *Tribolium castaneum* population being 119-fold more resistant to phosphine in comparison with a laboratory susceptible strain, and highlighted that there is an increasing trend of phosphine resistance in the last 21 years. Figure 2 summarizes the steps involved in the emergence of a resistant insect population due to the prolonged, excessive and unplanned use of an insecticide.

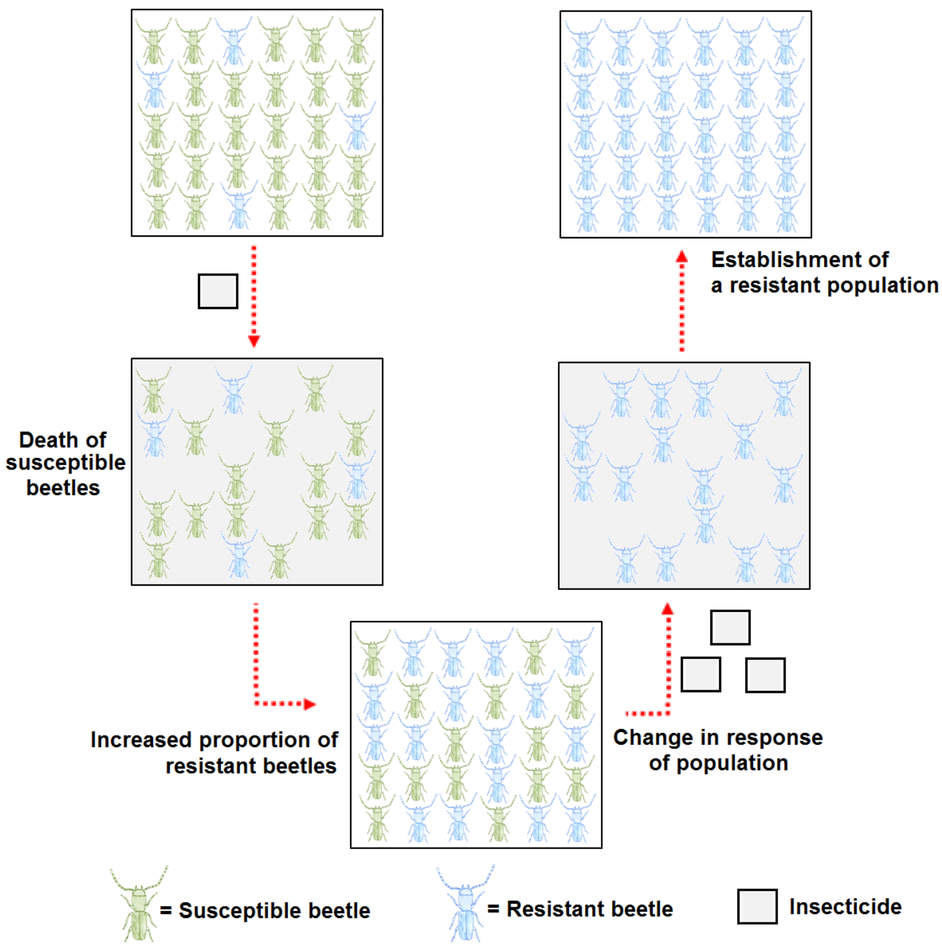

Figure 2. Establishment of an insect resistant population due to the excessive, intermittent and unplanned use of an insecticide.

4. Natural Insecticides for Control of Stored-Grain Beetles

The emergence of resistant populations and the risks that synthetic insecticides pose to human health and the environment have intensified the search for natural insecticides as an alternative in the control of agricultural pests. In general, natural products are environmentally safer because they are biodegradable and exhibit a greater selectivity than synthetic chemicals (Menezes, 2005; Duke et al., 2010; Kishore et al., 2011; Freitas et al., 2014).

Many parts of plants contain bioactive compounds that are involved in chemical defense against insect attack. A lot of naturally ant-insect substances have been extracted from plants in water and organic solvents. The entomotoxicity of plant preparations is mainly characterized by neurotoxic actions, feeding inhibition, digestion impairment, developmental delay and alterations of reproductive and behavioral aspects (Kim et al., 2003; Menezes, 2005; Correa and Salgado, 2011).

Several plant extracts have shown insecticidal activity against stored-grain beetles, affecting survival and physiology. Hexane extracts from African nutmeg (7.5 and 10 mg/100mL) was strongly toxic to *Callosobruchus maculatus* adults promoting 100% mortality after 1 hour of exposure (Ogunsina et al., 2011). Treatment of *Sitophilus oryzae* with hexane extract from the *Capparis decidua* stem by 16 hours interfered on insect physiology reducing the levels of glycogen, protein, and amino acid as well as activity of enzymes phosphatases, transaminases, dehydrogenases and acetylcholinesterase involved in the physiology processes (Upadhyay, 2013). The powdered leaves of *Azadirachta indica* containing saponins and azadirachtin promoted a mortality of 50% of larvae and adults of *Tribolium castenum*, and also reduced more than 10% amylase activity (Sami, 2014).

Essential oils are complex mixtures of volatile secondary metabolites, mainly extracted from aromatic plants. They are able to affect survival, behavior and physiology of insect pests. Wang et al. (2011) showed that the essential oil from *Illicium fargesii* promoted mortality of *S. zeamais* through contact (LC_{50}=28.95 µg/adult) and by fumigation (LC_{50}=11.36 mg/L). Mossi et al. (2014) reported that the essential oil from *Ocotea odorifera* containing camphor (43%) and safrole (42%) as major constituents killed *S. zeamais* (DL_{50}=14.1µl cm^2) by contact after 24 h and was also a repellent agent. Food deterrence (74.52%) and reduction in oviposition rate (35.66%) were detected after treatment of *S. oryzae* with oil from *Aegles quinces* leaves (Mishra et al., 2014). Gusmão et al. (2013) determined that essential oils from *Eucalyptus citriodora*, *Eucalyptus staigeriana*, *Cymbopogon winterianus* and *Foeniculum vulgare* were toxic to *Callosobruchus maculatus* by contact (LC_{50} ranging from 178.13 to 345.57 ppm) and fumigation (LC_{50} ranging from 2.58 to 7.85 µL/L of air), when used as repellent agents and reduced the oviposition rate as well as the emergence of adults in comparison with the control group.

In parallel, another progress in the search for alternative insecticides is the possible use of nanoparticles containing essential oils, since these systems are characterized by slow and persistent liberation of the oil in its active form. Gonzalez et al. (2014) determined that polyethylene glycol nanoparticles containing commercial essential oils (geranium and bergamot) have elevated residual toxicity against *Tribolium castaneum* and affected nutritional physiology reducing the relative growth rate, relative consumption rate and the efficiency of conversion of ingested food.

The deleterious effects of isolated secondary metabolites from different classes on insects are also reported. Sirinol, a compound isolated from garlic emulsion, showed a repellent effect on *T. castaneum* at a concentration of 10% while the metabolite allicin, also isolated from this plant, was toxic by fumigation to adults of *T. castaneum*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus* with LC_{50} of 0.38, 0.51 and 0.51 mL/L in air, respectively (Jahromi et al., 2012; Lu et al., 2013). The ar-turmerone metabolite extracted from the rhizome of *Curcuma longa* affected the survival of *S. zeamais* at 1% (m/m), after six days of exposure by contact (Tavares et al., 2013).

Peptides and proteins isolated from plants also show insecticidal activity and thus have potential use in strategies for control of pests of stored products. Peptides purified from *Cicer arietinum* (chickpea) seeds were able to kill 83% and 100% of *S. oryzae* adults after 7 and 14 days of feeding (Mouhouche et al., 2009). Fields et al. (2010) demonstrated that peptide mixtures obtained from peas reduced the feeding and increased the mortality of *S. oryzae*. These authors also reported a synergistic effect between these peptides and insecticidal saponins and attributed this effect to the ability of saponins in impairing the hydrolysis of peptides by digestive enzymes at insect gut. Consequently, the increased time of contact between the peptides and insect gut probably allows the improvement of insecticidal action.

Zottich et al. (2014) revealed that the lipid transfer protein isolated from *Coffea canephora* seeds (Cc-LTP1, 0.5 %) inhibited the development of *C. maculatus* larvae, reduced the weight and the number of larvae, as well as decreased the oviposition rate. The same study showed that Cc-LTP1 inhibited the α-amylase activity of larval gut and was able to interact with the endoplasmic reticulum, mitochondria and microvilli of columnar cells from larvae.

Lectins are proteins whose structure contains carbohydrate-binding sites, which are able to interact with glycosylated molecules present in the lumen of insect gut, on the surface of epithelial cells or/and in the peritrophic matrix (Napoleão et al., 2012). The binding of lectins to glycosylated proteins at the midgut of insect larvae interferes with the nutrient uptake and the efficiency of diet utilization, resulting in a drop in mass gain. In this sense, lectins are insecticides that promote mortality or delay development of insects. The *N*-acetylglucosamine-specific lectin isolated from *Griffonia simplicifolia* leaf (GSII) at 1.0% (w/v) increased the WDST (within seed developmental time) of *C. maculatus* twice (Zhu et al., 1996) and the lectin isolated from *Myracrodruon urundeuva* leaves had a strong deterrent effect on adults of *S. zeamais*, and also reduced the activities of amylases, proteases, phosphatases, trypsin and endoglucanases (Napoleão et al., 2013). The lectin isolated from *Bauhinia monandra* leaf (BmoLL) was active on *C. maculatus* and *Z. subsfasciatus* larvae reducing the survival rate (LC_{50} of 0.5% and 0.3%, w/v, respectively) and decreasing body weight (Macedo et al., 2007). The authors demonstrated that the larvicidal effects of BmoLL probably involve resistance to proteolysis by larval enzymes and interaction with molecules at the membrane from midgut cells. *Talisia esculenta* seed lectin (TEL) also induced mortality of *C. maculatus* larvae (LC_{50}=1.0% w/v), was resistant to hydrolysis by cysteine proteases from larval midgut and bound proteins from the midgut of larvae (Macedo et al., 2004).

Products based on entomopathogenic fungi have also attracted the interest of researchers because they usually do not generate negative impacts to the environment and humans; they exhibit a residual effect that allows prolonged protection to stored grain, and the fungi applied are selective to the insect and do not develop in the grains (Alves et al., 2008; Michereff Filho et al., 2009). The fungi *Beauveria bassiana* caused mortality of *C. maculatus* (LC_{50}=3.17×10^6 conidia/mL) and *S. granarius* (LC_{50}= 6.08×10^7 conidia/mL) after 9 days (Shams et al., 2011). Nabaei et al. (2012) reported that the combination between diatomaceous earth and the entomopathogenic fungi *B. bassiana* or *Metharizium anisopliae* resulted in high mortality rates of the *C. maculatus* adult with improved median lethal time. Pimentel and Ferreira (2012) reported on the insecticidal activity against *S. zeamais* of the products Metarril® (LC_{50}=181.9 ml/L for 3 days) and Boveril® (LC_{50}=2.1 g/L for 3 days). These products are formulations based on the entomopathogenic fungi *M. anisopliae* and *B. bassiana*, respectively. The fungi *Isaria fumosorosea* was able to induce the mortality of*S. oryzae* adults and it was demonstrated that the concentration was not a critical parameter that determined the speed of insect death (Kavallieratos et al., 2014). The insecticide spinosad, produced by fermentation of the soil actinobacteria, *Saccharopolyspora spinosa*, has been indicated as a promising insecticide for control of several species that attack stored grains such as *Cryptolestes ferrugineus*, *Cryptolestes pusillus*, *Liposcelis entomophila*, *Sitophilus oryzae*, *Sitophilus granarius*, *Tribolium castaneum* and *Tribolium confusum* (Chintzoglou et al., 2008; Vayias et al., 2010; Hertlein et al., 2011).

CONCLUSION

This chapter summarizes information on all families of stored-grain pests in relation to morphology, physiology, ecology, grains attacked and current strategies for control of insects. The finding of alternative insecticides will allow their use in rotation programs, which canlead to increasing efficiency in insect control as well as minimizing the development of resistance. The potential use as an insecticide of plant compounds (such as secondary metabolites, essential oils and peptides) and entomopathogenic fungi is described.

ACKNOWLEDGMENTS

The authors express their gratitude to the *Conselho Nacional de Desenvolvimento Científico e Tecnológico* for research grants and fellowship (P.M.G. Paiva). We are also grateful to the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES), the Brazilian Ministry for Science, Technology and Innovation (MCTI) and the *Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco* for financial support. B.R. Belmonte would like to thank FACEPE for their graduate scholarship. E.V. Pontual would like to thank CAPES and FACEPE for their post-doctoral scholarship.

REFERENCES

Adhikary, P., Mukherjee, A. & Barik, A. (2014). Role of surface wax alkanes from *Lathyrus sativus* L. seeds for attraction of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of Stored Products Research*, *59*, 113-119

Ahmedani, M. S., Afazal, S. N., Haque, M. I., Nadeem, S., Hussain, T. & Naz, S. (2011). Quantitative losses and physical damage caused to wheat kernel (*Triticum aestivum*) by khapra beetle infestation. *Pakistan Journal of Botany*, *43*, 659-668.

Akintunde, E. M. (2012). Reduction of the nutritional values of cowpea infested with *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Agriculture Science Developments*, *1*, 1-7.

Alencar, E. R., Faroni, L. R. D., Ferreira, L. G., Costa, A. R. & Pimentel, M. A. G. (2011). Qualidade de milho armazenado e infestado por *Sitophilus zeamais e Tribolium castaneum*. *Revista Engenharia na Agricultura*, *19*, 9-18.

Alves, S. B., Lopes, R. B., Vieira, S. A. & Tamai, M. A. (2008) Fungos entomopatogênicos usados no controle de pragas na América Latina. In: Alves, S.B., Lopes, R.B. (Eds.) Controle microbiano de pragas na América Latina: Avanços e Desafios. Piracicaba: FEALQ, 69-110.

Antunes, L. E. G., Viebrantz, P. C., Gottardi, R. & Dionello, R. G. (2011). Características físico-químicas de grãos de milho atacados por *Sitophilus zeamais* durante o armazenamento. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *15*, 615-620.

Antunes, L. E. G. & Dionello, R. G.(2010). Bioecologia de *Sitophilus zeamais* Motschulsky 1885 (Coleoptera: Curculionidae). Hipertext article. Available in: http://www.infobibos.com/Artigos/2010_2/Sitophilus/index.htm

Assem, L. & Takamiya, M. (2007). Phosphine General information. Institute of Environment and Health, Cranfield University.

Athié, I. & de Paula, D. C. (2002). Insetos de grãos armazenados: aspectos biológicos e identificação. São Paulo: Varela.

Balagopal, K., Muthusamy, K., Alexander, M. & Mani, S. (2011). Methyl bromide poisoning presenting as acute ataxia. *Neurology India*, *59*, 768-769.

Beckel, H. (2002). Detecção da resistência de *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae), praga de grãos de cevada armazenada, a inseticidas químicos. Passo Fundo: Embrapa Trigo.

Beckel, H. D. S., Lorini, I. & Lazzari, S. (2007). Rearing method of *Oryzaephilus surinamensis* (L.) (Coleoptera, Silvanidae) on various wheat grain granulometry. *Revista Brasileira de Entomologia*, *51*, 501-505.

Bilia, D. A. C., Fancelli, A. L., Marcos Filho, J. E. & Machado, J. A. (1994). Comportamento de sementes de milho híbrido durante o armazenamento sob condições variáveis de temperatura e umidade relativa do ar. *Scientia Agricola*, *51*, 153-157.

Bond, E. (1984). Manual of fumigation for insect control. FAO Plant Production and Protection Paper. Food & Agriculture Organization of the United Nations. 432 p.

Botton, M., Lorini, I., Loeck, A. E. & Afonso, A. P. S. (2005). O gorgulho do milho *Sitophilus zeamais* (Coleptera: Curculionidae) como praga em frutíferas de clima temperado. Embrapa Uva e Vinho. Circular Técnica.

Budnik, L. T., Kloth, S., Velasco-Garrido, M. & Baur, X. (2012). Prostate cancer and toxicity from critical use exemptions of methyl bromide: environmental protection helps protect against human health risks. *Environmental Health*, *11*, 5.

Buzzi, Z. J. (2010). Entomologia didática**.** Curitiba: Editora da UFPR.

Caneppele, M. A. B., Caneppele, C., Lazzari, A. F. & Lazzari, S. M. N. (2003). Correlation between the infestation level of *Sitophilus zeamais* Motschulsky, 1855 (Coleoptera, Curculionidae) and the quality factors of stored corn, *Zea mays* L. (Poaceae). *Revista Brasileira de Entomologia*, *47*, 625-630.

Chin, H. C., Jeffery, J., Ahmad, N. W., Kiang, H. S., Omar, B., Othman, H. & Lim, L. H. (2010). First Report of *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelidae) as a Museum Insect Pest in Malaysia. *Sains Malaysiana*, *39*, 329-331.

Chintzoglou, G., Athanassiou, C. G. & Arthur, F. H. (2008). Insecticidal effect of spinosad dust, in combination with diatomaceous earth, against two stored-grain beetle species. *Journal of Stored Products Research*, *44*, 347-353.

Collins, P. J., Daglish, G. J., Nayak, M. K., Ebert, P. R., Schlipalius, D., Chen, W., Pavic, H., Lambkin, T. M., Kopittke, R. & Bridgeman,B. W. (2001). Combating resistance to phosphine in Australia. In: Donahaye, E.J, Navarro, S., Leesch J.G. (Eds.), Int. Conf. Controlled Atmosphere and Fumigation in Stored Products. Fresno: Executive Printing Services. 593-607.

Copatti, E. C., Marcon, R. K. & Machado, B. M. (2013). Avaliação de dano de *Sitophilus zeamais*, *Oryzaephilus surinamensis* e *Laemophloeus minutus* em grãos de arroz armazenados *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*, 855-860.

Cope, M. J. & Fox, C. W. (2003). Oviposition decisions in the seed beetle, *Callosobruchus maculatus* (Coleoptera: Bruchidae): effects of seed size on superparasitism. *Journal of Stored Products Research*, *39*, 355–365.

Correa, J. C. R. & Salgado, H. R. N. (2011). Atividade inseticida das plantas e aplicações: revisão. *Revista Brasileira de Plantas Medicinais*, *13*, 500-506.

Danho, M., Gaspar, C. & Haubruge, E. (2002). The impact of grain quantity on the biology of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae): oviposition, distribution of eggs, adult emergence, body weight and sex ratio. *Journal of Stored Products Research*, *38*, 259-266.

Duke, S. O., Cantrell, C. L., Meepagala, K. M., Wedge, D. E., Tabanca, N. & Schrader, K. K. (2010). Natural toxins for use in pest management. *Toxins*, *2*, 1943-1962.

FAO. Food and Agriculture Organization of United Nations (1985). Prevention of post-harvest food losses: a training manual**.** Pest Biology and Identification.

FAO. Food and Agriculture Organization of United Nations (1994). The role of storage in the economy. Grain storage techniques, 109.

Faroni, L. R. D. A. (1992). Manejo das pragas dos grãos armazenados e sua influência na qualidade do produto final. *Revista Brasileira de Armazenamento*, *17*, 36-43.

Fields, P. G., Woods, S. & Taylor, W. G. (2010). Triterpenoid saponins synergize insecticidal pea peptides: effect on feeding and survival of *Sitophilus oryzae* (Coleoptera: Curculionidae). *The Canadian Entomologist*, *142*, 501-512.

Freitas, R. S., Queiroz, M. E. L. R., Faroni, L. R. A., Heleno, L. L. & Moura, V. V. (2014). Development of a solid-liquid extraction method with low-temperature partitioning for the determination of insecticides in ozonized maize grain. *Química Nova*, *37*, 238-243.

Gallo, D., Nakano, O., Silveira Neto, S., Carvalho, R. P. L., Batista, G. C., Berti Filho, E., Parra, J. R. P., Zucchi, R. A., Alves, S. B., Vendramin, J. D., Marchini, L. C., Lopes, J. R. S. & Omoto, C. (2002). Entomologia agrícola. Piracicaba: FEALQ.

Gonzalez, J. O. W., Gutierrez, M. M., Ferrero, A. A. & Band, B. F. (2014). Essential oils nanoformulations for stored-product pest control – Characterization and biological properties. *Chemosphere*, *100*, 130-138.

Gusmão, N. M. S., Oliveira, J. V., Navarro, D. M. A. F., Dutra, K. A., Silva, W. A. & Wanderley, M. J. A. (2013). Contact and fumigant toxicity and repellency of *Eucalyptus citriodora* Hook., *Eucalyptus staigeriana* F., *Cymbopogon winterianus* Jowitt and *Foeniculum vulgare* Mill. essential oils in the management of *Callosobruchus maculatus* (FABR.) (Coleoptera: Chrysomelidae, Bruchinae). *Journal of Stored Products Research*, *54*, 41-47.

Hertlein, M.B., Thompson, G. D., Subramanyam, B., Christo B. & Athanassiou, G. (2011). Spinosad: A new natural product for stored grain protection. *Journal of Stored Products Research*, *47*, 131-146.

Jahromi, M. G., Pourmirza, A. A. & Safaralizadeh, M. H. (2012). Repellent effect of sirinol (garlic emulsion) against *Lasioderma serricorne* (Coleoptera: Anobiidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae) by three laboratory methods. *African Journal of Biotechnology*, *11*, 280-288.

Jayas, D. S. & White, N. D. G. (2003). Storage and drying of grain in Canada: low cost approaches. *Food Control*, *14*, 255-261.

Kavallieratos, N. G., Athanassiou, C. G., Aountala, M. M. & Kontodimas, D. C. (2014). Evaluation of the entomopathogenic fungi *Beauveria bassiana*, *Metarhizium anisopliae*, and *Isaria fumosorosea* for control of *Sitophilus oryzae. Journal of Food Protection*, *77*, 87-93.

Kim, S. I., Roh, J. I., Kim, D. H., Lee, H. S. & Ahn, Y. J. (2003). Insecticidal activities of aromatic plant extracts and essential oils against *Sitophilus oryzae* and *Callosobruchus chinensis*. *Journal of Stored Products Research*, *39*, 293-303.

Kingsolver, J. M. (2004). Handbook of the Bruchidae of the United States and Canada (Insecta, Coleoptera). United States Department of Agriculture. Agricultural Research Service Technical Bulletin Number 1912.

Kishore, N., Mishra, B. B., Tiwari, V. K. & Tripathi, V. (2011). A review on natural products with mosquitosidal potentials. In: Tiwari, V.K., Mishra, B.B. (Eds.). Opportunity, Challenge and Scope of Natural Products in Medicinal Chemistry. Kerala: Research Signpost, 335-365.

Kucerova, Z. (2002). Weight losses of wheat grains caused by psocid infestation (*Liposcelis bostrychophila*: Liposcelididae: Psocoptera). *Plant Protection Science*, *38*, 103–107.

Lima, A. C. (1952). Coleópteros. In: Insetos do Brasil, 7° Tomo, Capítulo XXIX. Série Didática N° 9. Escola Nacional de Agronomia.

Lorini, I., Krzyzanowski, F. C., Franca-Neto, J. B. & Henning, A. A. (2010). Principais pragas e métodos de controle em sementes durante o armazenamento - Série Sementes. Londrina: Embrapa Soja. Circular Técnica.

Lu, Y., Zhong, J., Wang, Z., Liu, Z. & Wan, Z. (2013). Fumigation toxicity of allicin against three stored product pests. *Journal of Stored Products Research, 55*, 48-54.

Macedo, M. L. R., Castro, M. M. & Freire, M. G. M. (2004). Mechanisms of the insecticidal action of TEL (*Talisia esculenta* lectin) against *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Archives of Insect Biochemistry and Physiology*, *56*, 84–96.

Macedo, M. L. R., Freire, M. G. M., Silva, M. B. R. & Coelho, L. C. B. B. (2007). Insecticidal action of *Bauhinia monandra* leaf lectin (BmoLL) against *Anagasta kuehniella* (Lepidoptera: Pyralidae), *Zabrotes subfasciatus* and *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Comparative Biochemistry and Physiology, Part A*, *146*, 486-498.

Menezes, E. L. A. (2005). Inseticidas botânicos: seus princípios ativos, modo de ação e uso agrícola. Rio de Janeiro: Seropédica - Embrapa Agrobiologia.

Michereff Filho, M., Faria, M., Wraight, S. P. & Silva, K. F. A. S. (2009). Micoinseticidas e micoacaricidas no Brasil: como estamos após quatro décadas? *Arquivos do Instituto Biológico*, *76*, 769-779.

Mishra, B. B., Tripathi, S. P. & Tripathi, P. M. (2014). Chronic activity of plant volatiles essential oils in management of rice weevil *Sitophilus oryzae* (Coleoptera: Curculionidae). *Journal of Entomology*, *11*, 78-86.

Moreno-Martinez, E., Chapa-Oliver, A. M., Mejía-Teniente, L., Torres-Pacheco, I., Guevara-González, R. G., Vazquez-Cruz, M. A., Cervantes-Landaverde, J. J. & Preciado-Ortiz, R. E. (2011). Genetic resistance to drought in maize and its relationship in aflatoxins production. In: Guevara-González, R.G. (Ed.). *Aflatoxins - Biochemistry and Molecular Biology*. Rijeka: InTech, 151-161.

Mossi, A. J., Zanella, C. A., Kubiak, G., Lerin, L. A., Cansian, R. L., Frandoloso, F. S., Prá, V. D., Mazutti, M. A., Costa, J. A. V. & Treichel, H. (2014). Essential oil of *Ocotea odorifera*: An alternative against *Sitophilus zeamais*. *Renewable Agriculture and Food Systems*, *29*, 161-166.

Mouhouche, F., Fleurat-Lessard, F. & Bouznad, Z. (2009). Laboratory assessment of toxic activity of purified peptides extracted from chickpea seeds to two strains of the rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). *Journal of Stored Products Research*, *45*, 261-266.

Mutungi, C. M., Affognon, H., Njoroge, A. W., Baributsa, D. & Murdock, L. L. (2014). Storage of mung bean (*Vigna radiata* [L.] Wilczek) and pigeon pea grains (*Cajanus cajan* [L.] Millsp) in hermetic triple-layer bags stops losses caused by *Callosobruchu*s *maculatus* (F.) (Coleoptera: Bruchidae)**.** *Journal of Stored Products Research*, doi: 10.1016/j.jspr.2014.03.004

Nabaei, N., Mehrvar, A., Saber, M. & Bagheri, M. (2012). Efficacy of entomopathogenic fungi in combination with diatomaceous earth against *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Acta Entomologica Sinica*, *55*, 1282-1288.

Napoleão, T. H., Belmonte, B. R., Pontual, E. V., Albuquerque, L. P., Sá, R. A., Paiva, L. M., Coelho, L. C. B. B. & Paiva, P. M. G. (2013). Deleterious effects of *Myracrodruon urundeuva* leaf extract and lectin on the maize weevil, *Sitophilus zeamais* (Coleoptera, Curculionidae). *Journal of Stored Products Research*, *54*, 26–33.

Napoleão, T. H., Pontual, E. V., Lima, T. A., Santos, N. D. L., Sá, R. A., Coelho, L. C. B. B., Navarro, D. M. A. F. & Paiva, P. M. G. (2012). Effect of *Myracrodruon urundeuva* leaf lectin on survival and digestive enzymes of *Aedes aegypti* larvae. *Parasitology Research*, *110*, 609-616.

Nawrocka, A., Grundas, S. & Grodek, J. (2010). Losses caused by granary weevil larva in wheat grain using digital analysis of X-ray images. *International Agrophysics*, *24*, 63-68.

Nath, N. S., Bhattacharya, I., Tuck, A. G., Schlipalius, D. I. & Ebert, P. R. (2011). Mechanisms of phosphine toxicity. *Journal of Toxicology*, ID 494168.

Ongusina, O. O., Oladimeji, M. O. & Lajide, L. (2011). Insecticidal action of hexane extracts of three plants against bean weevil, *Callosobruchus maculatus* (F.) and maize weevil, *Sitophilus zeamais* Motsch. *Journal of Ecology and the Natural Environment*, *3*, 23-28.

Opit, G. P., Phillips, T. W., Aikins, M. J. & Hasan, M. M. (2012). Phosphine resistance in *Tribolium castaneum* and *Rhyzopertha dominica* from stored wheat in Oklahoma. *Journal of Economic Entomology*, *105*, 1107-1114.

Parr, M. J., Tran, B. M. D., Simmonds, M. S. J., Kite, G. C. & Credland, P. F. (1998). Influence of some fatty acids on oviposition by the bruchid beetle, *Callosobruchus maculatus*. *Journal of Chemical Ecology*, *24*, 1577-1593.

Perez-Mendonza, J. (1999). Survey of insecticide resistance in Mexican populations of maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *Journal of Stored Products Research*, *35*, 107-115.

Pimentel, M. A. G. & Ferreira, E. G. (2012). Toxicidade de produtos formulados à base de fungos entomopatogênicos para o caruncho-do-milho. *Revista Brasileira de Milho e Sorgo*, *11*, 209-215.

Puzzi, D. (1986). Abastecimento e Armazenamento de grãos. Campinas: Instituto Campineiro de Ensino Agrícola.

Rilett, R. O. (1949). The biology of *Laemophloeus ferrugineus* (Steph.). *Canadian Journal of Research*, *27*, 112-148.

Sami, A. J. (2014). *Azadirachta indica* derived compounds as inhibitors of digestive alpha-amylase in insect pests: Potential bio-pesticides in insect pest management. European *Journal of Experimental Biology*, *4*, 259-264.

Shams, G., Safaralizadeh, M. H., Imani, S., Shojai, M. & Aramideh, S. (2011). A laboratory assessment of the potential of the entomopathogenic fungi *Beauveria bassiana* (Beauvarin) to control *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) and *Sitophilus granarius* (L.) (Coleoptera: Curculionidae). *African Journal of Microbiology Research*, *5*, 1192-1196.

Siemianowska, E., Kosewska, A., Aljewicz, M., Skibniewska, K. A., Polak-Juszczak, L., Jarocki, A. & Jędras, M. (2013). Larvae of mealworm (*Tenebrio molitor* L.) as European novel food. *Agricultural Sciences*, *4*, 287-291.

Silveira, R. D., Faroni, L. R. D. A., Pimentel, M. A. G. & Zocolo, G. J. (2006). Influência da temperatura do grão de milho, no momento da pulverização, e do período de armazenamento, na mortalidade de *Sitophilus zeamais* e *Tribolium castaneum*, pela mistura bifenthrin e pirimifós-metil. *Revista Brasileira de Armazenamento*, *31*, 120-124.

Smith, L. E., Stoltzfus, R. J. & Prendergast, A. (2012). Food chain mycotoxin exposure, gut health, and impaired growth: A conceptual framework. *Advances in Nutrition*, *3*, 526-531.

Suleiman, R. A., Rosentrater, K. A. & Bern, C. J. (2013). Effects of deterioration parameters on storage of maize: A review. *Journal of Natural Sciences Research*, *3*, 147-165.

Tavares, M. A. G. C. & Vendramim, J. D. (2005). Bioatividade da Erva-de-Santa-Maria, *Chenopodium ambrosioides* L., sobre *Sitophilus zeamais* Mots. (Coleoptera: Curculionidae). *Neotropical Entomology*, *34*, 319-323.

Tavares, W. S., Freitas, S. S., Grazziottib, G. H., Parentec, L. M. L., Lião, L. M. & Zanuncio, J. C. (2013). Ar-turmerone from *Curcuma longa* (Zingiberaceae) rhizomes and effects on *Sitophilus zeamais* (Coleoptera: Curculionidae) and *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Industrial Crops and Products*, *46*, 158–164.

Tefera, T., Mugo, S. & Likhayo, P. (2011). Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus* *zeamais* and the larger grain borer *Prostephanus truncates*. *African Journal of Agricultural Research*, *6*, 2249-2254.

Turner, B. D. (1998). The pest status of psocids in the UK. *Pesticide Outlook*, *9*, 27-30.

Turner, B.D. (2002) Current trends in stored product research. *International Pest Control*, *44*, 110-113.

Upadhyay, R.K. (2013). *Capparis decidua* solvent and aqueous extracts affect biochemical and enzymatic parameters in *Sitophilus oryzae* Linn. (Coleoptera: Curculionidae). *World Journal of Zoology*, *8*, 245-255.

Vayias, B.J., Athanassiou, C.G. & Buchelos, C.T.H. (2009). Effectiveness of spinosad combined with diatomaceous earth against different European strains of *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae): influence of commodity and temperature. *Journal of Stored Products Research*, *45*, 165-176.

Wang, C.F., Liu, P., Yang, K., Zeng, Y., Liu, Z.L., Du, S.S. & Dend, Z.W. (2011). Chemical composition and toxicities of essential oil of *Illicium fragesii* fruits against *Sitophilus zeamais*. *African Journal of Biotechnology*, *10*, 18179-18184.

Yang R.S., Witt K.L., Alden C.J. & Cockerham L.G. (1995). Toxicology of methyl bromide. *Reviews of Environmental Contamination and Toxicology*, *142*, 65-85.

Zhu K., Huesing, J.E., Shade, R.E., Bressan, R.A., Hasegawa, P.M. & Murdock, L.L. (1996). An insecticidal N-acetylglucosamine-specific lectin gene from *Griffonia simplicifolia* (Leguminosae). *Plant Physiology*, *110*, 195-202.

Zottich, U., Da Cunha, M., Dias, G.B., Rabelo, G.R., Oliveira, A.E.A., Carvalho, A.O., Fernandes, K.V., Nascimento, V.V. & Gomes, V.M. (2014). The toxicity of a lipid transfer protein (Cc-LTP1) from *Coffea canephora* seeds on the larval development of *Callosobruchus maculatus* (Coleoptera: Bruchidae). *The Protein Journal*, doi: 10.1007/s10930-014-9575-9.