Food Bioprocess Technol (2015) 8:239–265
DOI 10.1007/s11947-014-1399-2

ORIGINAL PAPER

Insect Pest Management in Stored Pulses: an Overview

Debabandya Mohapatra · Abhijit Kar ·
Saroj Kumar Giri

Received: 5 September 2013 / Accepted: 31 August 2014 / Published online: 12 September 2014

Abstract Pulses, which constitute an important part in the daily diet of mostly the vegetarian population, suffer a great damage by insects during storage. In this review, different control measures such as chemical treatment, physical treatment, and biological control of insects in stored pulses are discussed in brief. Chemicals like methyl bromide, malathion, and dichlorvos are being phased out. In these circumstances, new age chemicals like carbonyl sulfide and sulfuryl fluoride are gaining acceptance. Carbon dioxide and biogas generated from cow dung can be used as fumigation measures. Natural products like vegetable oil, inert dusts, plant extracts like essential oils, lectins, proteins, and leaf powders, which have insecticidal and antimicrobial activity, have been used as fumigants for traditional storage worldwide. Simple technologies like sun drying and repeated sieving can be adopted by small-scale farmers and traders. Maintaining low oxygen, high carbon dioxide, or pure nitrogen atmosphere in the storage environment is also proving to be beneficial preventive methods. Hot air and irradiation are being used, while dielectric heating is still in the stage of development in many of the developed countries for insect control. Developing countries are beginning to consider the use of these methods to control stored product insects.

D. Mohapatra (✉) · S. K. Giri
Agro-Produce Processing Division, Central Institute of Agricultural Engineering, Nabi bagh, Berasia Road, Bhopal 462038, India
e-mail: debabandya@gmail.com

S. K. Giri
e-mail: giri.saroj@gmail.com

A. Kar
Food Science and Postharvest Technology Division, Indian Agricultural Research Institute, New Delhi 110012, India
e-mail: abhijit8366@gmail.com

Keywords Storage · Pulses · Bruchids · Dielectric heating · Plant derivatives · Irradiation · Sunning · Inert dusts

Introduction

Pulses are those food legumes, which are harvested as dry grain, excluding vegetable crops like green beans and green peas and grains like soybean and peanuts that are cultivated for oil extraction. Pulses are a good source of vegetable protein catering to the needs of mostly the vegetarian population. Even with increased production over the years, India, a top pulse-producing country, still relies on other countries for meeting her domestic demand (Mangaraj et al. 2013), because of her burgeoning population and cultivable area shrinking due to rapid urbanization. One of the means of increasing food supply is by improving the postharvest and storage practices to reduce food loss to insects.

Pulse yield is devastated by the attack of insects and other pests. This pest problem is not localized to India but everywhere in the world, where stored products are damaged by a number of storage pests. The major groups of storage pests are insects, fungi, bacteria, and rodents, which contribute to storage losses apart from the losses that occur during handling and transportation, due to lack of proper storage facilities and pillaging of grains. Among all the pests, insect damage in stored grains alone may amount to l0–50 % (FAO 2012). Insects are competing with human races for food. The insects do not only damage the field crops but also accompany the grains even to the store houses and warehouses to cause severe damage. These insects eat a considerable part of the stored product and also contaminate the sound grains with their dead bodies, wings, and excreta. In many instances, small improvements in storage methods had led to much better protection of stored product culminating in lesser losses. It is desirable to have a good storage building with proper grain handling system and good safety measures, which can reduce the losses to a large extent. Even with good storage practices that follow good hygiene practice during handling and storage, adequate drying of stored grains to a safe moisture level, and all other safety measures, may always not be effective in preventing storage losses (Ghosh et al. 2007). Storage pests may still manage to reach the product and cause irreparable damage. The insects could slip into the product from the field (Kawuki et al. 2005), during transit, storage, or from the processing and handling equipment. Storage of food grains, which have already been infested with pests, has been the cause of concern for farmers. Though most of the field pests do not thrive in the stored grains, some still manage to survive and cause collateral damage with the storage pests. These insects may cause damage as high as 50 % or more in a temperate region like Canada, as reported from a case study on lentils (Ghosh et al. 2007), but the losses could escalate to 100 % as reported for chick peas, in tropical countries like India (Dubey et al. 2008). As a result, small and marginal farmers who grow pulses are unable to store their produce and eventually are forced to sell their hard-earned commodities at a throwaway price. This compromises food safety and forces the farmers to continue living in drudgery and poverty. In this review, different pest control measures practiced worldwide, commercially and at the domestic level, and ongoing research findings are discussed.

Major Storage Insects in Pulses

Coleopteran insects of the family Bruchidae, one of the major seed weevils/bruchids, have been associated with the seeds of leguminous plants through co-evolutionary processes (Sales et al. 2000). These processes have permitted the bruchids to thrive on seeds full of toxic compounds, in contrast to the majority of the other potential aggressors, which are incapable of dealing with the toxic compounds (Sales et al. 2000). The bruchids, also commonly referred to as pulse weevils/beetles, lay their eggs on the maturing pods in the field, or in stored dry whole pulses. Some of the major pulse bruchids are *Callosobruchus maculatus*, *Callosobruchus chinensis*, *Callosobruchus analis*, *Callosobruchus rhodesianus*, *Callosobruchus dolichosi*, *Callosobruchus subinnotatus*, *Callosobruchus phaseoli*, *Acanthoscelides obtectus*, and *Zabrotes subfasciatus*. Apart from bruchids, other insects attacking the stored beans are *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Hbst.), *Rhyzopertha dominica* (F.), *Prostephanus truncatus* (Horn), *Sitophilus* spp., and nitidulids (Giles 1977). In this article, however, disinfestations methods are described vis-a-vis bruchid disinfestations. Bruchid infestation of pulses commences in the field itself, even before the crop is harvested (Kawuki et al. 2005), and this infestation is carried into warehouses, resulting in further infestation and deterioration of the stored pulses. These insects multiply at a rapid rate in suitable environmental conditions such as high humidity and optimum temperature conditions (Appleby and Credland 2004). The larvae that emerge out of the eggs bore into the pulses and start feeding on them. The association between bruchids and pulses is highly specific, with only seeds of a very few species being attacked by any one insect species (Tuda et al. 2005). A study conducted by Haines (1989) revealed that *C. analis* attacked the green gram and white soybean, whereas the beetle *Bruchidius atrolineatus* infested and damaged seeds of *Vigna unguiculata* (L.) Walp. in tropical Africa, but it did not infest the seeds of *Voandzeia subterranea* (L.) Thou., *Glycine max*, *Voandzeia subterranea* (L.) Thou., and *Phaseolus vulgaris* L. *Cicer arietinum* and *Vigna radiata*, however, may serve as primary or alternative hosts to the beetle (Ofuya and Credland 1996). Similarly, chick pea cultivars are primarily invaded by *C. analis* and *C. chinensis* (Jha et al. 2009).

Disinfestation Methods for Stored Pulses

Insect development in stored pulses causes depreciation in the crop quality. A wide range of methods are adopted worldwide for disinfesting stored pulses; they are specific to geographical distribution, grains or food commodities, etc. The severity of insect damage depends on the storage methods or disinfestation technology and commodity type. Since ancient times, insecticides and repellents have been used to protect grains from insect attack. Some archeological studies revealed that natural insecticides and insect repellents were used in storage structures. People at that time were using a wide range of methods such as airtight storage, use of plant and animal parts, oils, minerals, and ash for controlling insect pests in order to reduce storage losses (Panagiotakopulu et al. 1995).

The disinfestations of stored grains are mostly carried out with the help of chemical fumigants and contact insecticides. These chemicals pose health hazards to the workers, leave residue in the grain as well as pollute the environment. Despite these drawbacks, chemical fumigation is still one of the most effective methods for disinfesting the stored food, feedstuffs, and other agricultural commodities. Of late, there is growing public awareness regarding the adverse residual effect of these chemicals on mammalian health and ecology; this has resulted in prohibition of the use of toxic chemicals in food grain storage and led to banning of certain chemicals. This has limited the introduction of new compounds (Shaaya et al. 1997). Some of the treatments may be inappropriate for food due to the residues.

There is also a growing interest for the use of nonchemical or natural compounds, mostly plant derivatives to use as insect control measures, such as plant essential oils, vegetable oils, plant leaves, and bark powders. Among the nonchemical methods of disinfesting stored grains, simple physical measures such as sunning or applying sand layer on the grains for restricting the insect attack, adopting suitable postharvest management practices, and controlling the moisture content of the grain by adopting suitable drying methods could be effectively adopted at the small-scale level or cottage level. On the other hand, advanced technologies such as irradiation and dielectric heating could be adopted commercially as alternate methods to chemical disinfestations (Rahman 1990; Wang et al. 2010; Baoua et al. 2012a; Hallman 2013). Some of the treatments are recommended to be used before storage such as sieving, heating, ionizing, impact, and the use of natural products. Most of the physical treatments are effective before storage to prevent the increase in the number of insects. Some of these treatments used for controlling insects and pests are discussed in brief in the succeeding sections.

Chemical Treatments

Chemical treatments mainly comprise of fumigants and contact insecticides. Fumigants are applied to eliminate infestations already present, while protectants are mostly admixed with grain to prevent insect infestation from occurring during the storage period (Lindgren et al. 1968). It is not recommended to use synthetic insecticides with food grains that are for consumption. Only chemicals registered for direct application to pulses should be used and these should be applied according to recommended doses.

Fumigant

During the early 1990s, insect control was largely done by fumigants, which emit toxic gas that kills all insects in all stages in an enclosure. The enclosure should be airtight so that the gas can penetrate and remain in the commodity for a suitable time period in order to eliminate all stages of insects. Once the exposure time is over, the pulses must be aerated and the bin checked for residual fumigant before entry of workers inside the bin. Fumigants are widely used as a cheap source of insecticides and pesticides. The efficiency of the fumigation depends on the relative humidity and temperature of the storage environment and seed moisture content (Mulhearn et al. 1976; Gupta and Kashyap 1995; Zettler and Arthur 2000) and airtightness of the storage system. Mulhearn et al. (1976) postulated that wind-generated pressure may be encountered by the tall cylindrical storage structure, which would create turbulent flow and vertical air velocity around the structure, affecting the fumigation and controlled atmospheric storage of grains. Gupta and Kashyap (1995) observed that bruchid infestation was more severe at 12 % (wet basis, wb) grain moisture content, and the deterioration was lower at storage grain moisture content of 9 % (wb) or less. Some of the common fumigants used earlier such as methyl bromide, ethyl formate, ethylene dibromide, hydrocyanic acid, carbon tetrachloride, ethylene dichloride, and carbon disulfide (Lindgren et al. 1968) are being phased out in recent years. Major fumigants used worldwide for storage pests are discussed in the following sections.

Phosphine Phosphine fumigation is one of the widely used insect control measures. A recommended dose of tablets or pellets is usually applied into the grains, enclosed properly. On contact with humid air, these tablets generate toxic phosphine gas, which causes lethality in insects and eliminates all stages of insects, i.e., eggs, larvae, pupae to adults. Singh and Srivastava (1980) fumigated pea, cowpea, and green gram with different fumigants against *C. maculatus* and *C. chinensis* and observed that phosphine is more effective than ethylene dibromide, carbon disulfide, ethylene dichloride + carbon tetrachloride, and carbon tetrachloride. By aerating these pulses for 1.5–3 days, the residues of these fumigants were reduced and were completely removed after washing and cooking of the pulses. Their study recommended the use of 1–2 tablets/ton of food legume for complete elimination of pulse bruchids. Some researchers claim that phosphine does not impair the pulse grains nor leave residues that could be hazardous to the consumer when correctly applied and the pulses are aerated (Ahmad 1976; Rangaswamy and Gunasekaran 1996). It was observed that after the application of six phosphine tablets/ton to grains for the stipulated time and then airing, some food legumes desorbed the residual phosphine more rapidly than others, and within 1 day of aeration, the residues were significantly reduced. Based on this observation, Rangaswamy and Gunasekaran (1996) recommended the use of phosphine as a suitable fumigant for pulses. On the flip side, there are growing reports of insects developing resistance to phosphine (Benhalim et al. 2004). The misuse of phosphine in short exposures at high temperatures in poorly sealed enclosures has led to the development of resistant strains (Bell 2000). This has forced the farmers to use higher doses than the recommended limit, which eventually has turned ineffective and compromised the workers' and ecological safety. For achieving effectiveness, other chemicals like carbon dioxide, ethylene dibromide, methyl bromide and methyl iodide, and sulfur dioxide (Rajendran and Muthu 1989; Athié et al. 1998; Brice and Golob 2000) in combination with phosphine are being considered for fumigation purposes. These chemicals are cheap and are still in use in many countries. The combinations of chemicals are proving to be effective as of now. Inadequate dose and lack of airtightness during fumigation however becomes ineffective, presenting possible adverse effects on humans and the environment.

Ethyl Formate The phasing out of methyl bromide is paving the way for the use of ethyl formate as a stored grain fumigant. Ethyl formate was earlier used to disinfest fresh fruits and has been successfully used to disinfest various cereals, pulses, oil seeds, spices, dry fruits, and nuts. A dose of 300–400 g/m^3 for an exposure period of 48–72 h controls all the stages of insect life in stored grains and stored grain products. Muthu et al. (1984) have suggested the use of ethyl formate as fumigant in grain storage due to its low residue presence, which is below the permissible limit (250 ppm). Inadequate dose and lack of airtightness during fumigation, however becomes ineffective, presenting possible adverse effects on humans and the environment.

Sulfuryl Fluoride Sulfuryl fluoride is evolving as a new age fumigant, which may be accepted worldwide for disinfesting different grains. There are reports of success of this fumigant in warehouses, flour mills, and storage structures (Outram 1967; Chayaprasert et al. 2009; Baltaci et al. 2009; Tsai et al. 2011). This chemical has a good potential to act as a potent fumigant in stored pulses; however, airtightness should be maintained for the fumigant to be effective. This should be followed by aeration to eliminate the residual effect of the chemical.

Carbonyl Sulfide Carbonyl sulfide (COS) is another grain fumigant, a substitution to methyl bromide. It is to be noted that methyl bromide is to be phased out by 2015 in accordance with the Montreal Protocol on ozone-depleting substances. COS is also supplementing phosphine gas which is experiencing increased insect resistance. COS has low acute inhalational toxicity. It is neither genotoxic nor a developmental toxicant; however, it may impair male fertility and cause neurotoxicity on prolonged, repeated exposure. The adverse effect of prolonged exposure of this fumigant may be prevented through suitable safety management practices, by proper aeration and scrubbing of ventilated COS, at the completion of fumigation (Bartholomaeus and Haritos 2005). Its efficacy as a fumigant against pulse bruchids has been reported by Ren and Mahon (2007) with a dose of 50 mg/l and an exposure time of 4 days. The residues were desorbed after 2 days of aeration. This chemical also has the potential for disinfestation and can be used for a long time, provided suitable measurements are observed such as airtightness and aeration after the fumigation.

Carbon Dioxide Insects need oxygen for respiration like all living forms. When oxygen is replaced by carbon dioxide flushing in the storage place, this would create an adverse atmosphere for the insects. The enhanced CO_2 concentration would suffocate, dehydrate, and poison the insects (Navarro 2006; Navarro et al. 2012b). Elevated carbon dioxide levels must be maintained for a suitable time frame until all the insects die. The required exposure time depends on the carbon dioxide concentration and the temperature of the grains. Moreover, the prohibitive cost of CO_2 fumigation can be countered by using other fumigants in combination (Calderon and Carmi 1973; Banks and Pinkerton 1987; Riudavets et al. 2013). Mbata and Reichmund (1996) observed effective disinfestation of *C. subinnotatus* in bambara groundnuts while employing 100 % CO_2. Mbata et al. (1996) in their study suggested about 5–6 days of exposure time for 100 % mortality of pupal stage of *C. maculatus* and *C. subinnotatus*. It took only 48 h to kill the eggs and adult and 72 h for older adults in 100 % CO_2 atmosphere, at 32 °C and 70 % relative humidity (RH), in black eye cowpea and bambara groundnuts. Sinha et al. (2001) fumigated green gram with smoke produced by burning cow dung and achieved 80 % mortality in adult *C. maculatus* in 120 h of exposure. Banks and McCabe (1988) hypothesized that there may be a possibility of carbonation in the concrete bins and silos, which would result in corrosion of the structure with passage of time. Their observation was based on the absorption and desorption of CO_2 by the concrete walls of the bins during fumigation and aeration. They speculated that since the grains respire, producing CO_2 and water, which may form carbonic acid, would in turn corrode the iron parts of the storage structure. Since then, many concrete structures have been erected for grain and being fumigated with CO_2; no such adverse effects of CO_2 fumigation have come to the fore. Cheng et al. (2013) demonstrated the lethality of CO_2 on all developmental stages of *C. maculates*. It was observed that eggs were most vulnerable to hypoxia caused by CO_2, particularly at the early stage. A CO_2 concentration of 18 % was sufficient to cause mortality in the insect. The lethality of CO_2 at different concentrations (50, 70, and 90 %) on *C. maculatus*, *A. obtectus*, and *Z. subfasciatus* was also demonstrated by Wong-Corral et al. (2013). Application of CO_2 fumigation comes with a price such as anaerobic respiration, production of alcohol and acids, and loss of seed viability.

Biogas Biogas as alternative to phosphine fumigation has been evaluated and found to be effective against pulse bruchids (Subramanya et al. 1994). Biogas from cow dung comprising mainly of 60 % methane and 40 % carbon dioxide was used as a fumigant in an airtight bin specially designed for the control of *C. chinensis* L. Biogas, when applied to the seeds and grains of pigeon pea, achieved 100 % mortality of eggs, grubs, and adults within a period of 10 days of fumigation. Biogas fumigation did not affect the seed germination, seedling vigor, or grain quality. No gaseous methane residues were left in the grain after the fumigation period (Mohan and Gopalan 1992). A similar work reported by Subramanya et al. (1994) revealed that exposure of different life stages of *C. chinensis* to biogas for 5 days using airtight containers was effective on all life stages except the pupal stage. In countries like India, where agriculture is still animal dependent and many farmers are rearing cattle for milk production, generation of biogas from the cattle dung is a feasible option. Considering its potential as an insecticide, the gas can be bottled, transported, and applied to the grains in sealed chambers as an integrated pest management technology for small holders. However, research is being conducted at CIAE, Bhopal, India for collecting biogas in polyethylene chambers, which would be cost effective and easy to handle (personal communication). Once this technology is standardized, the problem of biogas collection and handling will be solved, and biogas can be used by small and marginal farmers to disinfest stored pulses easily.

Most fumigants are toxic to humans in high doses. Therefore, workers' safety issues should also be addressed while recommending any fumigant. For effective insect control, all fumigation practices should be carried out in airtight conditions for a suitable period of time and there should be aeration of grains, before allowing the workers to handle the grains.

Protectants

Grain protectants have been used since the 1960s in bulk grain storage systems; however, biological, sociological, and technological impacts have limited the use of protectants (Arthur 1996). The most common protectants used are malathion and pyrethrins plus piperonyl butoxide. The use of some insecticides, such as such as dimethoate, permethrin, carbosulfan, and malathion in stored products is facing restriction as some strains of *C. maculatus* have exhibited higher tolerance than normal to some insecticides (Mbata and Payton 2013). This has again raised the issue of biosafety for the use of these chemicals in higher doses in food commodities. Some of the present-day protectants including that of plant origin are discussed in brief in the following sections.

Malathion Malathion, once a widely used chemical, is toxic to insects if it comes into direct contact with the pest. It was considered one of the safest organophosphate insecticides as it was not highly toxic to humans or pets and broke down fast under tropical conditions (Titenko-Holland et al. 1997). Lalah and Wandiga (2002) applied malathion on bean and maize. The residue analysis revealed that malathion and its polar metabolites (malathion α- and β-monocarboxylic acids) were completely eliminated by boiling, though malaoxon was still detected in quite high quantities in the solvent extracts of cooked beans and maize. The addition of sodium chloride (NaCl) to the grains, however, increased the rate of removal of the residues from both maize grains and beans by boiling water. The effectiveness of these chemicals depends largely on the temperature and humidity of the storage environment and grain moisture level. Hunje et al. (1990) found that seed germination quality of cowpeas was not affected by the application of malathion (10 mg/kg seeds) during 6 months of storage period. The residue left after malathion exposure was found to be effective against controlling infestation of *C. maculatus* and *C. chinensis* in stored pulses (Azad and Srivastava 2007). The study of malathion residue on broad bean revealed that the content was reduced after 90 days of storage and there was almost negligible presence in the hulled and processed beans. Washing alone reduces the contents of these chemicals by about 69 % of the initial value, while cooking will reduce up to 99 % residue in beans (Kamil et al. 1996). Insects have developed a strong resistance to malathion and now this has been banned for food grain use by many countries.

Dichlorvos (2,2-Dichlorovinyl Dimethyl Phosphate, DDVP) Dichlorvos had been in widespread use as a pesticide for control of insects and rodents for a variety of foods, including packaged foods, grains, fruits, vegetables, and non-food items like soil and storage containers (Green and Wilkin 1969; Bond et al. 1972; Elms et al. 1972; Desmarchelier et al. 1977). Most studies reported the use of dichlorvos for insect control in cereals and their derivatives (Green and Wilkin 1969; Desmarchelier et al. 1977). There are limited reports on the control of pulse beetles by dichlorvos. The rapid metabolism of dichlorovus and excretion by mammals has superseded its toxic effects. Its carcinogenicity and genotoxicity have been evaluated extensively and no concrete evidence of genotoxicity was found in humans (Ishmael et al. 2006; Booth et al. 2007). The residues are, however, dose dependent and decrease with storage duration. Some studies implied that there was no external residue of these pesticides in beans when applied at a dose of 12 and 24 mg insecticide/kg seeds on faba bean and soybeans before storage; however, some residue (8–11 %) was found bound inside the grain after the storage period (Zayed et al. 2007). These chemical residues in food grains, however, are of major concern, which limits its application in the stored food grains.

Fenitrothion Fenitrothion is a phosphorothioate insecticide. It is cheap and widely used worldwide. A lower dose of fenitrothion is more effective than malathion and dichlorvos. The effectiveness of this chemical, however, depends on the temperature and humidity conditions in the stored bin and grain moisture content. While no effect was observed within 2 weeks of storage at the high-temperature environment, a cooler environment presented better residual effect even after prolonged period of storage (Tyler and Green 1968) for pulses.

Pyrethroids Pyrethroids are synthetic insecticides based on oil or alcohol. It has low mammalian toxicity and environment persistence; however, it affects the central nervous system of the workers (Casida 1973). This insecticide has a synergistic effect on the insects when applied in combination with other contact insecticides like piperonyl butoxide (Wickham 1998). This protectant was found to be effective at 0.25 ppm for disinfesting wheat grains (Athanassiou et al. 2004). Insects growing resistance to pyrethroids are being reported (Guedes et al. 1995) and also the toxicity effect on mammals may act as a deterrent for the future of this insecticide.

Chemical grain protectants have their residual effect on the grains. Moreover, there are reports of insect resistance to these chemicals. Hence, these chemicals do not have very promising future for food grains. They may be used with hazard restrictions.

Natural Products

Chemical fumigants and protectants have issues of leaving residue in the food grains. The growing concern over residue toxicity has opened the door for the usage of products of nonchemical nature for grain disinfestations. Though natural products have been in existence since ancient times, the evolution of chemical pesticides and commercialization had reduced its impact and use. However, natural products are still used by some farmers and traders. With more and more insects developing resistance to chemical pesticides, emphasis is now back on the use of natural products like plant extracts, inert dusts, etc. In the following sections, some of these products being used worldwide are discussed.

Inert Dusts

There is an increasing interest in employing inert dusts as insect control measures in the grain industry. These materials can be classified into different groups depending on their composition and particle size, i.e., nonsilica dusts and those composed of coarse grain silicates, such as kaolin and sand. These materials have been used traditionally as grain protectants by small-scale farmers in the developing world (Golob 1997). The usage of materials including diatomaceous earth and silica aerogels has been increasing in commercial storage in the developed world as replacement of chemical pesticides for control of a variety of common storage insect pests. The inert dusts remove the waxy layer of the cuticle of the exoskeleton by adsorption, resulting in water loss from the insect body that eventually leads to death by desiccation. Therefore, they are most effective in low humidity conditions. Usually, the dust form of these materials is applied in the grains; however, some are also reported to be effective when applied in water-based slurry form (Golob 1997). The natural inert dusts have some adverse effect on human health, resulting from inhalation, and concerns regarding abrasion of grain handling machinery. The synthetic inert dusts are overcoming such problems and are also effective in controlling primary pests of cereals and pulses (Golob 1997). Mortality of the insects depends largely on the amount of inert dust applied and the type rather than the duration of exposure (Vardeman et al. 2007). Fly ash, sand, kaolin, paddy husk ash, wood ash, and clays are commonly used by small-scale farmers in the developing world as grain protectants. The inert dusts should be applied at more than 5 % by weight of the total grain mass to be effective (Golob 1997).

Fly Ash Control of some insects can be achieved by using a nontoxic dust like fly ash which is produced from burning coal from the thermal power industries. This waste poses serious environmental hazard if not properly disposed off. Mendki et al. (2001) applied 1 g fly ash per 5 kg of pulses, viz. soybean (*G. max*), Bengal gram (*C. arietinum*), green gram (*V. radiata*), black gram (*Vigna mungo*), and red gram (*V. unguiculata*) under ambient storage conditions for 18 months and found that the fly ash effectively controlled the insect infestation at least for 12 months and no detrimental effect of fly ash on germination percentage or nutritional value of the pulses was observed.

Diatomaceous Earth (DE) DEs are amorphous dusts that are used to control insect growth. Natural and artificial DEs are applied as dusts, spray powder, suspensions, or granular forms (Mewis and Ulrichs 2001). The principle on which DEs work is desiccation. DEs cause water loss from the insects, resulting in death; however, at high RH (>60 %), they can reduce transpiration through the cuticle of the insect, thus affecting the lethality (Mewis and Ulrichs 2001). Stathers et al. (2004) applied commercial DE products at the rate of 0.02, 0.03, and 0.1 % (*w*/*w*) to eliminate *C. maculatus* on cowpea (*V. unguiculata* (L.) Walpers), and *A. obtectus* on red kidney bean (*P. vulgaris* L.). The adult mortality was observed after 3 days of exposure period, and it was found to be effective at lower humidity (50 %) as compared to 60 %. DEs are therefore recommended to be used in dry climates to be more effective and are not suitable for wet season or humid climates.

Silica Dusts Silica dusts gave variable results when used against different target organisms. To understand the basis for the variability, it is necessary to determine the mode of action of the dusts. Mewis and Ulrichs (2001) had compiled different theories that were proposed: (1) surface enlargement of the integument following dehydration; (2) impairment of the digestive tract; (3) blockage of spiracles and tracheae; (4) adsorption/absorption of cuticle lipids; and/or (5) damage of the protective wax layer. Furthermore, some authors related adsorption and/or absorption to symptoms of dehydration and to weight loss. Detailed mechanisms of dehydration are unknown, though it is postulated that the dust particles are trapped by the bodies of the insects as they walk over it. The dust is most effective against insects with setaceous and rough surfaces. Damage occurs to the insects' protective wax coat on the cuticle, mostly by sorption and to a lesser degree by abrasion, or both. The result is the loss of water from the insect's body through desiccation resulting in death (Korunic 1998). The efficacy of silica dust (500 μg silica dust/g wheat) was better at lower relative humidity (40 than 60 %) and higher temperature (30 than 20 °C) in controlling *R. dominica* (Aldryhim 1993).

Silica Aerogels Silica aerogels are produced by drying aqueous solutions of sodium silicate. The low dust density, hydrophobic powders are more effective than diatomaceous earth and require lower amounts to be applied on grains. The very low dust density has prevented the widespread application of these materials in the past because of the potential hazards which would occur during inhalation even for a small amount (Golob 1997). The natural dusts though proven effective are yet to be commercialized, as these need additional cleaning/sieving of the grains. Their use in the domestic and in the small holding is preferred.

Botanical Derivatives

Plant derivatives had long been used as insecticide or as fumigant for the stored grains and for food materials. Plant products have a great potential in pest management because of the nonphytotoxicity, systemicity, easy biodegradability, and stimulatory nature of the host metabolism (Dubey et al. 2008). They are still used by small-scale farmers and in households of the hinterlands of the African and Asian countries. Used widely until the 1940s, these natural pesticides were displaced by modern synthetic pesticides that at the time seemed cheaper, easier, and long-lasting (Dubey et al. 2008). Now that the ill effects of synthetic pesticides are haunting consumers and traders, researchers are now focusing more on the use of extracts and direct plant powders as an effective method of insect control. Though commercialization is not generally possible at this juncture, in the future, with advancing technologies, these methods may be easily adopted as integrated pest management (IPM) measures commercially, in the global arena. The biopesticides are biodegradable as they originated from plant sources and they do not leave toxic residues, hence can be used as green pesticides.

Vegetable Oil Application of vegetable oil on the surface of whole pulses also restricts the egg laying ability of the pulse beetle. In many parts of world, people apply neem oil, castor oil, and other edible oils on the whole and split dals to prevent insect attack (Ahmed et al. 1988; Khaire et al. 1992; Boeke et al. 2004a, b). Pulse beetle, a major pulse pest, which infests the whole grain, cannot lay eggs on smooth grain surface made more slippery by oil application on the grain surface (Lale and Mustapha 2000). Also, the structure of the eggs of different species of *Callosobruchus* discourages the oviposition on legume surface dabbed with oil. The vegetable oil has both ovicidal and larvicidal effect (Credland 1992). Most researchers reported that the germination of the seeds is not altered by the application of vegetable oil. Efficacy of vegetable oils for prevention of insect attack on various pulses is very well documented (Schoonhoven 1978; Varma and Pandey 1978; Hill and Schoonhoven 1981; Pandey et al. 1981; Messina and Renwick 1983; Ivbijaro 1984; Hall and Harman 1991; Pacheco et al. 1995). Some of the results are compiled in Table 1. Application of vegetable oil to protect grains from insect invasion is being practiced domestically as well as in a small scale in India.

Plant Powders or Products Traditionally, various plant leaf powders, seed powder, and bark powders are used all over the world to control damage to grains, and many of them have no toxic effect on humans (Ogunwolu and Odunlami 1996; Kestenholz et al. 2007; Lehman et al. 2007). These plant products can directly be applied in powder form or as a biofumigant (Shaaya and Kostyukovsky 2009) or may be impregnated in the bags into which pulses are stored, to prevent insect growth and cause mortality of all insect growth stages. Several works have reported the efficacy of such botanical powders in preventing insect growth in food legumes (Schmidt et al. 1991; Saxena et al. 1992a, b; Shaaya et al. 1997; Kim et al. 2003; Park et al. 2003a; Sadeghi et al. 2006; Rajendran and Sriranjini 2008; Kumar et al. 2009; Shimizu and Hori 2009; Coelho et al. 2010). Some of the results are compiled in Table 2. This method is meant for domestic use or for small-scale farmers and dealers.

Plant Essential Oils Plant essential oils have various pharmaceutical, cosmetological, and pesticidal uses. Plant essential oils are recommended for use as potent pesticides worldwide as they are biodegradable and less detrimental to nontarget organisms as compared to synthetic pesticides (Dubey et al. 2008). Plant essential oils are usually obtained from various parts of the plant including the bark, leaf, flower, bud, seed, tubers, and rhizomes. They are extracted through ultrasound, microwave-assisted super critical fluid extraction, or hydro or steam distillation methods. They are a complex mixture of mainly terpenoids, particularly monoterpenes (C10) and sesquiterpenes (C15), and a variety of aromatic phenols, oxides, ethers, alcohols, esters, aldehydes, and ketones that determine the characteristic aroma and odor of the donor plant (Batish et al. 2008). These monoterpenoids are believed to build the chemical defense mechanism in plants, against phytophagous insects. The probable insecticidal properties of these biochemicals are now being researched extensively. Various plant extracts have been very well documented by researchers for their insect repellent as well insecticidal effects (Shaaya et al. 1997; Kim et al. 2003; Batish et al. 2008; Nerio et al. 2010; Kumar et al. 2011; Stamopoulos 1991). A study conducted by Koona et al. (2007) has shown that the use of jute bags impregnated with aqueous extracts from *Chenopodium ambrosioides* and *Lantana camara* significantly reduced damage to stored legume seeds from *A. obtectus* and *C. maculatus*. Considering the biodiversity of the world, more and more plant species with insecticidal effect are being identified. These locally available plant extracts may be used as a cheap source of insecticide. Sabbour and E-Abd-El-Aziz (2010)

Table 1 List of some vegetable oils as insect control measures in stored pulses

Insect species	Vegetable oil	Bioefficacy	References
C. chinensis	Neem, rape, coconut, mustard, mahua, sesame, and palm oils	1 ml/100 g seed against all stages of the pest. Neem, coconut, mustard, mahua, and sesame caused 100 % egg mortality, while the neem and coconut oils caused 100 % larval mortality and 100 % adult mortality in green gram	Ali et al. (1983)
C. chinensis	Sesame, cottonseed, palm, neem seed, groundnut, and coconut oils	0.25 % neem oil or 0.5 % coconut oil prevented insect infestation in green gram	Sujatha and Punnaiah (1985)
C. chinensis	Neem, karanja, mustard, groundnut, and castor oils	Karanja oil (5–10 ml/kg green gram), castor oil (10 ml/kg green gram), reduced oviposition over 18 months storage in green gram	Babu et al. (1989)
C. chinensis	Neem, groundnut, castor, soybean, and sesame oils	All oils 0.5–1.0 ml/100 g of chickpea seed reduced infestation. Neem and groundnut oils effective at 0.25 ml/100 g chick pea seed	Choudhary (1990)
C. chinensis	Groundnut, coconut, mustard, sesame, soybean, and rapeseed oils	Mustard (5 ml/kg) and coconut oils (3 ml/kg oil): least oviposition (34.3 eggs) in chick pea mustard oil-treated seeds (5 and 3 ml/kg) Groundnut, soybean, and rapeseed oils (1 ml/kg): minimum percentage adult emergence (0.5 %) in chick pea	Singal and Singh (1990)
C. chinensis	Neem oil caster, karanja, mustard, palm, sunflower, and groundnut oils	100 days storage, at a dose of 1 % reduced oviposition and increased mortality, neem and karanja oil, no emergence in pigeon pea	Khaire et al. (1992)
C. chinensis	Sunflower, castor bean, mustard, safflower, groundnut, palm, sesame, neem, karanja, and corn oils	Neem, castor bean, and karanja oils at 1 % effective against oviposition and egg hatching up to 100 days treatment in pigeon pea, no hatching up to 33 days	Kachare et al. (1994)
C. chinensis	Neem (*Azadirachta indica*), karanja (*Pongamia glabra*) [*Pongamia pinnata*], mohua (*Madhuca latifolia*) [*Madhuca longifolia*], and palmolein oil (*Elaeis guineensis*)	0.5–1.0 % in green gram, protected against oviposition (25–50 %), neem oil most effective 5 % neem oil, 100 % adult emergence prohibition	Reddy et al. (1999)
C. chinensis	Coconut, mustard, sunflower, sesamum and mahua, neem, karanja, castor, tarpin, and noorani	All oils at 8 ml/kg pigeon pea prevented egg laying up to 9 months storage	Singh (2003)
C. chinensis	Sunflower, mustard, groundnut, sesame, soybean, olive, and palm oils	No adult emergence in pigeon pea treated with ground nut oil at 1 % up to 66 days storage	Khalequzzaman et al. (2007)
C. chinensis *C. maculatus* *C. rhodesianus*	Corn, groundnut, sunflower, and sesame oils	100 ml/kg for reduced oviposition in corn, sesame, ground nut, and sunflower seeds	Rajapakse and van Emden (1997)
C. maculatus	Neem kernel, karité, groundnut, palm kernel, and palm oils	3 ml neem seed oil/kg bambara ground nut: reduced oviposition 8 ml neem seed oil/kg cowpea: reduced oviposition, 3 months storage 3 ml neem seed oil/kg bambara ground nut: 6 months storage life	Pereira (1983)
C. maculatus *C. phaseoli*	Refined soybean and crude castor oils	Castor oil more effective at 10 ml/kg for *C. maculatus* for 150 days, *C. phaseoli* for 90 days in chick pea	Pacheco et al. (1995)
C. maculatus	Neem seed oil	75–100 mg oil/5 g reduced oviposition and higher mortality, damage 5 % (control 25 %) in cowpea	Lale and Mustapha (2000)
C. maculatus	Ground nut oil	5 ml/kg cowpea complete protection, for storage up to 180 days	Singh et al. (1978)
C. rhodesianus	Maize oil, a blend of cotton seed and soya oil, castor oil, and citrus oil	5 ml castor oil/kg cowpea most effective against oviposition and egg hatching	Giga and Munetsi (1990)

tested the efficacy of three essential oils, i.e., cumin, clove, and mustard oils against *Bruchidius incarnatus* (Boh.) and observed that mustard and clove oils had a strong repellent activity even after 7 days of storage. They recommended application of mustard oil and *Paecilomyces fumosoroseus* oil on foam covering gunny bags for oviposition deterrency, toxicity, and suppressing *B. incarnatus* infestation for protecting broad bean seeds during storage. Some of the plant essential oils, their source, and the target stored pulse insects are presented in Table 3. Despite being naturally available with minimum toxicological effect on mammalian population, the use of essential oil as fumigant and repellent is still not

Table 2 List of some plant powders as insecticide in stored pulses

Insect species	Botanical name (plant parts)	Doses, bioefficacy (%)	References
C. chinensis	Dry leaves powder: *Syzygium cumini* L. *Aegle marmelos* L. *Eupatorium cannabinum* L. *Murraya koenigii* L. *Ammomum subulatum* Roxb. *Citrus medica* L.	Dose 2 % (*w/w*) in chick pea 34.98 (adult), 63.7 (oviposition) 45.04 (adult), 71.27 (oviposition) 80.03 (adult), 82.5 (oviposition) 75.07 (adult), 86.15 (oviposition) 25.07 (adult), 45.17 (oviposition) 65.01 (adult), 72.58 (oviposition)	Shukla et al. (2007)
C. chinensis L.	Dry leaves powder: *Tridax procumbens* L. *Withania somnifera* L. *Pongamia pinnata* L. *Gliricidia maculata* L.	Dose 20 mg/g pulse 100 (adult) 100 (adult) 73 (adult) 69 (adult)	Yankanchi and Lendi (2009)
C. maculatus	Dry seed powder: *Piper nigrum*	Dose 2 % *w/w* pulse 94 (oviposition)	Govindan and Nelson (2007)
C. maculatus	Rhizome: *Alpania officinarum*, *Curcuma longa*, *Paspalum scrobiculatum* Seeds: *Anamirta cocculus*, *Nelumbium speciosum*, *Strychnos nuxvomica*, *Ternimalia chebula* Leaves: *Annona squamosa*, *Azadirachta indica*, *Celosia argentam*, *Coccnia indica*, *Nicotina tabacum*, *Targetes erecta* Tubers: *Asparagus racemosus* and *Glorisa superb* Resin: *Canarium strictum* Fruits: *Capsicum annum*, *Helicteres isora* Bark: *Cratacva magna*, *Terminalia arjuna*	Dose 0.5 % in peas 94.44 (adult) with *Annona squamosa+ Anamirta cocculus* 30 (oviposition) with *Nicotina tabacum+Helicteres isora*	Govindan and Nelson (2008)
C. maculatus	*Anchomanes difformis* (rhizome)	Dose 1.5 g/25 g in cowpea after 72 h exposure 100 % mortality of adults, 30 % adult emergence	Akinkurolere (2007)
C. maculatus	*Annona muricata* L., *Annona senegalensis* Pers., *Annonaceae*, *Azadirachta indica*, *Blumea aurita* L., *Carica papaya* L., *Chamaecrista nigricansa*, *Clausena anisata* (Willd.), *Combretum micranthum*, *Crateva religiosa*, *Cymbopogon citratus*, *Dracaena arborea* (Willd.), *Ficus exasperata*, *Iboza multiflora* (Benth.), *Momordica charantia* L., *Moringa oleifera* Lam., *Nicotiana tabacum* L., *Pergularia daemia* (Forsskal), *Securidaca longepedunculata*, *Tagetes minuta* L., *Tephrosia vogelii* (leaves) *Capsicum frutescens* L. (fruits) *Heliotropium indicum* and *Ocimum basilicum* L. (twigs and flowers) *Hyptis spicigera* Lam. and *Hyptis suaveolens* (L.) (leaves and flowers) *Khaya senegalensis* (Desr.) (bark) *Opilia celtidifolia* (Guill. and Perr.) (flowers)	Dose 25 g/kg cowpea Insect mortality ranged between 10 and 100 %, with highest efficacy from *N. tabacum* and lowest *C. papaya* At 10 g *Capsicum frutescens* L./kg cowpea prevented oviposition	Boeke et al. (2004a)
C. maculatus *C. chinensis* *C. rhodesianus*	Leaves: *Citrus sinensis* L., *C. limon* L., *C. aurantifolia* L., *Cymbopogon citratus* (DC), *Cinnamomum camphor* L., *Monodora myristica* L., *Derris inudata* L., *Opuntia burrageana* Britt., *O. burrageana* Rose Rhizome: *Zingiber zerumbet* and *Z. spectabile* L.	Dose 200–300 g/kg legume seeds, reduced oviposition	Rajapakse and van Emden (1997)

commercially viable because of the following few reasons: (i) the scarcity of the natural resource; (ii) the need for chemical standardization and quality control; and (iii) difficulties in registration of these materials as insecticides (Isman 2000). Considering the insect-repellent properties of these essential oils, which are effective in low quantities, they may be used in formulating green fumigants, after getting clearance from the legislation bodies. The effectiveness of natural products is proven by experiments only; however, most of the natural products are not present in legislation yet. These biochemicals have to clear the mammalian toxicity tests before being adopted in the integrated pest management system (Mbata and Payton 2013). They may be useful for small holding and domestic application, albeit with precaution.

Physical Treatments

Issues like the development of resistance to chemical pesticides by stored grain insect pests, residual chemicals in stored food grains, and worker and environmental safety have contributed to imposition of stricter restrictions on the use of chemicals. The focus of research is now on the physical methods or alternate methods of insect control. These methods can be very simple methods which utilize renewable or local

Table 3 List of some plant essential oils as insecticide in stored pulses

Insect species	Botanical name of plant essential oil source	References
Acanthoscelides obtectus	*Apium graveolens*, *Azadirachta indica*, *Chenopodium ambrosioides*, *Cinnamomum verum*, *Citrus sinensis*, *Cupressus lusitanica*, *Eucalyptus globules*, *Juniperus oxycedrus*, *Lavandula hybrida*, *Mentha microphylla*, *Mentha viridis*, *Ocimum basilicum*, *Origanum vulgare*, *Pistacia terebinthus*, *Rosmarinus officinalis*, *Thuja orientalis*, *Thymus serpyllum*, *Thymus vulgaris*, *Urtica dioica* L., *Taraxacum officinale* L., *Achillea millefolium* L., *Allium sativum*, *Cymbopogan nardus*, *Laurus nobilis*, *Origanum serpyllum*, *Satureia hortensis*, *Tilia cordata sylvestris*	Papachristos and Santamopoulos (2002a, b, 2003, 2004), Paul et al. (2009), Tapondjou et al. (2002), Regnault-Roger and Hamraoui (1993, 1994, 1995), Regnault-Roger et al. (1993; 2004), Jovanović et al. (2007)
Bruchus dentipes	*Achillea gypsicola*, *Hypericum scabrum* L., *Origanum acutidens*, *Satureja hortensis* L.	Tozlu et al. (2011)
Callosobruchus chinensis	*Acorus gramineus*, *Acorus calamus* L., *Aegle marmelos* L., *Ammomum subulatum* Roxb., *Calotropis procera*, *Chamaecyparis obtuse*, *Chenopodium ambrosioides*, *Cinnamomum glaucescens*, *Citrus medica*, *Cocholeria aroracia*, *Cymbopogon martini*, *Eupatorium cannabinum* L., *Lantana camara*, *Murraya koenigii* L., *Syzygium cumini* L., *Withania somnifera*	Saxena et al. (1992a, b), Tapondjou et al. (2002), Kim et al. (2003), Park et al. (2003b), Salunke et al. (2005), Kumar et al. (2007), Gupta and Srivastava (2008), Shukla et al. (2009), Prakash et al. (2013)
Callosobruchus maculatus	*Acacia arabica*, *Artemisia sieberi* Besser, *Azadirachta indica*, *Balanites aegyptiaca*, *Blumea aurita*, *Boscia senegalensis*, *Capsicum annuum*, *Capsicum frutescens*, *Carthamus tinctorius*, *Cassia sophera*, *Chenopodium ambrosioides*, *Chromolaena odorata* (L.), *Citrus sinensis*, *Clausena anisata*, *Cymbopogon citratus* (DC) Stapf., *Cymbopogon giganteus*, *Cymbopogon nardus*, *Cymbopogon schoenanthus*, *Dracaena arborea*, *Eucalyptus globules*, *Eugenia uniflora* L., *Heliotropium bacciferum*, *Hyptis spicigera*, *Hyptis suaveolens*, *Ipomoea sepiaria*, *Kaya senegalensis*, *Lantana camara* L., *Lippia adoensis* Hoschst, *Lippia multiflora*, *Mentha arvensis*, *Mentha piperata*, *Mentha spicata*, *Momordica charantia*, *Moringa oliferia*, *Nicotiana tabacum*, *Ocimum americanum*, *Ocimum basilicum*, *Ocimum canum*, *Ocimum gratissimum*, *Piper guineense*, *Ricinus communis*, *Rhazya stricta*, *Securidaca longepedunculata*, *Sesamum indicum*, *Syzgium aromaticum*, *Tagetes minuta*, *Tephrosia vogelii*, *Thevitia nerifolia*, *Zingiber officinale*, *Vitex negundo*	Lale (1992), Gbolade and Adebayo (1993), Ajayi and Lale (2000), Elhag (2000), Lale and Mustapha (2000), Kéita et al. (2000, 2001), Raja et al. (2001), Tapondjou et al. (2002), Mbaiguinam et al. (2006), Negahban et al. (2006, 2007), Sanon et al. (2002), Pascual-Villalobos and Ballesta-Acosta (2003), Boeke et al. (2004a, b), Ketoh et al. (2005), Rahman and Talukder (2006), Kestenholz et al. (2007), Nyamador et al. (2010), Ilboudo et al. (2010)
Callosobruchus phaseoli	*Acorus calamus*	Rahman and Schmidt (1999)
Callosobruchus subinnotatus	*Cymbopogon giganteus*, *Cymbopogon nardus*	Nyamador et al. (2010)
Zabrotes subfasciatus	*Azadirachta indica*, *Chenopodium ambrosioides*, *Cupressus lusitanica*, *Ocimum canum*	Paul et al. (2009), Weaver et al. (1991, 1994)

materials such as sun drying, sand layer application, repeated sieving, etc. Some of these techniques are discussed in the following subsections.

Simple Technologies

Sieving Simple sieving and aspiration can also reduce the insect population (Nahdy 1994; Armitage et al. 1996). Repeated sieving of infested grains can reduce insect infestation. This method can be easily adopted by small-scale farmers and traders with small holdings. In Uganda, Nahdy (1994) observed that repeated sieving every 5 days over a period of 50 days can control *A. obtectus* in stored beans up to 150 days after last sieving. A similar practice is followed in rural households and small holdings in tropical countries as an insect control measure. Freshly harvested grains stored in bins (37 tons), when cleaned using sieves, effectively controlled the insect population; however, the efficacy depended on the sieve size and insect type (Armitage 1994). Armitage et al. (1996) utilized aspirated sieve to remove, the insects but the insect population again increased during storage, which indicated that some of the grains that were already infested with the eggs would require repeated sieving or other severe treatments. The experiment was conducted on 1 kg sample with 1 and 2 mm sieves. Sieving as such cannot take care of the grains already damaged. It certainly can prevent further growth of insects and damage caused by them. This practice is suitable for domestic application, with knowledge of low quality of the food.

Application of Sand Layer While storing the pulses in containers, farmers can apply a thick layer of about 3 cm of locally available sieved fine sand on the top of the pulses and tightly close the lid. The application of sand layer above the grain is a physical barrier that fills the intergranular spaces in the top layers thereby effectively disrupting the reproduction of bruchids and preventing further infestation of pulses (Karthikeyan et al. 2006). The pulses treated by this method can be effectively stored for 1 year without any infestation as long as the sand layer is not disturbed and pulses are not exposed. This practice can only be adopted at the domestic level.

Aeration and Cooling

The most important of the many purposes for using aeration is to cool the grain to control insect infestations (Hunter and Taylor 1980; Navarro and Noyes 2002; Navarro et al. 2012a). A rule of thumb is that if the grain can be cooled below 20 °C, insect development is significantly slowed, and cooling the grain to about 8 °C arrests insect development (Burrell 1967). This is true for the major storage pests originating from warm climates, whose optimum temperatures for development range between 25 and 35 °C (Fields 1992; Donahaye 2000). Sinha and Watters (1985) (as cited by Rulon et al. 1999) reported that the egg laying ability of insects drops down below a storage temperature of 15 °C and the eggs laid above 15 °C will not hatch below this temperature. For most stored product insects, 25–33 °C is optimal for growth and reproduction; at 13–25 or at 33–35 °C, insects are able to complete their development and produce offspring, but at temperatures <13 or >35 °C, insects eventually die (Fields 1992). Storing the grains below 10 °C also lowers the metabolic rate of these insects and their growth (Beckett 2011), and at −20 °C, the insects will die immediately. However, exposure of grains to −20 °C storage temperature would require higher energy consumption and therefore is not a practical solution. The pupae and adults of the bruchids are equally heat tolerant and the pupae is especially cold tolerant. A study conducted by Loganathan et al. (2011) revealed that the lethal time for the pupae of *C. maculatus* population to reduce by 50 % was 274 and 122 min and 7 and 2 h for chick peas stored at 0, −5, −10, and−15 °C, respectively. Therefore, grain chilling can be a suitable integrated pest management practice in order to ward off infestation. Since insect growth and metabolic rates are influenced by temperature, a low temperature will eventually influence the growth of insects and their hatching behavior. An economic analysis of grain chilling for wheat grain done by a group of scientist in the USA revealed that the annual operating costs of chilled aeration were almost half as compared to phosphine fumigation with aeration at ambient conditions (Rulon et al. 1999). Though grain chilling could be a practical solution in temperate climates, for tropical and subtropical climates, grain chillers may be burdensome; however, the use of environment-friendly renewable energy sources like solar energy-based grain chillers such as solar-regenerated grain cooling device, solar-regenerated open-cycle desiccant bed grain cooling system, solar adsorption chillers, and solid adsorption-desiccant cooling system, which have been applied to different grains, can be adopted for stored pulses (Ismail et al. 1991; Thorpe 1998; Dai et al. 2002; Luo et al. 2006, 2007) to minimize grain cooling cost. Since during cooling the insect growths are arrested, but they are not killed, this method of control should be used as a preventive rather than a curative method.

Heating

Direct heating or cooling of grains is used extensively to control stored product insects. Using extreme temperatures can be lethal for insects of all stages. The higher the temperature, the more quickly the insects will die, with death occurring within a few minutes at −20 or 55 °C. Lethal temperatures for insects vary considerably and depend on species, stage of development, acclimation, and relative humidity (Fields 1992). Saxena et al. (1992b) exposed pupae of different stages of *C. chinensis* to high temperature; it was revealed that the insects developed sterility when exposed to temperature of 45 °C for 72 h. Since pulse proteins are sensitive to temperature above 60 °C, heating the pulses up to 55 °C for a few minutes can rid the pulses of insects of all stages without compromising much on the quality. Moreover, heating of grain silos/bins prior to storage of grains can provide some control of insects, which are already present in the storage structures and houses. Tilley et al. (2007) recommended heating of silos/bins to at least 50 °C and holding for 2–4 h to be effective in controlling some of the storage insects. This method can be an alternative to storage bin/silo fumigation as prestorage treatment. Thermal disinfestation methods though effective need to be carefully monitored for the temperature and time combinations as these may exceed the prescribed limit and severely damage the pulse quality. Loganathan et al. (2011) found that at 42 °C, the lethal time to reduce survival of *C. maculatus* egg, larvae, pupae, and adults was 18, 57, 78, and 71 h, respectively. Miceli and Miceli (2012) recommended the exposure of chick peas and lentils to 60 °C for 60 min but recommended cool treatment for kidney beans at −18 °C for not more than 24 h, so as to maintain the viability and cooking quality of these food legumes. Heating during drying or otherwise though effective affects the seed availability and other quality losses, if a high temperature is used. Care should be taken not to expose the grains to a very high temperature, which may lead to loss of protein and other nutritive value of the food legumes.

Sunning Since all stages of insect life—egg, larva, pupae, and adults—are heat sensitive, manipulation of the temperature of the storage environment has been practiced since a long time, usually in the form of sunning, solar heating, or other heating methods. Freshly harvested pulse grains should be dried in the sun for 3–5 days. Sunning can kill the insects to a large extent, since insects, especially bruchids, are sensitive to heat, and temperatures above 45 °C are fatal for them. After sunning, the grains should be cleaned, cooled, and stored in suitable metal/plastic bins/large earthen pots/brick/cement storage structure with tight lids. Some of the species are more susceptible to temperature than others. Sunning is usually done by spreading the grains on mats or threshing yard. Gbaye et al. (2011) have demonstrated that the temperature of the grains can be raised up to 52 °C, when sunning of grains was carried out in thin layers on a concrete floored threshing yard or on a black tarpaulin or black polyethylene sheet under the hot sun. Adopting this method would effectively kill all the life stages of bruchids and remove the existing field infestation. Lale (1998) observed that oviposition of the bruchid was reduced, and the mortality rate of adult insects was increased after 3 h of sunlight exposure. Sun drying of pulses on different surfaces also affects retention of its functional properties and the extent of insect infestation. Chinwada and Gigam (1996) found the sunning method to be effective in controlling *Z. subfasciatus* (Boheman) and *A. obtectus* in beans and recommended daily 5 h exposure periods of seeds to sun heating for successive 5 day duration. A study carried out in Nigeria, Africa, revealed that sun drying of cowpea on a wooden surface was better compared to concrete and corrugated iron steel surface in terms of retention of better functional properties and reduction in fungal and insect load. Even a 5 h exposure to the sun, can greatly reduce the microbial and insect infestation (Ugwu et al. 1999). It is observed that during solar heating of pigeon pea on polyethylene sheets, the seed temperature may increase to 65 °C, which is lethal enough to eradicate storage insects like bruchids. Exposing the seeds to sun heating for 7 days caused the pulses to be 100 % insect free for over 14 weeks of storage with no damage to germination ability (Chauhan and Ghaffar 2002). This practice is economical and may be adopted at the farm level. Though sunning or sun drying as a cheap renewable energy source is widely practiced in many developed and developing countries (Esper and Mühlbauer 1998) and has been in practice for centuries, uncertain weather and temperature variation during day- and nighttime can play havoc if the grains are not properly conditioned having suitable storage moisture content. A heating system based on solar energy (Baoua et al. 2012a) can also be used as a disinfestation unit and drying unit.

Mechanical Heating System One of the physical methods of grain disinfestation is heating, which can be accomplished by direct sun exposure or solar heating, but these methods are weather dependent and are especially troublesome for the crops which are harvested during less sunshine hours or during rainy and winter season. Therefore, mechanical driers, run on fossil fuel or electric energy, are used worldwide for hot air disinfestations of grains. Such mechanical dryers can also double up as disinfestation unit and drying units (Thorpe 1997) and are cost effective, where product quality can be maintained, infestation can be reduced, and further growth can be arrested. Exposure in these units to temperatures above 50 °C for a few minutes can completely eliminate storage insects (Dermott and Evans 1978; Evans et al. 1983).

Dielectric Heating The use of microwave (MW)/radiofrequency (RF) energy has been applied to drying, a pretreatment to drying, sterilization, pasteurization, extraction of phytochemicals, product development, etc. (Orsat and Raghavan 2005; Giri and Prasad 2007; Marra et al. 2009). Dielectric heating has been successful in disinfesting various pests in fruits, vegetables, stored grains, and food commodities (Wang and Tang 2004; Sumnu and Sahin 2005; Marra et al. 2009; Yadav et al. 2012). Dielectric heating causes volumetric heating in the insects that eventually kills all stages of insects (Wang et al. 2008, 2010). Moreover, there is a change in the DNA structure of the insects, which affects their reproductive behavior (Lu et al. 2010, 2011), a feature which is advantageous in grain pest management. Studies have indicated that there was abnormality in the insects/pupae exposed to MW heating (Carpenter and Livstone 1971; Olsen 1982). Dielectric properties of grains and insects vary substantially due to their composition differences, and thus, there is differential heating when the pulses infested with insects are exposed to dielectric heating systems (Jiao et al. 2011). A RF heating system generally consists of two main components: (i) a generator and (ii) an applicator. The generator section is where the RF power is generated, and the applicator section is where the material is placed and heated. MW heating system generally consists of MW generator or magnetron, wave guide, and applicator (Mohapatra and Mishra 2011). RF has the advantage over MW in that it can penetrate to a greater depth (22 m at 13.56 MHz) as compared to MW (0.3 to 7 cm at 2,450 to 915 MHz), is simpler in construction, and has higher electric to electromagnetic power conversion, hence can be used for handling bulk samples (Shrestha and Baik 2013). The application for handling bulk samples is of importance to grain storage, as RF heating can be employed to disinfest bulk samples in conveyors and bags.

Extensive research on disinfestations of various grains, including pulses using RF and MW, has been taken up in many countries like the USA and Canada and these methods have been found to be effective pest control measures. This technology is environment-friendly, the disinfestations process takes about a few minutes, and there is no chemical hazard associated with it, since it is regarded as safe (Mohapatra and Mishra 2011). Moreover, the time taken for reaching the temperature of the grains due to volumetric heating is far less compared to hot air heating (Wang et al. 2010). However, there was a decrease in the germination rate of the seeds treated by these treatments although the product cooking qualities were not influenced significantly (Jiao et al. 2011).

Microwave and radiofrequency heating had been used in disinfesting various grains including pulses (Shayesteh and Barthakur 1996; Jiao et al. 2012). Though MW/RF heating is uneven (Vadivambal and Jayas 2008; Wang et al. 2010), this problem can be overcome by flushing the system for disinfesting bulk samples or packaged grains with hot air (Das et al. 2013). Moreover, dielectric heating is associated with the change in product quality (Vadivambal and Jayas 2007; Zhao et al. 2007b) even for a few generations (Dolińiska et al. 2004; Zhao et al. 2007a) and reduced seed viability (Singh et al. 2012); this may act as a deterrent to the adoption of MW or RF heating as disinfestation measures for seed grains. Some of the RF/MW disinfestation systems developed worldwide for various grains and nuts are presented in Table 4. Care should also be taken not to allow the temperature of the grain to rise above 55 °C, to avoid nutrition loss.

Ionizing Radiation

Ionizing radiation has been used in many countries as a pest control measure as well as a quarantine measure (Ignatowicz and Brzostek 1990). It is used for achieving 100 % mortality of insects in storage materials. Ionizing radiation in the form of electromagnetic radiance or high-energy particles creates ions by breaking chemical bonds, hence fragments the DNA structure of the pest to which it is exposed (Todoriki et al. 2006; Hasan et al. 2012). Gamma rays generated from the isotopes cobalt-60 and cesium-137 are generally used for food. The doses that various countries apply for pulse grains vary from 1 to 10 kGy (Hallman 2013) for quarantine treatment and insect mortality. At lower doses, the ionizing radiation sterilizes the pests, which then can be released into the infested areas to mate, thereby controlling the pest population (Cornwell 1959; Hasan and Khan 1998); at higher doses, total insect mortality was observed within 7 days of radiation exposure. Since the disinfestations can be done without any heating effect, the functional qualities of the pulses are maintained. Various research works have corroborated the fact that radiation doses do not affect the protein quality, other nutritional qualities, cooking quality, and germination rate of pulses significantly (Delincée et al. 1998; Villavicencio et al. 2000; Ocloo et al. 2012; Yun et al. 2013). The antinutritional factors in the pulses are found to be reduced (Siddhuraju et al. 2002), and in some cases, the bioavailability of iron in beans increased (Brigide and Canniatti-Brazaca 2006). The use of irradiated grains is limited but authorized in many developed countries; however, the commodity must be labeled. In India, the Bhaba Atomic Research Centre has set up some irradiation facilities, which are used to irradiate grains and spices. Irradiation of commodities like pulse grains has not garnered much emphasis in India, as the establishment of this facility requires lots of investment and there are mandatory safety guidelines to be followed.

Impact

Certain insects are vulnerable to the physical impact caused by moving pulses. Pneumatic conveyors and centrifugal separators subject the pulse kernels to large forces and operate at high pressure. As insects go through the pneumatic conveyer or centrifugal separator, they are killed. Like the high-temperature treatment, this method may be useful when the pulse grain is being moved for sale (Donahaye 2000).

Ozone Treatment

Ozone (O_3) application is currently being explored as an alternative pest control measure. Its use in stored grains is being investigated because of its inherent advantages, such as (i) it can be electrically generated on-site at the time of use, eliminating the need to store and dispose of insecticide packages; and (ii) it leaves no residue. Ozone has been used to control stored pests in legumes (Sousa et al. 2008). The US Food and Drug Administration (FDA) has approved its use as a direct additive for food treatment, storage, and processing (Sousa et al. 2008). Based on reviews, the following facts have been found: (1) O_3 significantly suppressed insect populations at ≤50 ppm with 4 days of treatment; (2) O_3 at >135 ppm with more than 8 days of treatment could be used for eradication of insect infestation; (3) O_3 at 50 ppm with 3 days of treatment could reduce 63 % of stored fungi; (4) O_3 at 5–30 ppm could reduce mycotoxin contamination; however, high concentration and long treatment times were required to eliminate mycotoxins; (5) application of O_3 at doses that were sufficient for the effective disinfestation of grain might affect the qualities of grain; and (6) O_3 at 47–106 ppm could noticeably damage equipment in 2 months by corrosion (Jian et al. 2013). However, the technology for the production and application of O_3 in grain storage installations has not been commercialized because of its prohibitive cost.

Storage Environment

Storage conditions largely affect insect growth rate as the insects depend on oxygen and moisture for their survival apart from food. People all around the world use different storage structures, which modify the microenvironment, and thereby prohibit insect growth. This knowledge has been passed from generation to generation. Various systematic scientific studies

Table 4 Dielectric heating disinfestation of different stored grains

Commodity	Heating source	Target insect	Results	References
Chick pea, green gram, pigeon pea	MW, 2.45 GHz	*Callosobruchus malculatus*	600 W/200 g, exposure time=90–110 s, 100 % mortality at 10–12 % moisture content (mc) (wb)	Singh et al. (2012)
Chickpeas, green peas, and lentils	RF, 27 MHz	*Callosobruchus maculatus*	60 °C for 10 min, 100 % mortality at 8 % mc (wb)	Johnson et al. (2010)
Green gram	MW, 2.45 GHz	Weevil	808 W, exposure time=80 s, 99.5 % mortality, 8.9 % mc (wb)	Pande et al. (2012)
Green gram	MW, 2.45 GHz	*Callosobruchus malculatus* Egg, young and old larvae, pupae, adult	400 W/50 g, 28 s exposure time, 100 % mortality for all stages, at 11.4 % mc (wb)	Purohit et al. (2013)
Green gram	MW, 2.45 GHz	*Callosobruchus malculatus* Adult	1.5–13 W/g, 50–120 s exposure time, 100 % mortality, 8 % mc (wb)	Mohapatra et al. (2014)
Lentil	RF, 27.12 MHz, +60 °C hot air	Cowpea weevil	6 kW/6.4 kg, 100 % mortality, 20 min exposure time, at 6.9 % mc (wb)	Jiao et al. (2012)
Paddy	MW, 20–200 GHz	*Rhyzopertha dominica*	1 kW, 60 s, 100 % mortality, at 27 mc (% db)	Ahmed et al. (2011)
Paddy/rough rice	RF, 27 MHz	*Rhyzopertha dominica* *Sitotroga cerealella*	60 °C for 1 h, 100 W/200 g, 100 % mortality, 60 °C (0.5 h) at 0.3 to 27.12 MHz, at 11 and 13.5 % mc (wb)	Lagunas-Solar et al. (2007)
Rice	MW	*Sitophilus oryzae* L. (eggs and adults)	100 % mortality at 0.017 kWh/kg energy consumption, final rice temperature=55 °C, 13–14 % mc (wb)	Zhao et al. (2007a)
Walnut	RF 27 MHz	*Cydia pomonella* [L.] *Amyelois transitella* [Walker] *Plodia* [Hübner]	12 kW/2.5 kg, 55 °C (7.3 min), 100 % mortality at 3–15 % mc (wb)	Mitcham et al. (2004)
Walnut	RF, 27 MHz	*Amyelois transitella*	25 kW/11 kg, 75 m/h belt speed, 52 °C, for 5 min, 100 % mortality, at 3–7.5 % mc (wb)	Wang et al. (2007)
Walnut (in-shell)	RF, 27 MHz+hot air 55 °C	*Amyelois transitella* Fifth instars	1 kW/kg, 100 % mortality RF heating to 55 °C and holding for 5 min in hot air, 2.6 % kernel, 7.8 % (shell) mc	Wang et al. (2002)
Walnut (in-shell)	RF, 27 MHz	*Cydia pomonella* (L.)	0.27 kW/kg, 3 min in RF, 53 °C, 100 % mortality	Wang et al. (2001)
Wheat	MW (2.45 GHz)	*Tribolium confusum*, *Lasioderma serricorne*, *Corcyra cephalonica*, or *Rhyzopertha dominica* (all stages)	850 W/20 g, 50 °C for 50 s, 100 % mortality	El-Naggar and Mikhaiel (2011)
Wheat	MW, 10.6 GHz	*Sitophilus zeamais* Motschulsky *Tribolium castaneum*	93 % mortality, 51 J/g 94 % mortality, specific energy input 53 J/g	Halverson et al. (1996)
Wheat	MW	*Rhylzopertha dominica* (F.) *Sitotroga cerealella* *Sitophilus oryzae* (L.)	82 % mortality, 88 % mortality, 90 % mortality, 10 s exposure time	Kirkpatrick et al. (1971)
Wheat	MW+gamma	*Rhyzopertha dominica*	99 % mortality with MW+gamma	Kirkpatrick et al. (1973)
Wheat	MW, 2.45 GHz	*Tribolium castaneum* *Cryptolestes ferrugineus* *Sitophilus granaries* (pupae, larvae, adults)	500 W/50 g, 28 s 100 % mortality of all stages for moisture range 14–18 % (wb)	Vadivambal et al. (2007)
Wheat	MW, 8·5 GHz and 30 W	*Tribolium confusum*	Mortality at 60 °C	Watters (1976)
Wheat, barley, and rye	MW, 2.45 GHz	*Tribolium castaneum* (Herbst), *Sitophilus granarius* (L.), and *Cryptolestes ferrugineus*	500 W/50 g, exposure time=28 s, 100 % mortality at 14–18 % mc (wb)	Vadivambal (2009)

conducted for storage of grains, including pulses, are re-establishing the age old practices of using the hermetic system for safe grain storage. By modifying the storage atmosphere (modified atmosphere (MA) storage) and controlling the gas composition (controlled atmosphere (CA) storage) by artificially flushing the storage containers/bins with CO_2 or N_2 prevent insect growth (Navarro 2012). Banks (1984) compiled various literatures citing the effects of low oxygen and higher carbon dioxide systems for the storage of grains. The atmospheres considered are (i) low oxygen systems

(<1 %) in nitrogen, (ii) nitrogen/CO_2 mixtures (O_2<1 %), (iii) high CO_2 (>70 %), (iv) intermediate CO_2 (40 %) mixtures, and (v) hermetic storages or MA storage (<6 % O_2, >14 % CO_2). To develop a high carbon dioxide in the storage pits, mostly local resources are used apart from other processes which are basically oxygen depletion systems or nitrogen flushing systems, including pressure swing absorption systems; burners fueled with propane, producer gas, biogas, or hydrogen; various forms of enhanced hermetic storage systems; fermentation processes; and electrolytic or photolytic oxygen removal systems. Some of such methods are delineated in the following paragraphs.

Inert Atmosphere In various parts of the world, storing grains in inert atmosphere has proven to be beneficial in reducing insect load and maintaining the quality as compared to air storage (Adesuyi et al. 1980). Inert atmospheric conditions can kill insects of all life stages. Ofuya and Reichmuth (1993) treated adults, eggs, larvae, and pupae of the cowpea bruchid, *C. maculatus* (F.) and the bean bruchid, *A. obtectus*, to 100 % nitrogen (N_2) atmosphere at 25 and 32 °C, respectively, and at 70±5 % relative humidity. Irrespective of the storage temperatures, 100 % mortality was achieved within 1–9 days of exposure for all the stages of pulse bruchids.

Controlled Atmospheric Storage CAs offer an effective, safe, and residue-free alternative to chemical fumigants and protectants for controlling insects and mites infesting stored grain and grain products. CA treatment for stored product protection involves two main methods of producing physiological and biochemical stress in the pest organisms: an increase in the carbon dioxide (CO_2) content of the storage environment producing hypercarbia, or a reduction in the oxygen (O_2) content, obtained usually by flushing with nitrogen (N_2), producing hypoxia or anoxia (Cheng et al. 2012, 2013). Some studies have demonstrated the capability of some stored product insects to develop tolerance to CA treatments. As with chemical protectants and fumigants, development of tolerance by insects to CA would be disadvantageous. Methods for enhancing CA action such as the use of the synergistic effect of high CO_2 and low O_2 in mixtures and manipulation of storage temperature and RH may be important in forestalling or preventing the phenomenon of pest tolerance (Navarro and Calderon 1980). Mbata et al. (2000) observed that exposing three stages (pupae, early pharate, and late pharate adults) of *C. subinnotatus* to different atmospheres ($CO_2/N_2/O_2$, (i) 0:98:2, (ii) 60:32:8, (iii) 0:99:1, and (iv) 99:0:1, at 10 °C and 76 % RH) affected the insects' metabolic growth rate in bambara nuts. The hypercarbic atmospheres required lesser period to cause mortality than the hypoxic atmospheres. Late pharate adults died earlier than pupae or early pharate adults. Those, late pharate adults that survived the exposure took a longer time to eclose than the pupae or early pharate adults. Ofuya and Reichmuth (2002) demonstrated that mortality of eggs and adults of the bruchid stored in air saturated with 70 % CO_2 and in 1.0 % O_2 in nitrogen (N_2) was higher at 10.3 and 34.2 % than at 70.2 and 90.3 % RH, respectively. Their study revealed that mortality of larvae and pupae of the bruchid was not affected by RH of the storage space. Development period was longer for adults emerging from bruchid eggs exposed for 12 h to these atmospheres at the lower RH. Freshly emerged adult bruchids from treated eggs also laid fewer eggs after 12 h of exposure to these atmospheres at lower RH. Though the CA storage is effective against infestation, it causes darkening of the seed coat and contributes to other physiochemical changes. A study conducted by Nasar-Abbas et al. (2008) revealed that faba bean seeds under CA storage in O_2 for 12 months were more susceptible to seed coat darkening, but purging with N_2 effectively reduced the darkening. It can be concluded that CA storage conditions affect the phenolic compounds and other chemicals, which in turn affects the color of the grains.

Hermetic Storage Since storage insects are aerobic organisms, they require oxygen for their survival. In case of altered atmospheric gas compositions containing low O_2 or high CO_2, their metabolic rate changes. At lower grain moisture content and the corresponding intergranular humidity, insects suffer higher mortality, due to the desiccation caused by low O_2 or elevated CO_2 concentrations (Murdock et al. 2012). This concept of grain preservation has been known to humankind for centuries as underground pits were used for safekeeping of grains (Hill et al. 1983). The *kaccha kothis* or underground pits which keep the grain cooler and have low O_2 atmosphere (Girish 1980) are still used to store grains in villages of tropical countries like India. To achieve insect control, the temperature of the grain should be above 21 °C. Hermetic storage is based on the principle of the development of an oxygen-depleted, carbon dioxide-enriched atmosphere caused by the respiration of the living organisms in the ecology of a sealed storage system (Navarro 2012). Heat of respiration generated by a wet commodity under storage may be high enough to destroy both the stored product and the resident organisms. By blocking the supply of oxygen interdicts the main supply of water for the pests, forcing the insect to shift to anaerobic metabolism. Eventually, this results in accumulation of acids and lactates in the insect body, leading to inactivity, cessation of population growth, desiccation, and eventual death (Maekawa and Elert 2003; Murdock et al. 2012). An O_2 ingress rate of 0.05 %/day is sufficient to arrest the theoretical weight loss at a level of 0.018 % over a 1 year storage period. At this ingress rate, the possibility of a residual surviving insect population is eliminated. This low O_2 ingress level could serve as a guideline for the sealing specifications of structures appropriate to the hermetic storage method (Navarro 2012). Seck et al. (1996) have observed a decline of O_2 level from 19.2 to 2.3 % and rise of CO_2 from 1.2 to 22.8 % during hermetic storage of cowpea which resulted in increased *C. maculatus* adult mortality and 60–80 % reduction in F1 progeny. Recently, there has been a growing interest in the use of hermetically sealed containers to control grain pests in Argentina; East, North, and Central Africa; India; and the USA (Dunkel 1995; Girish 1980). Hermetic storage can be (i) aboveground rigid structures, (ii) aboveground flexible structures, (iii) underground flexible structures, and (iv) aboveground rigid structures. Aboveground rigid structures like bins and silos, made up of concrete and metal, are used worldwide. Metal silos, also hermetically sealed but physically stronger, have been heavily promoted all over the world, despite being relatively expensive (Kimenju and De Groote 2010), especially compared to the super grain bags. Aboveground flexible structures like flexible plastic liners with or without support by wire frames have been developed in the UK and Canada for bulk grain storage. Low oxygen concentration causes insect mortality, so hermetic storage such as the Purdue Improved Cowpea Storage, super grain bags, cocoons, and other systems are being promoted as cheap and effective ways to control storage insect pests in the Asia and Africa. Bags, consisting of a double layer of high-density polyethylene (HDPE), within the standard polypropylene woven bags, were shown to effectively protect cowpeas against bruchid beetles. Super grain bags consist of a single high-density polyethylene bag used as a liner in the standard polypropylene bags and have been successfully disseminated in Asia (De Groote et al. 2013). Sanon et al. (2011) demonstrated that using three-layered high-density polyethylene bags for storage of cowpea prevented infestation of cowpea beetle. Baoua et al. (2012b) used Purdue Improved Cowpea Storage (PICS) bags that are composed of two inner liners of HDPE 80 μm thick enclosed by a woven polyethylene or nylon outer sack for controlling cowpea bruchids. PICS bags and GrainPro SuperGrain bags performed equally well in depleting the O_2 level up to 1–3 % and preventing insect growth (Baoua et al. 2013a). The effectiveness of PICS in controlling *C. maculatus* in green gram and pigeon pea during 6 months of storage period in Kenya was also reported by Mutungi et al. (2014). Surveys conducted at various countries in Africa reveal that PICS are very effective in controlling pulse bruchids (Ibro et al. 2014; Moussa et al. 2014; Murdock and Baoua 2014). The bags have been adopted by small-scale holders and in the domestic level. Since the PICS bag looks promising and is economical (Vales et al. 2014) as compared to gunny bags, similar bags providing hermetic storage conditions can also be adopted by various tropical countries, relying on the bag storage system. García-Lara et al. (2013) used multilayer SGB-IV-R coextruded hermetic bag, having ultralow oxygen permeability (<4 cc/m^2/day) for successfully controlling insects. These bags created hermetic conditions due to depletion of O_2 from 21 to 5 %, which resulted in 100 % mortality of *C. maculatus* in 4 weeks. Though this bag could be destroyed by *P. truncatus* and *R. dominica*, it still was effective for controlling *C. maculatus* and, hence, can be utilized for storing pulses without adversely affecting the germination rate (Baoua et al. 2013b).

Underground rigid structures made up of concrete and lined with polyethylene are used in many Asian and African countries. This structure very well takes care of the moisture migration into the stored grains, in the tropical countries. Underground pits lined with polyethylene serving as underground flexible structures are also practiced in the subtropics (Navarro et al. 1994), but in tropical climates, moisture migration is an issue in this type of structures, which has to be handled carefully. The effectiveness of CO_2 retention could be improved for the underground concrete double-walled structure with bitumen and PVC lining sandwiched between them, when the cracks in the walls are sealed and coated with araldite epoxy resins (Kamel et al. 1980). The bulk storage of grains on concrete platform with low wall, covered with PVC and lined with polyethylene on the bottom, has been found to be successful for long-term storage, in the Mediterranean conditions (Varnava et al. 1995). The seed viability in hermetic storage largely depends on moisture content which has been observed for green gram by Hong and Ellis (1992). They have claimed in their report that the loss of viability in green gram was more rapid at −20 °C than at warmer temperatures for a moisture content of 4.3 % (wb). If the grain moisture level is high, then there is a possibility of fermentation and development of off-flavor in the stored grains. Therefore, the grains should be suitably dried before subjected to hermetic storage.

Low Pressure Storage Insect-resistant properties of seeds can be integrated with physical control measures such as low storage pressure to reduce postharvest insect infestation. Creating low oxygen atmospheres through the exhaustion of air to achieve low pressure is effective in the control of postharvest insect pests including *C. maculatus* (Mbata et al. 2004, 2005a, 2009; Mbata and Phillips 2001). Different life stages of *C. maculatus* required exposure periods between 28 and 153 h at a pressure of 32.5 mmHg and temperatures of 20–35 °C to achieve 99 % mortality (Mbata et al. 2004, 2005a). The egg and the pupae were the most tolerant stages to low pressure while the larva was the most susceptible stage. Mbata et al. (2009) had observed that low pressure (32.5± 0.5 mmHg) creates a low oxygen-controlled atmosphere that can kill all developmental stages of *C. maculatus* (F.) on different varieties of cowpea even at 30 °C. Their study revealed that with the exception of eggs, exposure periods required to achieve 99 % mortality varied with life stage and variety of cowpea. The larval stage was the most susceptible and required relatively shorter exposure periods to low pressure when reared on *C. maculatus*-resistant varieties as compared to susceptible varieties. The time period to achieve 99 % mortality in a low pressure environment for eggs and pupae ranged between 116 and 133.9 h and between 71.6 and 98.6 h, respectively, for different varieties of cowpea. Mbata et al. (2009) recommended the integration of low pressure applications with storage of cowpea varieties resistant to *C. maculatus* as an alternative pest management tool to fumigants.

Biological Control

Live or dead insects are not at all acceptable in products. In many countries especially in developed and developing countries, the buying power of the consumer is increasing and consumers are demanding safe products. For years, the efficacy of disinfestations was directed to the control of pests only; however, growing public awareness of product quality and environmental issues has encouraged the scientists to develop alternative insect control measures. Chemical pesticides are being phased out and novel biological methods are being developed, which can be adopted in integrated pest management practice to prevent insect damage of the grains. Biological control could be through the use of biotechnological intervention or using parasitoids or predator for the destruction of insects and/or prevention of insect infestation (Schöller et al. 1997).

Parasitoids and Predators

Depending on their nutritional ecology, parasitoids and predators are either generalists or specialists. Generalists prey on a variety of species which are biosystematically not closely related to one other. Predators kill their prey immediately and are mostly generalists (Schöller et al. 1997). Wasps and fungi are biological vectors released into grain storage facilities to control pulse beetles. These parasitoids feed on or infect the damage-causing insects. Several works on the use of biological control for insects of different grains had been published, a very few of which mentioned the control of pulse bruchids through these biological agents (Lecato et al. 1977; Haines 1984; Islam et al. 1985; Verma 1990; van Huis 1991; Monge and Huignard 1991; Schmale et al. 2003, 2006; Campan and Benrey 2004; Sood and Pajni 2006; Rojas-Rousse et al. 2007; Velten et al. 2007a, 2008). *Dinarmus basalis*, a larva-pupae eating wasp, had been employed to control *A. obtectus* (Schmale et al. 2003; Velten et al. 2007a, 2008), *C. maculatus* (Sanon et al. 2002), *C. chinensis* (Islam and Kabir 1995), and *Z. subfasciatus* (Schmale et al. 2003). In a similar study, a specialist parasitoid *Stenocorse bruchivora* was used to control bruchids (Campan and Benrey 2004). *Pteromalus cerealellae* has been used to control *C. maculatus* (Mbata et al. 2005b). Fungi, i.e., *Vuillemin* and *Metarhizium anisopliae* (Metschnikoff), were introduced into stored pulse to control *C. maculatus* (Cherry et al. 2005). However, the control of these biological agents and their probable effect on the ecosystem has not been reported extensively. Hence, the use of biological control is still to be recommended as a pest control measure.

Semiochemicals

Pheromones are secreted or excreted from the insects to affect the social behavior of the insects (Qi and Burkholder 1981; Shu et al. 1996). These compounds are used as attractants in traps for detecting and monitoring pests in storage facilities (Angerilli et al. 1998). Direct control of storage pests with pheromones can be approached with the attracticide and mating disruption methods (Tanaka et al. 1981). Both techniques utilize synthetic female sex pheromones to prevent males from reproducing (Burkholder 1981; Cork et al. 1991; Phillips et al. 1996). Semiochemicals, used to manipulate female behavior, may provide new tools for many different pest management approaches (Nazzi et al. 2008). Pheromones, which are also responsible for male aggression behavior, can be used effectively in controlling the mating and population growth of insects (Phillips 1997). These pheromones may be available for use to manipulate the behavior of beneficial natural enemies of storage pests (Burkholder and Ma 1985). With proper knowledge of bruchid pheromones, pest control measures can gain a new insight and focus on developing a new trapping system for insects in stored pulses. Pheromones from a parasitoid *P. cerealellae* have inhibiting effect on cowpea weevil growth (Onagbola and Fadamiro 2011). Nazzi et al. (2008) in their study found that the female dry bean beetle preferred the odor of clean beans to that of beans where conspecifics had developed; an ether extract of such beans was repellent to the insect. A reduced receptivity to mating was observed in *C. chinensis* and *C. maculatus*, by the injection of octopamine and tyramine, respectively (Yamane and Miyatake 2010).

Biological control of grains is still limited to research only. It has to pass through various hurdles before being commercialized. It is still out of sufficient control of consequences; hence, sufficient research is needed prior to adopting this practice as an IPM measure.

Biotechnological Interventions

It is observed that plant proteins such as lectins, albumins, vicilins, and arcelin, which are naturally present in some of the pulse seeds, prevent the attack of various insects due to the chitin-binding properties (Macedo et al. 1993; Sales et al. 2000, 2001; Louis et al. 2004, 2007; Moura et al. 2007; Velten et al. 2007b; Uchôa et al. 2009). These lectins, which are multivalent, have the ability to agglutinate cells (Carlini and Grossi-de-Sá 2002; Janarthanan et al. 2012) and are also vector specific; for example, the lectin found in African yam bean seed can resist cowpea weevil, but it is not effective against legume pod borer (Machuka et al. 2000). This suggests that choosing a suitable plant breeding program by cultivating the insect-resistant varieties (Appleby and Credland 2004) or incorporating these insect-resistant peptides in the plant DNA (Popelka et al. 2004), or screening the insect-resistant varieties, can very well take care of the future infestation issues and provide food security.

Conclusions

Different disinfestation methods have been in practice for centuries and some of these are still relevant today. In the early 1990s, with the advent of chemical pesticides, the world agricultural scenario has undergone a great change. It may be concluded that the range of safe fumigant chemicals that can be used is now restricted to phosphine. The chemicals now must be judiciously applied in airtight containers to prevent insects developing resistance to it. Carbon dioxide fumigation is effective, but the exorbitant cost of production and application debars many farmers and dealers to use it as a fumigant; however, producing CO_2 from burning of biomass like cow dung can be adopted by small-scale farmers. Moreover, biogas generated from biomass containing methane can also be an alternative means of fumigation in tropical as well as temperate climates. The bottling and distribution of biogas at the farm level is still a challenge. Fumigation must be conducted in sealed chambers, i.e., bins and silos or in a bagged structure, properly insulated with plastic covers.

Vegetable oils both edible and nonedible, when coated on the pulses, prohibit insects from laying eggs and adult insects from emergence. Some of these oils do have insecticidal properties which have been used worldwide at the domestic or small-scale level. These oils do not interfere with the germination quality of the seeds and, hence, can be adopted in commercial scale storage of different pulses for both bagged and bin storage of temperate and tropical climate. There is growing interest in using the plant extract or plant leaf powders directly or as fumigant instead of using chemicals, as a measure for biosafety; however, with caution. Sunning is still an effective and cheap method of disinfestation, which has been in practice since centuries; however, this method is weather and season dependent. Many of the physical methods such as the use of irradiation and dielectric heating take only a few minutes to disinfest the grains. Despite their high infrastructural cost, some of them are practiced commercially; however, proper safety measures are to be taken. The disinfested grains must be immediately packed in a suitable packaging material to avoid future infestation. Modifying the storage atmosphere by creating low oxygen and high carbon dioxide and flushing the storage containers with nitrogen also impacts insect growth rate. Since in tropical climates grains are stored in bags, hermetic storage with low (2–5 %) O_2 and high CO_2 (18–20 %) environment will be an economical and feasible option, whereas in temperate climates, where grains are stored in bulk, aeration and cooling will be a more viable option. Some of the simple technologies such as sieving, storing in hermetically sealed bags, and storing grains with sand layer, inert dusts, vegetable oil, and plant extracts can be adopted domestically ensuring proper hygiene, to reduce the damage caused by insects. The efficacy of pest control measure no longer emphasizes only on the lethality of insects, it now focuses on the worker, consumer, and environmental safety. Some of these methods such as dielectric heating, ionizing radiation, and ozone treatment cause minimum environmental problems and deliver hygienic product. Therefore, despite the high initial cost, industries and consumers are beginning to prefer them over the chemically treated food items.

An integrated pest management practice is the key to food sustainability and safety. Choosing the suitable plant breeding program and screening the insect-resistant varieties will not only increase the yield but also safeguard the stored pulses from the attack of storage insects. It is said that a grain saved is a grain produced. Drying the harvested grains to safe storage moisture content, aeration, and cooling, followed by suitable packaging in sanitized insect proof container, can prevent grain loss to a large extent.

References

Adesuyi, S. A., Shejbal, J., Oyeniran, J. O., Kuku, F. O., Sowunmi, O., Akinnusi, O., & Onayemi, O. (1980). Application of artificial controlled atmospheres to grain storage in the tropics: case study of Nigeria. *Developments in Agricultural Engineering, 1*, 259–279.

Ahmad, M. (1976). Effect of phosphine fumigation on the germination of edible legume seeds. *Journal of Stored Product Research, 12*, 211–212.

Ahmed, K., Khalique, F., Afzal, M., Malik, B. A., & Malik, M. R. (1988). Efficacy of vegetable oils for protection of greengram from attack of bruchid beetle. *Pakistan Journal of Agricultural Research, 9*, 413–416.

Ahmed, M., Malek, F. R., Ahmad, B., Rahman, M., & Juni, K.-M. (2011). Disinfestation of Rhyzopertha dominica (F.) using microwave heat treatment to the Malaysian paddy. *World Academy of Science Engineering & Technology, 57*, 399–404.

Ajayi, F. A., & Lale, N. E. S. (2000). Susceptibility of unprotected seeds & seeds of local bambara groundnut cultivars protected with insecticidal essential oils to infestation by Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 37*, 47–62.

Akinkurolere, R. O. (2007). Assessment of the insecticidal properties of Anchimanes difformis (P. Beauv.) powder on five beetles of stored produce. *Journal of Entomology, 4*, 51–55.

Aldryhim, Y. N. (1993). Combination of classes of wheat and environmental factors affecting the efficacy of amorphous silica dust, dryacide, against Rhyzopertha dominica (F.). *Journal of Stored Product Research, 29*, 271–275.

Ali, S. I., Singh, O. P., & Misra, U. S. (1983). Effectiveness of plant oils against pulse beetle Callosobruchus chinensis Linn. *Indian Journal of Entomology, 45*, 6–9.

Angerilli, N. P. D., Permana, A. D., Sasaerila, Y., Hallett, R., Zilahi-Balogh, R., & Edmonds, R. (1998). Prospecting for insect pheromones in Indonesia: finds, failures & the future. *Journal of Asia-Pacific Entomology, 1*, 25–33.

Appleby, J. H., & Credland, P. F. (2004). Environmental conditions affect the response of West African Callosobruchus maculatus (Coleoptera: Bruchidae) populations to susceptible and resistant cowpeas. *Journal of Stored Product Research, 40*, 269–287.

Armitage, D. M. (1994). Some effects of grain cleaning on mites, insects and fungi. In *Proceedings of the 6th International Working Conference on Stored Product Protection* (pp. 17–23).

Armitage, D. M., Cook, D. A., & Duckett, C. (1996). The use of an aspirated sieve to remove insects, mites and pesticides from grain. *Crop Protection, 15*, 675–680.

Arthur, F. H. (1996). Grain protectants: current status and prospects for the future. *Journal of Stored Product Research, 32*, 293–302.

Athanassiou, C. G., Papagregoriou, A. S., & Buchelos, C. T. (2004). Insecticidal and residual effect of three pyrethroids against Sitophilus oryzae (L.) (Coleoptera: Curculionidae) on stored wheat. *Journal of Stored Products Research, 40*, 289–297.

Athié, I., Gomes, R. A. R., Bolonhezi, S., Valentini, S. R. T., & De Castro, M. F. P. M. (1998). Effects of carbon dioxide and phosphine mixtures on resistant populations of stored-grain insects. *Journal of Stored Products Research, 34*, 27–32.

Azad, B. S., & Srivastava, S. P. (2007). Assessment of protective role of Malathion residues in various stored pulses against bruchids at different relative humidity and storage periods. *Journal of Applied Zoological Research, 18*, 85–88.

Babu, T. R., Reddy, V. S., & Hussaini, S. H. (1989). Effect of edible and non-edible oils on the development of the pulse beetle (Callosobruchus chinensis L.) and on viability and yield of mungbean (Vigna radiata (L.) Wilczek). *Journal of Tropical Science, 29*, 215–220.

Baltaci, D., Klementz, D., Gerowitt, B., Drinkall, M. J., & Reichmuth, C. (2009). Lethal effects of sulfuryl fluoride on eggs of different ages and other life stages of the warehouse moth Ephestia elutella (Hübner). *Journal of Stored Product Research, 45*, 19–23.

Banks, H. J. (1984). Current methods and potential systems for production of controlled atmospheres for grain storage. *Developments in Agricultural Engineering, 5*, 523–542.

Banks, H. J., & McCabe, J. B. (1988). Uptake of carbon dioxide by concrete and implications of this process for grain storage. *Journal of Stored Product Research, 24*, 183–192.

Banks, H. J., & Pinkerton, A. (1987). Bromine-containing residues resulting from fumigation of grain with methyl bromide-carbon dioxide mixtures. *Journal of Stored Product Research, 23*, 105–113.

Baoua, I. B., Amadou, L., Margam, V., & Murdock, L. L. (2012a). Comparative evaluation of six storage methods for postharvest preservation of cowpea grain. *Journal of Stored Product Research, 49*, 171–175.

Baoua, I. B., Margam, V., Amadou, L., & Murdock, L. L. (2012b). Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger. *Journal of Stored Products Research, 51*, 81–85.

Baoua, I. B., Amadou, L., & Murdock, L. L. (2013a). Triple bagging for cowpea storage in rural Niger: questions farmers ask. *Journal of Stored Products Research, 52*, 86–92.

Baoua, I. B., Amadou, L., Lowenberg-DeBoer, J. D., & Murdock, L. L. (2013b). Side by side comparison of GrainPro and PICS bags for postharvest preservation of cowpea grain in Niger. *Journal of Stored Products Research, 54*, 13–16.

Bartholomaeus, A. R., & Haritos, V. S. (2005). Review of the toxicology of carbonyl sulfide, a new grain fumigant. *Food and Chemical Toxicology, 43*, 1687–1701.

Batish, D. R., Singh, H. P., Kohli, R. K., & Kaur, S. (2008). Eucalyptus essential oil as a natural pesticide. *Forest Ecological Management, 256*, 2166–2174.

Beckett, S. J. (2011). Insect and mite control by manipulating temperature and moisture before and during chemical-free storage. *Journal of Stored Product Research, 47*, 284–292.

Bell, C. H. (2000). Fumigation in the 21st century. *Crop Protection, 19*, 563–569.

Benhalim, H., Chaudhry, M. Q., Mills, K. A., & Price, N. R. (2004). Phosphine resistance in stored-product insects collected from various grain storage facilities in Morocco. *Journal of Stored Product Research, 40*, 241–249.

Boeke, S. J., Baumgart, I. R., van Loon, J. A., van Huis, A., Dicke, M., & Kossou, D. K. (2004a). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against Callosobruchus maculatus. *Journal of Stored Product Research, 40*, 423–438.

Boeke, S. J., Boersma, M. G., Alink, G. M., van Loon, J. A., van Huis, A., Dicke, M., & Rietjens, I. M. C. M. (2004b). Safety evaluation of neem (Azadirachta indica) derived pesticides. *Journal of Ethnopharmacology, 94*, 25–41.

Bond, E. J., Monro, H. A. U., Dumas, T., Benazet, J., & Turtle, E. E. (1972). Control of insects in empty cargo ships with dichlorvos. *Journal of Stored Product Research, 8*, 11–18.

Booth, E. D., Jones, E., & Elliott, B. M. (2007). Review of the in vitro and in vivo genotoxicity of dichlorvos. *Regulatory Toxicology & Pharmacology, 49*, 316–326.

Brice, J. R., & Golob, P. (2000). Fumigation with phosphine and carbon dioxide in metal grain tanks for on-farm use in Swaziland. *Journal of Agricultural Engineering Research, 76*, 17–26.

Brigide, P., & Canniatti-Brazaca, S. G. (2006). Antinutrients and "in vitro" availability of iron in irradiated common beans (Phaseolus vulgaris). *Food Chemistry, 98*, 85–89.

Burkholder, W. E. (1981). Sex pheromone biology and behavior of the cowpea weevil Callosobruchus maculatus (Coleoptera: Bruchidae). *Journal of Chemical Ecology, 8*, 527–534.

Burkholder, W. E., & Ma, M. (1985). Pheromones for monitoring and control of stored-product insects. *Annual Review of Entomology, 30*, 257–272.

Burrell, N. J. (1967). Grain cooling studies—II: effect of aeration on infested grain bulks. *Journal of Stored Product Research, 3*, 145–154.

Calderon, M., & Carmi, Y. (1973). Fumigation trials with a mixture of methyl bromide and carbon dioxide in vertical bins. *Journal of Stored Product Research, 8*, 315–321.

Campan, E., & Benrey, B. (2004). Behavior and performance of a specialist and a generalist parasitoid of bruchids on wild and cultivated beans. *Biological Control, 30*, 220–228.

Carlini, C. R., & Grossi-de-Sá, M. F. (2002). Plant toxic proteins with insecticidal properties. A review on their potentialities as bioinsecticides. *Toxicology, 40*, 1515–1539.

Carpenter, R. L., & Livstone, E. M. (1971). Evidence for nonthermal effects of microwave radiation: abnormal development of irradiated insect pupae. Microwave theory and techniques. *IEEE Transactions, 16*, 173–178.

Casida, J. (Ed.). (1973). *Pyrethrum: the natural insecticide*. New York: Academic.

Chauhan, Y. S., & Ghaffar, M. A. (2002). Solar heating of seeds—a low cost method to control bruchid (Callosobruchus spp.) attack during storage of pigeonpea. *Journal of Stored Product Research, 38*, 87–91.

Chayaprasert, W., Maier, D. E., Ileleji, K. E., & Murthy, J. Y. (2009). Effects of weather conditions on sulfuryl fluoride and methyl bromide leakage during structural fumigation in a flour mill. *Journal of Stored Product Research, 45*, 1–9.

Cheng, W., Lei, J., Ahn, J.-E., Liu, T.-X., & Zhu-Salzma, K. (2012). Effects of decreased O_2 and elevated CO_2 on survival, development, and gene expression in cowpea bruchids. *Journal of Insect Physiology, 58*, 792–800.

Cheng, W., Lei, J., Ahn, J.-E., Wang, Y., Lei, C., & Zhu-Salzman, K. (2013). CO_2 enhances effects of hypoxia on mortality, development, and gene expression in cowpea bruchid, Callosobruchus maculatus. *Journal of Insect Physiology, 59*, 1160–1168.

Cherry, A. J., Abalo, P., & Hell, K. (2005). A laboratory assessment of the potential of different strains of the entomopathogenic fungi Beauveria bassiana (Balsamo) Vuillemin and Metarhizium anisopliae (Metschnikoff) to control Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) in stored cowpea. *Journal of Stored Product Research, 41*, 295–309.

Chinwada, P., & Gigam, D. P. (1996). Sunning as a technique for disinfesting stored beans. *Postharvest Biology & Technology, 9*, 335–342.

Choudhary, B. S. (1990). Residual effect of eight vegetable oils in chickpea against pulse beetle, Callosobruchus chinensis (Linnaeus). *Indian Journal of Plant Protection, 18*, 89–92.

Coelho, M. B., Macedom, M. L. R., Marangoni, S., da Silva, D. S., Cesarino, I., & Mazzafera, P. (2010). Purification of legumin-like proteins from Coffea arabica and Coffea racemosa seeds and their insecticidal properties toward cowpea weevil (Callosobruchus maculatus) (Coleoptera: Bruchidae). *Journal of Agricultural Food Chemistry, 58*, 3050–3055.

Cork, A., Hall, D. R., Blaney, W. M., & Simmonds, M. S. J. (1991). Identification of a component of the female sex pheromone of Callosobruchus analis (Coleoptera: Bruchidae). *Tetrahedron Letters, 32*, 129–132.

Cornwell, P. B. (1959). The disinfestation of foods, particularly grain. *The International Journal of Applied Radiation Isotopes, 6*, 188–193.

Credland, P. F. (1992). The structure of bruchid eggs may explain the ovicidal effect of oils. *Journal of Stored Product Research, 28*, 1–9.

Dai, Y. J., Wang, R. Z., & Xu, Y. X. (2002). Study of a solar powered solid adsorption–desiccant cooling system used for grain storage. *Renewable Energy, 25*, 417–430.

Das, I., Kumar, G., & Shah, N. G. (2013). Microwave heating as an alternative quarantine method for disinfestation of stored food grains. *International Journal of Food Science*. doi:10.1155/2013/926468.

De Groote, H., Kimenju, S. C., Likhayo, P., Kanampiu, F., Tefera, T., & Hellin, J. (2013). Effectiveness of hermetic systems in controlling maize storage pests in Kenya. *Journal of Stored Product Research, 53*, 27–36.

Delincée, H., Villavicencio, A.-L. C. H., & Mancini-Filho, J. (1998). Protein quality of irradiated Brazilian beans. *Radiation Physics & Chemistry, 52*, 43–47.

Dermott, T., & Evans, D. E. (1978). An evaluation of fluidized-bed heating as a means of disinfesting wheat. *Journal of Stored Product Research, 14*, 1–12.

Desmarchelier, J. M., Banks, H. J., Williams, P., & Minett, W. (1977). Toxicity of dichlorvos vapour to insects in aerated and non-aerated wheat and comparison of the vapour action of dichlorvos and malathion. *Journal of Stored Product Research, 13*, 1–12.

Dolińiska, R., Warchalewski, J. R., Gralik, J., & Jankowski, T. (2004). Effect of gamma-radiation and microwave heating of wheat grain on some starch properties in irradiated grain as well as in grain of the next generation crops. *Nahrung, 48*, 195–200.

Donahaye, E. J. (2000). Current status of non-residual control methods against stored product pests. *Crop Protection, 19*, 571–576.

Dubey, N. K., Srivastava, B., & Kumar, A. (2008). Current status of plant products as botanical pesticides in storage pest management. *Journal of Biopesticides, 1*, 182–186.

Dunkel, F. V. (1995). Applying current technologies to large-scale, underground grain storage. *Tunnell Underground Space Technology, 10*, 477–496.

Elhag, E. A. (2000). Deterrent effects of some botanical products on oviposition of the cowpea bruchid Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *International Journal of Pest Management, 4*, 109–113.

Elms, K. D., Kerr, J. D., & Champ, B. R. (1972). Breakdown of malathion and dichlorvos mixtures applied to wheat. *Journal of Stored Product Research, 8*, 55–63.

El-Naggar, S. M., & Mikhaiel, A. A. (2011). Disinfestation of stored wheat grain and flour using gamma rays and microwave heating. *Journal of Stored Product Research, 47*, 191–196.

Esper, A., & Mühlbauer, W. (1998). Solar drying—an effective means of food preservation. *Renewable Energy, 15*, 95–100.

Evans, D. E., Thorpe, G. R., & Dermott, T. (1983). The disinfestation of wheat in a continuous-flow fluidized bed. *Journal of Stored Product Research, 19*, 125–137.

FAO (2012). www.faostat.org. Accessed on 28th June 2012.

Fields, P. G. (1992). The control of stored-product insects and mites with extreme temperatures. *Journal of Stored Product Research, 28*, 89–118.

García-Lara, S., Ortíz-Islas, S., & Villers, P. (2013). Portable hermetic storage bag resistant to Prostephanus truncatus, Rhyzopertha dominica and Callosobruchus maculatus. *Journal of Stored Product Research, 54*, 23–25.

Gbaye, O. A., Millard, J. C., & Holloway, G. J. (2011). Legume type and temperature effects on the toxicity of insecticide to the genus Callosobruchus (Coleoptera: Bruchidae). *Journal of Stored Product Research, 47*, 8–12.

Gbolade, A. A., & Adebayo, T. A. (1993). Fumigant effects of some volatile oils on fecundity and adult emergence of Callosobruchus maculatus F. *International Journal of Tropical Insect Science, 14*, 631–636.

Ghosh, P. K., Jayas, D. S., Srivastava, C., & Jha, A. N. (2007). Drying and storing lentils: engineering and entomological aspects. In S. S. Yadav, D. L. McNeil, & P. C. Stevenson (Eds.), *Lentil: an ancient crop for modern times* (pp. 385–414). Dordrecht: Springer.

Giga, D. P., & Munetsi, M. M. (1990). The effectiveness of vegetable and citrus oils as protectants of cowpeas against infestations by Callosobruchus rhodesianus (Pic.). *Plant Protection, 5*, 148–151.

Giles, P. H. (1977). Bean storage problems in Nicaragua. *Tropical Stored Products Information, 34*, 63–67.

Giri, S. K., & Prasad, S. (2007). Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *Journal of Food Engineering, 78*, 512–521.

Girish, G. K. (1980). Studies on the preservation of food grains under natural airtight storage. *Developments in Agricultural Engineering, 1*, 15–23.

Golob, P. (1997). Current status & future prospects for inert dusts for control of stored product insects. *Journal of Stored Product Research, 33*, 69–79.

Govindan, K., & Nelson, S. J. (2007). Effect of Piper nigrum seed powder and dust formulation on Callosobruchus maculatus (f.). *Annals of Plant Protection Sciences, 15*, 39–42.

Govindan, K., & Nelson, S. J. (2008). Effect of mixtures of plant powder against pulse beetle *Callosobruchus maculatus*. *Journal of Plant Protection Environment, 5*, 52–55.

Green, A. A., & Wilkin, D. R. (1969). The control of insects in bagged grain by the injection of dichlorvos. *Journal of Stored Product Research, 5*, 11–19.

Guedes, R. N. C., Lima, J. G., Santos, J. P., & Cruz, C. D. (1995). Resistance to DDT and pyrethroids in Brazilian populations of Sitophilus zeamais Motsch. (Coleoptera: Curculionidae). *Journal of Stored Products Research, 31*, 145–150.

Gupta, M., & Kashyap, R. K. (1995). Phosphine fumigation against pulse beetle: germination and vigour of green gram seed. *Seed science & Technology, 23*, 429–438.

Gupta, L., & Srivastava, M. (2008). Effect of Withania somnifera extracts on the mortality of Callosobruchus chinensis L. *Journal of Biopesticides, 1*, 190–192.

Haines, C. P. (1984). Biological methods for integrated control of insects and mites in tropical stored products. III: The use of predators and parasites. *Tropical Stored Product Information, 48*, 17–25.

Haines, C. P. (1989). Observations on Callosobruchus analis (F.) in Indonesia, including a key to storage Callosobruchus spp (Col., Bruchidae). *Journal of Stored Product Research, 25*, 9–16.

Hall, J. S., & Harman, G. E. (1991). Efficacy of oil treatments of legume seeds for control of Aspergillus and Zabrotes. *Crop Protection, 10*, 315–319.

Hallman, G. J. (2013). Control of stored product pests by ionizing radiation. *Journal of Stored Product Research, 52*, 36–41.

Halverson, S. L., Burkholder, W. E., Bigelow, T. S., Nordheim, E. V., & Misenheimer, M. E. (1996). High-power microwave radiation as an alternative insect control method for stored products. *Journal of Economic Entomology, 89*, 1638–1648.

Hasan, M., & Khan, A. R. (1998). Control of stored-product pests by irradiation. *Integrated Pest Management Review, 3*, 15–29.

Hasan, M. M., Todoriki, S., Miyanoshita, A., & Imamura, T. (2012). Age- and time interval-specific gamma radiation-induced DNA damage in adult maize weevils, Sitophilus zeamais Motschulsky, assessed using comet assays. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis, 741*, 95–100.

Hill, J. M., & Schoonhoven, A. V. (1981). The use of vegetable oils in controlling insect infestations in stored grains and pulses. *Recent Advances Food Science & Technology, 1*, 473–481.

Hill, R. A., Lacey, J., & Reynolds, P. J. (1983). Storage of barley grain in Iron Age type underground pits. *Journal of Stored Product Research, 19*, 163–171.

Hong, T. D., & Ellis, R. H. (1992). The survival of germinating orthodox seeds after desiccation and hermetic storage. *Journal of Experimental Biology, 43*, 239–247.

Hunje, R. V., Kulkarni, G. N., Shashidhara, S. D., & Vyakaranahal, B. S. (1990). Effect of insecticide and fungicide treatment on cowpea seed quality. *Seed Research, 18*, 90–92.

Hunter, A. J., & Taylor, P. A. (1980). Refrigerated aeration for the preservation of bulk grain. *Journal of Stored Product Research, 16*, 123–131.

Ibro, G., Sorgho, M. C., Idris, A. A., Moussa, B., Baributsa, D., & Lowenberg-DeBoer, J. (2014). Adoption of cowpea hermetic storage by women in Nigeria, Niger and Burkina Faso. *Journal of Stored Products Research*. doi:10.1016/j.jspr.2014.02.007.

Ignatowicz, S., & Brzostek, G. (1990). Use of irradiation as quarantine treatment for agricultural products infested by mites and insects. *International Journal of Radiation Applications Instrumentation. Part C. Radiation Physics & Chemistry, 35*, 263–267.

Ilboudo, Z., Dabiré, L. C. B., Nébié, R. C. H., Dicko, I. O., Dugravot, S., Cortesero, A. M., & Sanon, A. (2010). Biological activity and persistence of four essential oils towards the main pest of stored cowpeas, Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 46*, 124–128.

Ishmael, J., MacGregor, J. A., & Manley, A. (2006). Dichlorvos—a comprehensive review of 11 rodent carcinogenicity studies. *Regulatory Toxicology & Pharmacology, 44*, 238–248.

Islam, W., & Kabir, S. M. H. (1995). Biological control potential of Dinarmus basalis (Rond.) (Hymenoptera: Pteromalidae), a larval-pupal ectoparasitoid of the pulse beetle, Callosobruchus chinensis (L.). *Crop Protection, 14*, 439–443.

Islam, W., Ahmed, K. N., & Malek, M. A. (1985). Hymenopterous parasites on insect pest of two stored pulses. *Bangladesh Journal of Zoology, 13*, 81–85.

Ismail, M. Z., Angus, D. E., & Thorpe, G. R. (1991). The performance of a solar-regenerated open-cycle desiccant bed grain cooling system. *Solar Energy, 46*, 63–70.

Isman, M. B. (2000). Plant essential oils for pest and disease management. *Crop Protection, 19*, 603–608.

Ivbijaro, M. F. (1984). Toxic effects of groundnut oil on the rice weevil Sitophilus oryzae (L.). *Insect Science & Its Application, 5*, 251–252.

Janarthanan, S., Sakthivelkumar, S., Veeramani, V., Dixit, R., & Muthukrishanan, S. (2012). A new variant of antimetabolic protein, arcelin from an Indian bean, Lablab purpureus (Linn.) and its effect on the stored product pest, Callosobruchus maculatus. *Food Chemistry, 135*, 2839–2844.

Jha, A. N., Srivastava, C., & Kumar, J. (2009). Relative susceptibility of chickpea cultivars to Callosobruchus chinensis (Linn.) and C. annalis (Fab.). *Journal of Food Legume, 22*, 149–151.

Jian, F., Jayas, D. S., & White, N. D. G. (2013). Can ozone be a new control strategy for pests of stored grain? *Agricultural Research, 2*, 1–8.

Jiao, S., Johnson, J. A., Tang, J., Tiwari, G., & Wang, S. (2011). Dielectric properties of cowpea weevil, black-eyed peas and mung beans with respect to the development of radio frequency heat treatments. *Biosystems Engineering, 108*, 280–291.

Jiao, S., Johnson, J. A., Tang, J., & Wang, S. (2012). Industrial-scale radio frequency treatments for insect control in lentils. *Journal of Stored Product Research, 48*, 143–148.

Johnson, J. A., Wang, S., & Tang, J. (2010). Radio frequency treatments for insect disinfestation of dried legumes. 10th International Working Conference on Stored Product Protection (pp. 688–694). doi:10.5073/jka.2010.425.106.

Jovanović, Z., Kostić, M., & Popović, Z. (2007). Grain-protective properties of herbal extracts against the bean weevil Acanthoscelides obtectus Say. *Indian Crops Production, 26*, 100–104.

Kachare, B. V., Khaire, V. M., & Mote, U. N. (1994). Efficacy of different vegetable oils as seed treatment in increasing storage ability of pigeonpea seed against pulse beetle, Callosobruchus chinensis Linn. *Indian Journal of Entomology, 56*, 58–62.

Kamel, A. H., Fam, E. Z., & Jay, E. G. (1980). Problems and their solutions found in the construction of concrete bins for hermetic storage. *Developments in Agricultural Engineering, 1*, 409–425.

Kamil, M. E.-D. M., Abou-Zahw, M. M., & Hegazy, N. A. (1996). Efficiency of some technological processes on reducing the residues of malathion and pirimiphos methyl in mature broad bean seeds. *Food/Nahrung, 40*, 277–281.

Karthikeyan, C., Veeraragavathatham, D., Karpagam, D., & Firdouse, S. A. (2006). Indigenous storage practices in pulses. *Indian Journal of Traditional Knowledge, 5*, 104–107.

Kawuki, R. S., Agona, A., Nampala, P., & Adipala, E. (2005). A comparison of effectiveness of plant-based and synthetic insecticides in the field management of pod and storage pests of cowpea. *Crop Protection, 24*, 473–478.

Kéita, S. M., Vincent, C., Schmit, J.-P., Ramaswamy, S., & Bélanger, A. (2000). Effect of various essential oils on Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 36*, 355–364.

Kéita, S. M., Vincent, C., Schmit, J.-P., Arnason, J. T., & Bélanger, A. (2001). Efficacy of essential oil of Ocimum basilicum L. and O. gratissimum L. applied as an insecticidal fumigant and powder to control Callosobruchus maculatus (Fab.) [Coleoptera: Bruchidae]. *Journal of Stored Product Research, 37*, 339–349.

Kestenholz, C., Stevenson, P. C., & Belmain, S. R. (2007). Comparative study of field and laboratory evaluations of the ethnobotanical Cassia sophera L. (Leguminosae) for bioactivity against the storage pests Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) and Sitophilus oryzae (L.) (Coleoptera: Curculionidae). *Journal of Stored Product Research, 43*, 79–86.

Ketoh, G. K., Koumaglo, H. K., & Glitho, I. A. (2005). Inhibition of Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) development with essential oil extracted from Cymbopogon schoenanthus L. Spreng. (Poaceae), and the wasp Dinarmus basalis (Rondani) (Hymenoptera: Pteromalidae). *Journal of Stored Product Research, 41*, 363–371.

Khaire, V. M., Kachare, B. V., & Mote, U. N. (1992). Efficacy of different vegetable oils as grains protectants against pulse beetle Callosobruchus chinensis L. in increasing the storability of pigeonpea. *Journal of Stored Product Research, 28*, 153–156.

Khalequzzaman, M., Mahdi, S. H. A., & Goni, O. S. H. M. (2007). Efficacy of edible oils in the control of pulse beetle, Callosobruchus chinensis L. in stored pigeonpea. *University Journal of Zoology Rajshahi University, 26*, 89–92.

Kim, S.-I., Roh, J.-Y., 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 Product Research, 39*, 293–303.

Kimenju, S. C., & De Groote, H. (2010). Economic analysis of alternative maize storage technologies in Kenya. Paper presented at the Third Conference of the African Association of Agricultural Economists (AAAE), September 19–23, 2010, Cape Town, South Africa (http://econpapers.repec.org/scripts/search/search.asp?ft¼simonþkimenju).

Kirkpatrick, R. L., Roberts, J., & John, R. (1971). Insect control in wheat by use of microwave energy. *Journal of Economic Entomology, 64*, 950–951.

Kirkpatrick, R. L., Brower, J. H., & Tilton, E. W. (1973). Gamma, infra-red and microwave radiation combinations for control of Rhyzopertha dominica in wheat. *Journal of Stored Product Research, 9*, 19–23.

Koona, P., Tatchago, V., & Malaa, D. (2007). Impregnated bags for safer storage of legume grains in West and Central Africa. *Journal of Stored Product Research, 43*, 248–251.

Korunic, Z. (1998). Review: diatomaceous earths, a group of natural insecticides. *Journal of Stored Product Research, 34*, 87–97.

Kumar, R., Srivastava, M., & Dubey, N. K. (2007). Evaluation of Cymbopogon martinii oil extract for control of postharvest insect deterioration in cereals and legumes. *Journal of Food Protection, 70*, 172–178.

Kumar, A., Shukla, R., Singh, P., Singh, A. K., & Dubey, N. K. (2009). Use of essential oil from Mentha arvensis L. to control storage moulds and insects in stored chickpea. *Journal of Science, Food & Agriculture, 89*, 2643–2649.

Kumar, P., Mishra, S., Malik, A., & Satya, S. (2011). Insecticidal properties of Mentha species: a review. *Indian Crops Production, 34*, 802–817.

Lagunas-Solar, M. C., Pan, Z., Zeng, N. X., Truong, T. D., Khir, R., & Amaratunga, K. S. P. (2007). Application of radiofrequency power for non-chemical disinfestation of rough rice with full retention of quality attributes. *Applied Engineering in Agriculture, 23*, 647–654.

Lalah, J. O., & Wandiga, S. O. (2002). The effect of boiling on the removal of persistent malathion residues from stored grains. *Journal of Stored Product Research, 38*, 1–10.

Lale, N. E. S. (1992). Oviposition-deterrent and repellent effects of products from dry chilli pepper fruits, Capsicum species on Callosobruchus maculatus. *Postharvest Biology & Technology, 1*, 343–348.

Lale, N. E. S. (1998). Preliminary studies on the effect of solar heat on oviposition, development and adult mortality of the cowpea bruchid Callosobruchus maculatus (F.) in the Nigerian savanna. *Journal of Arid Environments, 40*, 157–162.

Lale, N. E. S., & Mustapha, A. (2000). Potential of combining neem (Azadirachta indica A. Juss) seed oil with varietal resistance for the management of the cowpea bruchid, Callosobruchus maculatus (F.). *Journal of Stored Product Research, 36*, 215–222.

Lecato, G. L., Collins, J. M., & Arhogast, R. T. (1977). Reductions of residual populations of stored-product insects by Xylocoris flavipes (Hemiptera: Anthocordiae). *Journal of Kansas Entomological Society, 50*, 84–88.

Lehman, A. D., Dunkel, F. V., Klein, R. A., Ouattara, S., Diallo, D., Gamby, K. T., & N'Diaye, M. (2007). Insect management products from Malian traditional medicine—establishing systematic criteria for their identification. *Journal of Ethnopharmacology, 110*, 235–249.

Lindgren, D. L., Sinclair, W. B., & Vincent, L. E. (1968). Residues in raw processed foods resulting from post-harvest insecticidal treatments. In F. A. Gunther (Ed.), *Residue reviews 21* (pp. 1–121). Berlin: Springer.

Loganathan, M., Jayas, D. S., Fields, P. G., & White, N. D. G. (2011). Low and high temperatures for the control of cowpea beetle, Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) in chick-peas. *Journal of Stored Product Research, 47*, 244–248.

Louis, S., Delobel, B., Gressent, F., Rahioui, I., Quillien, L., Vallier, A., & Rahbé, Y. (2004). Molecular and biological screening for insect-toxic seed albumins from four legume species. *Plant Science, 167*, 705–714.

Louis, S., Delobel, B., Gressent, F., Duport, G., Diol, O., Rahioui, I., Charles, H., & Rahbé, Y. (2007). Broad screening of the legume family for variability in seed insecticidal activities and for the occurrence of the A1b-like knottin peptide entomotoxins. *PhytoChemistry, 68*, 521–535.

Lu, H. H., Zhou, J. C., Xiong, S. B., & Zhao, S. M. (2010). Effects of low-intensity microwave radiation on Tribolium castaneum physiological and biochemical characteristics and survival. *Journal of Insect Physiology, 56*, 1356–1361.

Lu, H. H., Zhou, J. C., Yan, D., Zhao, S. M., & Xiong, S. B. (2011). Effects of microwave radiation and conductive heating on Tribolium castaneum microstructure. *Micra, 42*, 36–41.

Luo, H. L., Dai, Y. J., Wang, R. Z., Wu, J. Y., Xu, Y. X., & Shen, J. M. (2006). Experimental investigation of a solar adsorption chiller used for grain depot cooling. *Applied Thermal Engineering, 26*, 1218–1225.

Luo, H. L., Wang, R. Z., Dai, Y. J., Wu, J. Y., Shen, J. M., & Zhang, B. B. (2007). An efficient solar-powered adsorption chiller and its application in low-temperature grain storage. *Solar Energy, 81*, 607–613.

Macedo, M. L. R., Andrade, L. B. S., Moraes, R. A., & Xavier-Filho, J. (1993). Vicilin variants and the resistance of cowpea (Vigna unguiculata) seeds to the cowpea weevil (Callosobruchus maculatus). *Comparative Biological Chemistry & Physiology Part C: Comparative Pharmacology, 105*, 89–94.

Machuka, J. S., Okeola, O. G., Chrispeels, M. J., & Jackai, L. E. N. (2000). The African yam bean seed lectin affects the development of the cowpea weevil but does not affect the development of larvae of the legume pod borer. *PhytoChemistry, 53*, 667–674.

Maekawa, S., & Elert, K. (2003). *The use of oxygen-free environments in the control of museum insect pests*. Los Angeles: Getty Publications.

Mangaraj, S., Mohapatra, D., & Patil, R. T. (2013). Processing of pulses: equipments technology. *Indian Food Industry, 32*, 27–44.

Marra, F., Zhang, L., & Lyng, J. G. (2009). Radio frequency treatment of foods: review of recent advances. *Journal of Food Engineering, 91*, 497–508.

Mbaiguinam, M., Maoura, N., Bianpambe, A., Bono, G., & Alladoumbaye, E. (2006). Effect of six common plant seed oils on survival, egg-laying, and development of the cowpea weevil Callosbruchus maculatus (F.) (Coleoptera: Bruchidae). *Journal of Biological Science, 6*, 420–425.

Mbata, G. N., & Payton, M. E. (2013). Effect of monoterpenoids on oviposition and mortality of Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) under hermetic conditions. *Journal of Stored Product Research, 53*, 43–47.

Mbata, G. N., & Phillips, T. A. (2001). Effects of temperature and exposure time on mortality of stored-product insects exposed to low pressure. *Journal of Economic Entomology, 94*, 1302–1307.

Mbata, G. N., & Reichmuth, C. (1996). The comparative effectiveness of different modified atmospheres for the disinfestation of bambarra groundnuts, Vigna subterranea (L.) Verde, infested by Callosobruchus subinnotatus (Pic) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 32*, 45–51.

Mbata, G. N., Reichmuth, C., & Ofuya, T. (1996). A comparative study on the toxicity of carbon dioxide to the developmental stages of Callosobruchus maculatus (Fab.) and Callosobruchus subinnotatus (Pit.). *Postharvest Biology & Technology, 7*, 271–276.

Mbata, G. N., Hetz, S. K., Reichmuth, C., & Adler, C. (2000). Tolerance of pupae and pharate adults of Callosobruchus subinnotatus (Coleoptera: Bruchidae) to modified atmospheres: a function of metabolic rate. *Journal of Insect Physiology, 46*, 145–151.

Mbata, G. N., Phillips, T. W., & Payton, M. E. (2004). Mortality of eggs of stored-product insects held under vacuum: effect of pressure, temperature and exposure time. *Journal of Economic Entomology, 97*, 695–702.

Mbata, G. N., Johnson, M., Phillips, T. W., & Payton, M. E. (2005a). Mortality of life stages of cowpea weevil (Coleoptera: Bruchidae) exposed to low pressure at different temperatures. *Journal of Economic Entomology, 98*, 1070–1075.

Mbata, G. N., Thomas, A., & Fadamiro, H. F. (2005b). Parasitism by Pteromalus cerealellae (Hymenoptera: Pteromalidae) on the Cowpea weevil, Callosbruchus maculatus (Coleoptera: Bruchidae): host density, temperature effects, and host finding ability. *Biological Control, 33*, 286–292.

Mbata, G. N., Phillips, T. A., & Payton, M. E. (2009). Effects of cowpea varietal susceptibility and low pressure on the mortality of life stages of Callosobruchus maculatus (Coleoptera: Bruchidae). *Journal of Stored Product Research, 45*, 232–235.

Mendki, P. S., Maheshwari, V. L., & Kothari, R. M. (2001). Flyash as a post-harvest preservative for five commonly utilized pulses. *Crop Protection, 20*, 241–245.

Messina, F. J., & Renwick, J. A. A. (1983). Effectiveness of oils in protecting stored cowpea from the cowpea weevil (Coleoptera: Bruchidae). *Journal of Economic Entomology, 76*, 634–635.

Mewis, I., & Ulrichs, C. (2001). Action of amorphous diatomaceous earth against different stages of the stored product pests Tribolium confusum, Tenebrio molitor, Sitophilus granarius and Plodia interpunctella. *Journal of Stored Product Research, 37*, 153–164.

Miceli, A., & Miceli, C. (2012). Effect of thermal treatments on vitality and physical characteristics of bean, chickpea and lentil. *Journal of Stored Product Research, 51*, 86–91.

Mitcham, E. J., Veltman, R. H., Feng, X., de Castro, E., Johnson, J. A., Simpson, T. L., Biasi, W. V., Wang, S., & Tang, J. (2004). Application of radio frequency treatments to control insects in in-shell walnuts. *Postharvest Biology & Technology, 33*, 93–100.

Mohan, S., & Gopalan, M. (1992). Study on the use of biogas from cowdung for storage insect control. *Bioresource Technology, 39*, 229–232.

Mohapatra, D. & Mishra S. (2011). Current trends in drying and dehydration of foods. In B. C. Siegler (Ed.), *Food engineering* (Series: Food Sci. & *Technology*) (pp. 311–351).

Mohapatra, D., Giri, S. K., & Kar, A. (2014). Effect of microwave aided disinfestation of Callosobruchus maculatus on green gram quality. *International Journal of Agriculture and Food Science Technology, 5*, 55–62.

Monge, J. P., & Huignard, J. (1991). Population fluctuation of two bruchid species Callosobruchus maculatus F. and Bruchidius atrolineatus Pit (Coleoptera: Bruchidae) and their parasitoids Dinarmus basalis (Rond.) and Eupelmus vuilleti (Crw) in a storage situation in Niger. *Journal of African Zoology, 105*, 187–196.

Moura, F. T., Oliveira, A. S., Macedo, L. L. P., Vianna, A. L. B. R., Andrade, B. S. L., Martins-Miranda, A. S., Oliveira, J. T. A., Santos, E. A., & de Sales, M. P. (2007). Effects of a chitin-binding vicilin from Enterolobium contortisiliquum seeds on bean bruchid pests (Callosobruchus maculatus and Zabrotes subfasciatus) and phytopathogenic fungi (Fusarium solani and Colletrichum lindemuntianum). *Journal of Agricultural Food Chemistry, 5*, 260–266.

Moussa, B., Abdoulaye, T., Coulibaly, O., Baributsa, D., & Lowenberg-DeBoer, J. (2014). Adoption of on-farm hermetic storage for cowpea in West and Central Africa in 2012. *Journal of Stored Products Research*. doi:10.1016/j.jspr.2014.02.008.

Mulhearn, P. J., Banks, H. J., Finnigan, J. J., & Annis, P. C. (1976). Wind forces and their influence on gas loss from grain storage structures. *Journal of Stored Product Research, 12*, 129–142.

Murdock, L. L., & Baoua, I. B. (2014). On Purdue Improved Cowpea Storage (PICS) technology: background, mode of action, future prospects. *Journal of Stored Products Research*. doi:10.1016/j.jspr.2014.02.006.

Murdock, L. L., Margam, V., Baoua, I., Balfe, S., & Shade, R. E. (2012). Death by desiccation: effects of hermetic storage on cowpea bruchids. *Journal of Stored Products Research, 49*, 166–170.

Muthu, M., Rajendran, S., Krishnamurthy, T. S., Narasimhan, S., Rangaswamy, J. R., Jayaram, M., & Majumder, S. K. (1984). Ethyl formate as a safe general fumigant. *Developments in Agricultural Engineering, 5*, 369–393.

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

Nahdy, M. S. (1994). Bean sieving, a possible control measure for the dried bean beetles, Acanthoscelides obtectus (Say) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 30*, 65–69.

Nasar-Abbas, S. M., Plummer, J. A., Siddique, K. H. M., White, P. F., Harris, D., & Dods, K. (2008). Nitrogen retards and oxygen accelerates colour darkening in faba bean (Vicia faba L.) during storage. *Postharvest Biology & Technology, 47*, 113–118.

Navarro, S. (2006). Modified atmospheres for the control of stored-product insects and mites. In J. W. Heaps (Ed.), *Insect management for food storage and processing* (2nd ed., pp. 105–146). St. Paul: AACC International.

Navarro, S. (2012). The use of modified and controlled atmospheres for the disinfestation of stored products. *Journal of Pest Science, 85*, 301–322.

Navarro, S., & Calderon, M. (1980). *Integrated approach to the use of controlled atmospheres for insect control in grain storage* (pp. 73–78). Amsterdam: Elsevier.

Navarro, S. & Noyes, R. (2002) (Eds.). The mechanics and physics of modern grain aeration management. Boca Raton: CRC, 647 pp.

Navarro, S., Donahaye, E., & Fishman, S. (1994). The future of hermetic storage of dry grains in tropical and subtropical climates. In *Proceedings of 6th International Working Conference on Stored Product Protection* (pp. 130–138). Wallingford: CAB International.

Navarro, S., Noyes, R. T., Cassada, M., & Arthur, F. H. (2012a). Aeration of grain. In D. W. Hagstrum, T. W. Phillips, G. Cuperus (Eds.), *Stored product protection, chapter 11, Kansas State Research and Extension as Publication S156* (pp. 121–134). http://www.ksre.ksu.edu/bookstore/pubs/S156.pdf.

Navarro, S., Timlick, B., Demianyk, C. J., & White, N. D. G. (2012b). Controlled or modified atmospheres. In D.W. Hagstrum, T.W. Phillips, G. Cuperus (Eds.), *Stored product protection, chapter 16, Kansas State Research and Extension as Publication S156* (p. 16). http://www.entomology.ksu.edu/doc4989.ashx.

Nazzi, F., Vidoni, F., & Frilli, F. (2008). Semiochemicals affecting the host-related behaviour of the dry bean beetle Acanthoscelides obtectus (Say). *Journal of Stored Product Research, 44*, 108–114.

Negahban, M., Moharramipour, S., & Sefidkon, F. (2006). Chemical composition and insecticidal activity of Artemisia scoparia essential oil against three coleopteran stored-product insects. *Journal of Asia-Pacific Entomology, 9*, 381–388.

Negahban, M., Moharramipour, S., & Sefidkon, F. (2007). Fumigant toxicity of essential oil from Artemisia sieberi Besser against three stored-product insects. *Journal of Stored Product Research, 43*, 123–128.

Nerio, L. S., Olivero-Verbel, J., & Stashenko, E. (2010). Repellent activity of essential oils: a review. *Bioresource Technology, 101*, 372–378.

Nyamador, W. S., Ketoh, G. K., Amévoin, K., Nuto, Y., Koumaglo, H. K., & Glitho, I. A. (2010). Variation in the susceptibility of two Callosobruchus species to essential oils. *Journal of Stored Product Research, 46*, 48–51.

Ocloo, F. C. K., Darfour, B., Ofosu, D. O., & Wilson, D. D. (2012). Effects of irradiation on physical and sensory characteristics of cowpea seed cultivars (Vigna unguiculata L. Walp). *Radiation Physics & Chemistry, 81*, 77–81.

Ofuya, T. I., & Credland, P. F. (1996). The ability of Bruchidius atrolineatus (Pic) (Coleoptera: Bruchidae) to infest and damage seeds of different tropical legumes. *Journal of Stored Product Research, 32*, 323–328.

Ofuya, T. I., & Reichmuth, C. (1993). Control of two bruchid pests of stored grain legumes in a nitrogen atmosphere. *Crop Protection, 12*, 394–396.

Ofuya, T. I., & Reichmuth, C. (2002). Effect of relative humidity on the susceptibility of Callosobruchus maculatus (Fabricius) (Coleoptera: Bruchidae) to two modified atmospheres. *Journal of Stored Product Research, 38*, 139–146.

Ogunwolu, E. O., & Odunlami, A. T. (1996). Suppression of seed bruchid (Callosobruchus maculatus F.) development and damage on cowpea (Vigna unguiculata (L.) Walp.) with Zanthoxylum zanthoxyloides (Lam.) Waterm. (Rutaceae) root bark powder when compared to neem seed powder and pirimiphos-methyl. *Crop Protection, 15*, 603–607.

Olsen, R. G. (1982). Constant-dose microwave irradiation of insect pupae. *Radio Science, 17*(5S), 145S–148S.

Onagbola, E. O., & Fadamiro, H. Y. (2011). Electroantennogram and behavioral responses of Pteromalus cerealellae to odor stimuli associated with its host, Callosobruchus maculatus. *Journal of Stored Product Research, 47*, 123–129.

Orsat, V., & Raghavan, G. S. V. (2005). Radio-frequency processing. In D. W. Sun (Ed.), *Emerging technologies for food processing* (pp. 445–468). London: Elsevier.

Outram, I. (1967). Factors affecting the resistance of insect eggs to sulphuryl fluoride—I: the uptake of sulphuryl-35S fluoride by insect eggs. *Journal of Stored Product Research, 3*, 255–260.

Pacheco, A. I., De Castro, F., De Paula, D., Lourencao, A., Bolonhezi, S., & Barbieri, K. M. (1995). Efficacy of soybean and caster oils in the control of Callosobruchus maculatus (F.) and Callosobruchus phaseoli (Gyllenhal) in stored chick-peas (Cicer arietinum L.). *Journal of Stored Product Research, 19*, 57–62.

Panagiotakopulu, E., Buckland, P. C., Day, P. M., & Doumas, C. (1995). Natural insecticides and insect repellents in antiquity: a review of the evidence. *Journal of Archaeol Science, 22*, 705–710.

Pande, R., Mishra, H. N., & Singh, M. N. (2012). Microwave drying for safe storage and improved nutritional quality of green gram seed (Vigna radiata). *Journal of Agricultural Food Chemistry, 60*, 3809–3816.

Pandey, G. P., Doharey, R. B., & Varma, B. K. (1981). Efficacy of some vegetable oils for protecting greengram against the attack of Callosobruchus maculatus (Fabr.). *Indian Journal of Agricultural Sciences, 51*, 910–912.

Papachristos, D. P., & Santamopoulos, D. C. (2002a). Repellent, toxic and reproduction inhibitory effects of essential oil vapours on Acanthoscelides obtectus (Say) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 38*, 117–128.

Papachristos, D. P., & Santamopoulos, D. C. (2002b). Toxicity of vapours of three essential oils to the immature stages of Acanthoscelides obtectus (Say) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 38*, 365–373.

Papachristos, D. P., & Santamopoulos, D. C. (2003). Selection of Acanthoscelides obtectus (Say) for resistance to lavender essential oil vapour. *Journal of Stored Product Research, 39*, 433–441.

Papachristos, D. P., & Santamopoulos, D. C. (2004). Fumigant toxicity of three essential oils on the eggs of Acanthoscelides obtectus (Say) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 40*, 517–525.

Park, C., Kim, S.-I., & Ahn, Y.-J. (2003a). Insecticidal activity of asarones identified in Acorus gramineus rhizome against three coleopteran stored-product insects. *Journal of Stored Product Research, 39*, 333–342.

Park, I.-K., Lee, S.-G., Choi, D.-H., Park, J.-D., & Ahn, Y.-J. (2003b). Insecticidal activities of constituents identified in the essential oil from leaves of Chamaecyparis obtusa against Callosobruchus chinensis (L.) and Sitophilus oryzae (L.). *Journal of Stored Product Research, 39*, 375–384.

Pascual-Villalobos, M. J., & Ballesta-Acosta, M. C. (2003). Chemical variation in an Ocimum basilicum germplasm collection and activity of the essential oils on Callosobruchus maculatus. *Biochemical System and Ecology, 31*, 673–679.

Paul, U. V., Lossini, J. S., Edwards, P. J., & Hilbeck, A. (2009). Effectiveness of products from four locally grown plants for the management of Acanthoscelides obtectus (Say) and Zabrotes subfasciatus (Boheman) (both Coleoptera: Bruchidae) in stored beans under laboratory and farm conditions in Northern Tanzania. *Journal of Stored Product Research, 45*, 97–107.

Pereira, J. (1983). The effectiveness of six vegetable oils as protectants of cowpeas and bambara groundnuts against infestation by Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 19*, 57–62.

Phillips, T. W. (1997). Semiochemicals of stored-product insects: research and applications. *Journal of Stored Product Research, 33*, 17–30.

Phillips, T. W., Phillips, J. K., Webster, F. X., Tang, R. T., & Burkholder, W. E. (1996). Identification of sex pheromones from the cowpea weevil, Callosobruchus maculatus, and related studies with C. analis (Coleoptera: Bruchidae). *Journal of Chemical Ecology, 22*, 2233–2249.

Popelka, J., Terryn, N., & Higgins, T. J. V. (2004). Gene technology for grain legumes: can it contribute to the food challenge in developing countries? *Plant Science, 167*, 195–206.

Prakash, B., Singh, P., Yadav, S., Singh, S. C., & Dubey, N. K. (2013). Safety profile assessment and efficacy of chemically characterized Cinnamomum glaucescens essential oil against storage fungi, insect, aflatoxin secretion and as antioxidant. *Food & Chemical Toxicology, 53*, 160–167.

Purohit, P., Jayas, D. S., Yadav, B. K., Chelladurai, V., Fields, P. G., & White, N. D. G. (2013). Microwaves to control Callosobruchus maculatus in stored mung bean (Vigna radiata). *Journal of Stored Product Research, 53*, 19–22.

Qi, Y. T., & Burkholder, W. E. (1981). Sex pheromone biology and behavior of the cowpea weevil Callosobruchus maculatus (Coleoptera: Bruchidae). *Journal of Chemical Ecology, 8*, 527–534.

Rahman, M. M. (1990). Some promising physical, botanical and chemical methods for the protection of grain legumes against bruchids in storage under Bangladesh conditions. *Bruchids and Legumes: Economics, Ecology and Coevolution: Series Entomology, 46*, 63–73.

Rahman, M. M., & Schmidt, G. H. (1999). Effect of Acorus calamus (L.) (Araceae) essential oil vapours from various origins on Callosobruchus phaseoli (Gyllenhal) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 35*, 285–295.

Rahman, A., & Talukder, F. A. (2006). Bioefficacy of some plant derivatives that protect grain against the pulse beetle, Callosobruchus maculatus. *Journal of Insect Science, 6*, 3.

Raja, N., Albert, S., Ignacimuthu, S., & Dorn, S. (2001). Effect of plant volatile oils in protecting stored cowpea Vigna unguiculata (L.) Walpers against Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) infestation. *Journal of Stored Product Research, 37*, 127–132.

Rajapakse, R., & van Emden, H. F. (1997). Potential of four vegetable oils and ten botanical powders for reducing infestation of cowpeas by Callosobruchus maculatus, C. chinensis and C. rhodesianus. *Journal of Stored Product Research, 33*, 59–68.

Rajendran, S., & Muthu, M. (1989). The toxic action of phosphine in combination with some alkyl halide fumigants and carbon dioxide against the eggs of Tribolium castaneum Herbst (Coleoptera: Tenebrionidae). *Journal of Stored Products Research, 25*, 225–230.

Rajendran, S., & Sriranjini, V. (2008). Plant products as fumigants for stored-product insect control. *Journal of Stored Product Research, 44*, 126–135.

Rangaswamy, J. R., & Gunasekaran, N. (1996). Phosphine residue and its desorption from legumes fumigated with phosfume pellets. *LWT - Food Science Technology, 29*, 234–237.

Reddy, M. U., Bharati, S. R., & Reddy, D. D. R. (1999). Efficacy of some vegetable oils as protectants against the pulse beetle (Callosobruchus chinensis) in green gram (Phaseolus aureus) during storage. *Indian Journal of Nutrition & Dietetics, 36*, 436–442.

Regnault-Roger, C., & Hamraoui, A. (1993). Efficiency of plants from the South of France used as traditional protectants of Phaseolus vulgaris L. against its bruchid Acanthoscelides obtectus (Say). *Journal of Stored Product Research, 29*, 259–264.

Regnault-Roger, C., & Hamraoui, A. (1994). Inhibition of reproduction of Acanthoscelides obtectus Say (Coleoptera), a kidney bean (Phaseolus vulgaris) bruchid, by aromatic essential oils. *Crop Protection, 13*, 624–628.

Regnault-Roger, C., & Hamraoui, A. (1995). Fumigant toxic activity and reproductive inhibition induced by monoterpenes on Acanthoscelides obtectus (Say) (Coleoptera), a bruchid of kidney bean (Phaseolus vulgaris L.). *Journal of Stored Product Research, 31*, 291–299.

Regnault-Roger, C., Hamraoui, A., Holeman, M., Theron, E., & Pinel, R. (1993). Insecticidal effect of essential oils from Mediterranean plants upon Acanthoscelides obtectus (Say) (Coleoptera, Bruchidae), a pest of kidney bean (Phaseolus vulgaris L.). *Journal of Chemical Ecology, 19*, 1231–1242.

Regnault-Roger, C., Ribodeau, M., Hamraoui, A., Bareau, I., Blanchard, P., Gil-Munoz, M.-I., & Barberan, F. T. (2004). Polyphenolic compounds of Mediterranean Lamiaceae and investigation of orientational effects on Acanthoscelides obtectus (Say). *Journal of Stored Product Research, 40*, 395–408.

Ren, Y. L., & Mahon, D. (2007). Evaluation of 35S-residues in grains and grain fractions fumigated with 35S-labelled carbonyl sulfide. *Journal of Stored Product Research, 43*, 356–361.

Riudavets, J., Pons, M. J., Gabarra, R., Castañé, C., Alomar, O., Vega, L. F., & Guri, S. (2013). The toxicity effects of atmospheres with high content of carbon dioxide with addition of sulphur dioxide on two stored-product pest species: Sitophilus oryzae and Tribolium confusum. *Journal of Stored Products Research*. doi:10.1016/j.jspr.2013.12.003.

Rojas-Rousse, D., Poitrineau, K., & Basso, C. (2007). The potential of mass rearing of Monoksa dorsiplana (Pteromalidae) a native gregarious ectoparasitoid of Pseudopachymeria spinipes (Bruchidae) in South America. *Biological Control, 41*, 348–353.

Rulon, R. A., Maier, D. E., & Boehlje, M. D. (1999). A post-harvest economic model to evaluate grain chilling as an IPM technology. *Journal of Stored Product Research, 35*, 369–383.

Sabbour, M., & E-Abd-El-Aziz, S. (2010). Efficacy of some bioinsecticides against Bruchidius incarnatus (Boh.) (Coleoptera: Bruchidae) infestation during storage. *Journal of Plant Protection Research, 50*, 28–34.

Sadeghi, A., van Damme, E. J. M., Peumans, W. J., & Smagghe, G. (2006). Deterrent activity of plant lectins on cowpea weevil Callosobruchus maculatus (F.) oviposition. *PhytoChemistry, 67*, 2078–2084.

Sales, M. P., Gerhardt, I. R., Grossi-de-Sá, M. F., & Xavier-Filho, J. (2000). Do legume storage proteins play a role in defending seeds against bruchids? *Plant Physiology, 124*, 515–522.

Sales, M. P., Pimenta, P. P., Paes, N. S., Grossi-de-Sá, M. F., & Xavier-Filho, J. (2001). Vicilins (7S storage globulins) of cowpea (Vigna unguiculata) seeds bind to chitinous structures of the midgut of Callosobruchus maculatus (Coleoptera: Bruchidae) larvae. *Brazilian Journal of Medical & Biological Research, 34*, 27–34.

Salunke, B. K., Kotkar, H. M., Mendki, P. S., Upasani, S. M., & Maheshwari, V. L. (2005). Efficacy of flavonoids in controlling Callosobruchus chinensis (L.) (Coleoptera: Bruchidae), a post-harvest pest of grain legumes. *Crop Protection, 24*, 888–893.

Sanon, A., Garba, M., Auger, J., & Huignard, J. (2002). Analysis of the insecticidal activity of methylisothiocyanate on Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) and its parasitoid Dinarmus basalis (Rondani) (Hymenoptera: Pteromalidae). *Journal of Stored Product Research, 38*, 129–138.

Sanon, A., Dabiré-Binso, L. C., & Ba, N. M. (2011). Triple-bagging of cowpeas within high density polyethylene bags to control the cowpea beetle Callosobruchus maculatus F. (Coleoptera: Bruchidae). *Journal of Stored Product Research, 47*, 210–215.

Saxena, B. P., Sharma, P. R., Thappa, R. K., & Tikku, K. (1992a). Temperature induced sterilization for control of three stored grain beetles. *Journal of Stored Product Research, 28*, 67–70.

Saxena, R. C., Dixit, O. P., & Harshan, V. (1992b). Insecticidal action of Lantana camara against Callosobruchus chinensis (Coleoptera: Bruchidae). *Journal of Stored Product Research, 28*, 279–281.

Schmale, I., Wäckers, F. L., Cardona, C., & Dorn, S. (2003). Combining parasitoids and plant resistance for the control of the bruchid Acanthoscelides obtectus in stored beans. *Journal of Stored Product Research, 39*, 401–411.

Schmale, I., Wäckers, F. L., Cardona, C., & Dorn, S. (2006). Biological control of the bean weevil, Acanthoscelides obtectus (Say) (Col.: Bruchidae), by the native parasitoid Dinarmus basalis (Rondani) (Hym.: Pteromalidae) on small-scale farms in Colombia. *Journal of Stored Product Research, 42*, 31–41.

Schmidt, G. H., Risha, E. M., & El-Nahal, A. K. M. (1991). Reduction of progeny of some stored-product Coleoptera by vapours of Acorus calamus oil. *Journal of Stored Product Research, 27*, 121–127.

Schöller, M., Prozell, S., Al-Kirshi, A.-G., & Reichmuth, C. (1997). Towards biological control as a major component of integrated pest management in stored product protection. *Journal of Stored Product Research, 33*, 81–97.

Schoonhoven, A. V. (1978). The use of vegetable oils to protect stored beans from bruchid attack. *Journal of Economic Entomology, 71*, 254–256.

Seck, D., Logany, G., Haubruge, E., Marlier, M., & Gaspar, C. (1996). Alternative protection of cowpea seeds against Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) using hermetic storage alone or in combination with Boscia senegalenis (Pers.) Lam ex Poir. *Journal of Stored Product Research, 32*, 39–44.

Shaaya, E., & Kostyukovsky, M. (2009). The potential of biofumigants as alternatives to methyl bromide for the control of pest infestation in grain and dry food products. *Recent Advances in Plant Biotechnology*, pp 389–403.

Shaaya, E., Kostyukovsky, M., Eilberg, J., & Sukprakarn, C. (1997). Plant oils as fumigants and contact insecticides for the control of stored-product insects. *Journal of Stored Product Research, 33*, 7–15.

Shayesteh, N., & Barthakur, N. N. (1996). Mortality and behaviour of two stored-product insect species during microwave irradiation. *Journal of Stored Product Research, 32*, 239–246.

Shimizu, C., & Hori, M. (2009). Repellency and toxicity of troponoid compounds against the adzuki bean beetle, Callosobruchus chinensis (L.) (Coleoptera: Bruchidae). *Journal of Stored Product Research, 45*, 49–53.

Shrestha, B., & Baik, O.-D. (2013). Radio frequency selective heating of stored-grain insects at 27.12 MHz: a feasibility study. *Biosystems Engineering, 114*, 195–204.

Shu, S., Koepnick, W. L., Mbata, G. N., Cork, A., & Ramaswamy, S. B. (1996). Sex pheromone production in Callosobruchus maculatus (Coleoptera: Bruchidae): electroantennographic and behavioral responses. *Journal of Stored Product Research, 32*, 21–30.

Shukla, R., Srivastava, B., Kumar, R., & Dubey, N. K. (2007). Potential of some botanical powders in reducing infestation of chickpea by Callosobruchus chinensis L. (Coleoptera : Bruchidae). *Journal of Agricultural Technology, 3*, 11–19.

Shukla, R., Kumar, A., Prasad, C. S., Srivastava, B., & Dubey, N. K. (2009). Efficacy of Acorus calamus L. leaves and rhizome on mortality and reproduction of Callosobruchus chinensis L. (Coleoptera: Bruchidae). *Applied Entomology Zoology, 44*, 241–247.

Siddhuraju, P., Makkar, H. P. S., & Becker, K. (2002). The effect of ionising radiation on antinutritional factors and the nutritional value of plant materials with reference to human and animal food. *Food Chemistry, 78*, 187–205.

Singal, S. K., & Singh, Z. (1990). Studies of plant oils as surface protectants against pulse beetle, Callosobruchus chinensis (L.) in chickpea, Cicer arietinum L. in India. *Tropical Pest Management, 36*, 314–316.

Singh, P. K. (2003). Effect of some oils against pulse beetle, Callosobruchus chinensis in infesting pigeon pea. *Indian Journal of Entomology, 65*(1), 55–58.

Singh, K. N., & Srivastava, B. P. (1980). Studies of the efficacy and extent of residues of phosphine in stored pulses. *Pesticides, 14*, 32–34.

Singh, S. R., Luse, R. A., Leuschner, K., & Nangju, D. (1978). Groundnut oil treatment for the control of Callosobruchus maculatus (F.) during cowpea storage. *Journal of Stored Product Research, 14*, 77–80.

Singh, R., Singh, K. K., & Kotwalewale, N. (2012). Study on disinfestation of pulses using microwave technique. *Journal of Food Science & Technology, 49*, 505–509.

Sinha, R. N., & Watters, F. L. (1985). Insect pests of flour mills, grain elevators, and feed mills and their control. Agric. Can. Publ. No. 1776, 1–290

Sinha, S.N., Singh, S.P. & Srivastava, C. (2001). Effect of smoke on rhyzopertha dominica and Callosobruchus maculatus mortality and its susceptibility to phosphine. Donahaye EJ, Navarro S and Leesch JG (Eds.) Proc. Int. Conf. controlled atmosphere and fumigation in stored products, Fresno, CA. 29 Oct.–3 Nov. 2000, Executive Printing Services, Clovis. pp. 431–437.

Sood, S., & Pajni, H. R. (2006). Effect of honey feeding on longevity and fecundity of Uscana mukerjii (Mani) (Hymenoptera: Trichogrammatidae), an egg parasitoid of bruchids attacking stored products (Coleoptera: Bruchidae). *Journal of Stored Product Research, 42*, 438–444.

Sousa, A. H., Faroni, L. R. D. A., Guedes, R. N. C., Totola, M. R., & Urruchi, W. I. (2008). Ozone as a management alternative against phosphine-resistant insect pests of stored products. *Journal of Stored Product Research, 44*, 379–385.

Stamopoulos, D. C. (1991). Effects of four essential oil vapours on the oviposition and fecundity of Acanthoscelides obtectus (Say) (Coleoptera: Bruchidae): laboratory evaluation. *Journal of Stored Product Research, 27*, 199–203.

Stathers, T. E., Denniff, M., & Golob, P. (2004). The efficacy and persistence of diatomaceous earths admixed with commodity against four tropical stored product beetle pests. *Journal of Stored Products Research, 40*, 113–123.

Subramanya, S., Prabhanjan, D. G., Babu, C. K., Ramakumar, M. V., Krishnappa, C., & Krishnamurthy, K. C. (1994). Biogas as a grain protectant against Callosobruchus chinensis (Bruchidae, Coleoptera). *Journal of Food Processing & Preservation, 18*, 217–227.

Sujatha, A., & Punnaiah, K. C. (1985). Effect of coating stored seed of greengram with vegetable oils on the development of pulse beetle. *Indian Journal of Agricultural Sciences, 55*, 475–477.

Sumnu, G., & Sahin, S. (Eds.). (2005). *Recent developments in microwave heating, in emerging technologies for food processing* (pp. 419–444). San Diego: Academic.

Tanaka, K., Ohsawa, K., Honda, M., & Yamomoto, I. (1981). Copulation release pheromone, erectin, from the Azuki bean weevil, Callosobruchus chinensis L. *Journal of Pesticide Science, 7*, 535–537.

Tapondjou, L. A., Adler, C., Bouda, H., & Fontem, D. A. (2002). Efficacy of powder and essential oil from Chenopodium ambrosioides leaves as post-harvest grain protectants against six-stored product beetles. *Journal of Stored Product Research, 38*, 395–402.

Thorpe, G. R. (1997). The thermodynamic performance of a continuous-flow fluidized bed grain disinfector and drier. *Journal of Agricultural Engineering Research, 37*, 27–41.

Thorpe, G. R. (1998). The modelling and potential applications of a simple solar regenerated grain cooling device. *Postharvest Biology & Technology, 13*, 151–168.

Tilley, D. R., Casada, M. E., & Arthur, F. H. (2007). Heat treatment for disinfestation of empty grain storage bins. *Journal of Stored Product Research, 43*, 221–228.

Titenko-Holland, N., Windham, G., Kolachana, P., Reinisch, F., Parvatham, S., Osorio, A. M., & Smith, M. T. (1997). Genotoxicity of malathion in human lymphocytes assessed using the micronucleus assay in vitro and in vivo: a study of malathion-exposed workers. *Mutation Research/Genetic Toxicology Environment Mutagenesis, 388*, 85–95.

Todoriki, S., Hasan, M., Miyanoshita, A., Imamura, T., & Hayashi, T. (2006). Assessment of electron beam-induced DNA damage in larvae of chestnut weevil, Curculio sikkimensis (Heller) (Coleoptera: Curculionidae) using comet. *Radiation Physics & Chemistry, 75*, 292–296.

Tozlu, E., Cakir, A., Kordali, S., Tozlu, G., Ozer, H., & Akcin, T. A. (2011). Chemical compositions and insecticidal effects of essential oils isolated from Achillea gypsicola, Satureja hortensis, Origanum acutidens and Hypericum scabrum against broadbean weevil (Bruchus dentipes). *Scientia Horticulturae, 130*, 9–17.

Tsai, W.-T., Mason, L. J., Chayaprasert, W., Maier, D. E., & Ileleji, K. E. (2011). Investigation of fumigant efficacy in flour mills under real-world fumigation conditions. *Journal of Stored Product Research, 47*, 179–184.

Tuda, M., Chou, L.-Y., Niyomdham, C., Buranapanichpan, S., & Tateishi, Y. (2005). Ecological factors associated with pest status in Callosobruchus (Coleoptera: Bruchidae): high host specificity of non-pests to Cajaninae (Fabaceae). *Journal of Stored Product Research, 41*, 31–45.

Tyler, P. S., & Green, A. A. (1968). The effectiveness of fenitrothion and malathion as grain protectants under severe practical conditions. *Journal of Stored Product Research, 4*, 119–126.

Uchôa, A. F., de Miranda, M. R. A., de Souza, A. J., Gomes, V. M., Fernandes, K. V. S., Lemos, F. J. A., Oliveira, A. E. A., & Xavier-Filho, J. (2009). Toxicity of hydrolyzed vicilins toward Callosobruchus maculatus and phytopathogenic fungi. *Journal of Agricultural & Food Chemistry, 57*, 8056–8061.

Ugwu, F. M., Ekwu, F. C., & Abu, J. O. (1999). Effect of different sun-drying surfaces on the functional properties, cooking and insect infestation of cowpea seeds. *Bioresource Technology, 69*, 87–90.

Vadivambal, R. (2009). Disinfestation of stored grain insects using microwave energy. MS thesis (unpublished) submitted to University of Manitoba, Canada. doi:http://hdl.handle.net/1993/3152.

Vadivambal, R., & Jayas, D. S. (2007). Changes in quality of microwave-treated agricultural products—a review. *Biosystems Engineering, 98*, 1–16.

Vadivambal, R., & Jayas, D. S. (2008). Non-uniform temperature distribution during microwave heating of food materials—a review. *Food & Bioprocess Technology*. doi:10.1007/s11947-008-0136-0.

Vadivambal, R., Jayas, D. S., & White, N. D. G. (2007). Wheat disinfestation using microwave energy. *Journal of Stored Product Research, 43*, 508–514.

Vales, M. I., Ranga Rao, G. V., Sudini, H., Patil, S. B., & Murdock, L. L. (2014). Effective and economic storage of pigeonpea seed in triple layer plastic bags. *Journal of Stored Products Research*. doi:10.1016/j.jspr.2014.01.004.

van Huis, A. (1991). Biological methods of bruchid control in the tropics: a review. *Insect Science, 12*, 87–102.

Vardeman, E. A., Campbell, J. F., Arthur, F. H., & Nechols, J. R. (2007). Behavior of female Rhyzopertha dominica (Coleoptera: Bostrichidae) in a mono-layer of wheat treated with diatomaceous earth. *Journal of Stored Product Research, 43*, 297–301.

Varma, B. K., & Pandey, G. P. (1978). Treatment of stored greengram seed with edible oils for protection from Callosohruchus maculatus (Fabr.). *Indian Journal of Agricultural Sciences, 48*, 72–75.

Varnava, A., Navarro, S., & Donahaye, E. (1995). Long-term hermetic storage of barley in PVC-covered concrete platforms under Mediterranean conditions. *Postharvest Biology and Technology, 6*(1–2), 177–186.

Velten, G., Rott, A. S., Cardona, C., & Dorn, S. (2007a). Effects of a plant resistance protein on parasitism of the common bean bruchid Acanthoscelides obtectus (Coleoptera: Bruchidae) by its natural enemy Dinarmus basalis (Hymenoptera: Pteromalidae). *Biological Control, 43*, 78–84.

Velten, G., Rott, A. S., Cardona, C., & Dorn, S. (2007b). The inhibitory effect of the natural seed storage protein arcelin on the development of Acanthoscelides obtectus. *Journal of Stored Product Research, 43*, 550–557.

Velten, G., Rott, A. S., Petit, B. J. C., Cardona, C., & Dorn, S. (2008). Improved bruchid management through favorable host plant traits and natural enemies. *Biological Control, 47*, 133–140.

Verma, R. (1990). Host habitat location and host location by Dinarmus hasalis, a parasite of bruchids of stored legumes. *Indian Journal of Experimental Biology, 28*, 179–184.

Villavicencio, A.-L. C. H., Mancini-Filho, J., Delincée, H., & Bognár, A. (2000). Effect of gamma irradiation on the thiamine, riboflavin and vitamin B6 content in two varieties of Brazilian beans. *Radiation Physics & Chemistry, 57*, 299–303.

Wang, S., & Tang, J. (2004). Radio frequency heating: a potential method for post-harvest pest control in nuts and dry products. *Journal of Zhejiang University. Science, 5*, 1169–1174.

Wang, S., Ikediala, J. N., Tang, J., Hansen, J. D., Mitcham, E., Mao, R., & Swanson, B. (2001). Radio frequency treatments to control codling moth in in-shell walnuts. *Postharvest Biology & Technology, 22*, 29–38.

Wang, S., Tang, J., Johnson, J. A., Mitcham, E., Hansen, J. D., Cavalieri, R. P., Bower, J., & Biasi, B. (2002). Process protocols based on radio frequency energy to control field and storage pests in in-shell walnuts. *Postharvest Biology & Technology, 26*, 265–273.

Wang, S., Monzon, M., Johnson, J. A., Mitcham, E., & Tang, J. (2007). Industrial-scale radio frequency treatments for insect control in walnuts. I: Heating uniformity and energy efficiency. *Postharvest Biology & Technology, 45*, 240–246.

Wang, S., Yue, J., Chen, B., & Tang, J. (2008). Treatment design of radio frequency heating based on insect control and product quality. *Postharvest Biology & Technology, 49*, 417–423.

Wang, S., Tiwari, G., Jiao, S., Johnson, J. A., & Tang, J. (2010). Developing postharvest disinfestation treatments for legumes using radio frequency energy. *Biosystems Engineering, 105*, 341–349.

Watters, F. L. (1976). Microwave radiation for control of Tribolium confusum in wheat and flour. *Journal of Stored Product Research, 12*, 19–25.

Weaver, D. K., Dunkel, F. V., Ntezurubanza, L., Potter, R. C., Jackson, L. L., & Stock, D. T. (1991). The efficacy of linalool, a major component of freshly-milled Ocimum canum Sims (Lamiaceae), for protection against postharvest damage by certain stored product Coleoptera. *Journal of Stored Product Research, 27*, 213–220.

Weaver, D. K., Dunkel, F. V., Potter, R. C., & Ntezurubanza, L. (1994). Contact and fumigant efficacy of powdered and intact Ocimum canum Sims (Lamiales: Lamiaceae) against Zabrotes subfasciatus (Boheman) adults (Coleoptera: Bruchidae). *Journal of Stored Product Research, 30*, 243–252.

Wickham, J. C. (1998). The use of synergized pyrethroids to control insect pests in and around. In D. G. Jones (Ed.), *Piperonyl butoxide* (pp. 239–260). San Diego: Academic.

Wong-Corral, F. J., Castañé, C., & Riudavets, J. (2013). Lethal effects of CO_2-modified atmospheres for the control of three Bruchidae species. *Journal of Stored Products Research, 55*, 62–67.

Yadav, D. N., Anand, T., Sharma, M., & Gupta, R. K. (2012). Microwave technology for disinfestation of cereals and pulses: an overview. *Journal of Food Science & Technology*. doi:10.1007/s13197-012-0912-8.

Yamane, T., & Miyatake, T. (2010). Reduced female mating receptivity and activation of oviposition in two Callosobruchus species due to injection of biogenic amines. *Journal of Insect Physiology, 56*, 271–276.

Yankanchi, S. R., & Lendi, G. S. (2009). Bioefficacy of certain plant leaf powders against pulse beetle, Callosobruchus chinensis L. (Coleoptera: Bruchidae). *Biological Forum—An International Journal, 1*, 54–57.

Yun, J., Li, X., Fan, X., Li, W., & Jiang, Y. (2013). Growth and quality of soybean sprouts (Glycine max L. Merrill) as affected by gamma irradiation. *Radiation Physics & Chemistry, 82*, 106–111.

Zayed, S. M. A. D., Farghaly, M., Mahdy, F., & Soliman, S. M. (2007). Fate of the organophosphorus insecticide dichlorvos in stored beans. *Journal of Stored Product Research, 43*, 474–479.

Zettler, J. L., & Arthur, F. H. (2000). Chemical control of stored product insects with fumigants and residual treatments. *Crop Protection, 19*, 577–582.

Zhao, S., Qiu, C., Xiong, S., & Cheng, X. (2007a). A thermal lethal model of rice weevils subjected to microwave irradiation. *Journal of Stored Product Research, 43*, 430–434.

Zhao, S., Xiong, S., Qiu, C., & Xu, Y. (2007b). Effect of microwaves on rice quality. *Journal of Stored Product Research, 43*, 496–502.