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# Management of Stored Grain Pests - Novel Strategies

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## ABSTRACT

The potential presence of pests in store products is the reason of treatments to prevent continued damage to the products. Treatments that have been developed are generally tailor-made to fit within commodity tolerances and pest intolerance. Conventional treatments rely on the use of chemicals. Chemicals, by their nature, are harmful to either the environment or human health. Alternative treatments are being developed to be more environments friendly and have less impact on human health. Hermetic storage technology with modified atmosphere has emerged as a significant alternative to other methods of storage that protect commodities from insects and molds. Irradiation is used to suppress pest populations in stored products. Active research is going on to exploit ozone as a potential treatment for controlling stored product pests. Many of these treatments have already bridged the gap between research and implementation, such as Ultraviolet C radiation, freezing, microwave, elevated temperature etc. Many other treatments are still in development and may require more research to gain widespread acceptance. The aim of this review is to shed light on alternative environmental friendly methods to protect stored products from pests attack for healthy safe food.

**Keywords:** Ecofriendly, Stored Grain Pests, Management

## Introduction

Food grains form an important part of the Indian diet. Grain production has been steadily increasing due to advancement in production technology, but improper storage results in high losses in grains. The grain production in India is currently 263.2 million tonnes (Anon., 2014). According to World Bank Report (1999), post-harvest losses in India amount to 12 to 16 million metric tons of food grains each year, an amount that the World Bank stipulates could feed one-third of India's poor. The monetary value of these losses amounts to more than Rs 50,000 crores.

Because of high humidity and warm climate safe storage of agricultural produce is a problem in almost all the countries. Storage of agricultural produce particularly cereals, pulses and oilseeds for long duration is associated with the losses in quality, quantity, viability and monetary values. The main bio-deteriorating agents are rodents, insects, birds, mites and microorganisms. Insect occupy a key position among these bioagents. Stored products of agricultural and animal origins are attacked by more than 600 species of beetle pests, 70 species of moths and about 355 species of mites causing quantitative and qualitative losses (Prakash and Rao, 1995).

The major economic loss caused by grain infesting insects is not always the actual material they consume, but also the amount contaminated by them, their excreta, cast skins and dead bodies which makes food unfit for human consumption (Scott 1991) and are responsible for worldwide loss of grains upto 10-40% annually (Mathews, 1993).

There is a need to protect stored food from attack by insects because they can destroy large quantities, particularly during long term storage (Pimentel, 1991). The control of pests in commodity storage (farm and commercials) and food plants (food manufacturing processing and warehousing) requires a high degree of professionalism combined with experience and knowledge.

Control of this insect population throughout the world has relied principally on the application of synthetic insecticides, viz. organophosphates and fumigants such as methyl bromide and phosphine, which are still the most effective means of protection of stored food and other agricultural commodities from insect infestation (EPA, 2001). Although effective, such synthetic pesticides cause consequently residual pollution of the environment and toxicity to consumers. Their repeated use for decades has disrupted biological control by natural enemies and has led to the resurgence of stored product insect pests. Many of these stored product insects have developed resistance to the commonly used chemicals (Srivastava and Singh, 2001). Therefore, there is an urgent need for technologists and scientists to develop simple, ecosmart and economical codes of practice, which can be implemented to minimize any avoidable wastage of stored products, both on farms and at the farmer storage level.

Earlier, there were several of non-chemical methods used in grain stores and food processing facilities. Hereunder, some ecofriendly novel strategies using to render the habitat unsuitable for the growth and reproduction of stored-product insects to emphasize the non chemical aspects of pest control is reviewed.

## Hermetic Storage

Hermetic storage is based on the principle of generating an oxygen-depleted, carbon dioxide-enriched interstitial atmosphere caused by the respiration of the living organisms in the ecological system of a sealed storage structure (De Bruin and Murali, 2006; Vachanth et al., 2010). It has been shown that hermetic storage allows safe storage for periods ranging from weeks to many months, as well as during shipment across intercontinental distances with storage losses typically well below 1% (Villers et al., 2010). Navarro et al. (2012) termed these structures as Volcani Cubes or Grain Pro Cocoon™.

Hermetic Storage (HS) or ‘airtight’ technology has emerged as a significant alternative to other methods of storage that protect commodities from insects and molds. Hermetic storage is a type of Modified Atmosphere (MA) that has now been applied for the protection of stored agricultural commodities including cocoa beans as well as coffee, rice, maize, pulses and seeds (Navarro et al., 1993; Navarro, 2006). Hermetic storage takes three distinct forms. 1) “Organic- Hermetic storage”, relies on the metabolic activity and respiration of insects, microflora and the commodity itself to generate a modified, non-life sustaining low oxygen atmosphere, 2) “Vacuum-Hermetic Fumigation” (V-HF) - uses a vacuum pump to rapidly create a very low pressure atmosphere for accelerated disinfestations of non crushable commodities through asphyxiation; and 3) Gas-Hermetic Fumigation (G-HF) uses an external gas source (usually $CO_2$) for crushable commodities, such as dried fruit, prior to shipment (Navarro et al., 1984). A more recent but increasingly popular form of hermetic storage system is the triple layer bag. This system utilizes a thin, transparent and low permeability co-extruded multi layer plastic as a liner to a conventional jute or polypropylene bag. The triple bag consists of 2 layers of polyethylene bags which are expected to be as hermetic as possible and both are included in a protective polypropylene woven bag (Navarro and Donahaye, 2005). Triple-bagging prevents the development of mycotoxins such as aflatoxins and ochratoxin (Navarro et al., 2002; Rickman and Aquino, 2004). It also prevents quality loss due to increase of Free Fatty Acids (FFAs) in the low oxygen environment (Obeng-Ofori, 2007; Moussa, 2006; Navarro et al., 2012). Triple layer bag capacities range from 5kg to 1,000 kg, with 43-60 kg capacity being the most common. At the individual small farm level they can be protected from rodents by storage in empty 55-gallon drums. By preventing the entry of water vapour into a hermetically sealed container, adequately dried commodities are protected from external humidity, preventing a rise in their moisture content beyond their critical moisture level of 14% (Villers et al., 2006). Many studies in various countries have shown that triple-bagging maintains germination of 85% or more for periods up to 9 months, while conventional storage in jute bags reduces germination down by14% to 76% within 3 months (Omondi et al., 2011).

A new technology, Purdue Improved Crop Storage (PICS) triple-layer hermetic storage bags, may provide an improved alternative for insecticide-free, long-term storage of common beans with minimal grain damage (Ognakossan et al., 2010). Triple-layer hermetic Purdue Improved Crop Storage (PICS) bags were developed under the Bean/Cowpea CRSP project in the late 1980s through funding from USAID (Murdock et al., 2003).

## Irradiation

Irradiation prevents development and/or reproduction of regulated pests so that regulated articles can be shipped out of regulated areas (Hallman, 2011). Irradiation is used to suppress pest populations in stored products when the products are moved (Salimov et al., 2000). Ionizing radiation in the form of electromagnetic radiance or high-energy particles creates ions by breaking chemical bonds. The ionizing portion of the electromagnetic spectrum comprises visible light and shorter wavelengths, although visible light ionizes only certain chemicals, e.g., chlorophyll which is ionized to initiate photosynthesis. Ionizing ultraviolet light (wavelengths of 10e 400 nm, photon energies of 3e124 eV) has been researched as a surface treatment for grain and to control stored product pests (Faruki et al., 2007).

Radiation usage is one of the healthiest methods that do not have the bad effects of chemical materials in pest management (Khaghani et al., 2010). The gamma radiator, because of its great effect strength, fast and easy dosimetry in each time and each condition (different conditions, such as different temperature, humidity, air components) and usage security has the highest level of application (Ignatowicz, 2004; Salimov, et al., 2000). Tuncbilek et al. (2003) and Follett and Armstrong (2004) studied the radiation on Tribolium confusum and found no survival to the adult stage.

The major problem with irradiation of stored products is the sheer volume of product that needs to be treated. Considerable research has proven that although irradiation against many stored products pests is effective, volume and cost have proven to be inhibitory to its application (Johnson and Marcotte, 1999; Aegerter and Folwell, 2001). Treatments have been developed to control stored product pests of grains, dried fruits and nuts. The major pests in grains for which irradiation treatments have been developed are Angoumois grain moth, Sitotroga cerealella (Olivier) and Indianmeal moth, Plodia interpunctella (Hubner) (Hallman and Phillips, 2008), where a generic dose of 600 Gy has been recommended for all insects in grains, mostly due to the high radio tolerance of the Angoumois grain moth. Most of the irradiation treatments against pests in dried fruits and nuts has focused on the Indianmeal moth (Ayvaz et al., 2006) where it was found that a dose of 350 Gy was required to prevent egg hatch and adult development from irradiated larvae.

## Ultraviolet C Radiation (UVC)

The potential of using Ultraviolet C (UVC) radiation as an alternative treatment and hygiene measure in storage premises was investigated in the laboratory and the effect of UVC on development and progeny production was assessed for pest species of the storage beetles Oryzaephilus surinamensis and Tribolium castaneum, the mites, Acarus siro and Tyrophagus putrescentiae (Collins and Kitchingman, 2010).

In principle, Ultraviolet C (UVC) radiation may provide an effective means of combating pest infestations associated with the structure of a building and may serve as a potential new hygiene measure. UVC is short wavelength (100-280 nm) radiation and is primarily used for the disinfection of air, surfaces and liquids from microbial contaminants. The UV destroys the DNA of bacteria and other microbial contaminants, thereby preventing further replication and growth. The use of UVC radiation as a method of pest control has not been extensively investigated due to the perceived risks to human health and the lack of penetration through substrates.

The efficacy of UVC has been previously demonstrated against house dust mites and some stored product beetle and mite pests (Needham et al., 2006; Faruki et al., 2007) with sensitivity varying with species and life stage. It is, however, difficult to make direct comparisons between studies as the level of UV dose achieved is not always stated and UV intensities vary with light sources. Sensitivity to UVC is determined by the transmittance of surface membranes and the presence of sensitive substrate. An increased sensitivity has been demonstrated in the eggs of stored product moths and beetles (Calderon et al., 1985), with moth eggs less sensitive than beetle eggs (Faruki et al., 2007).

## Low Temperature or Freezing

Freezing has also proven to be effective for beans against cowpea weevil, Callosobruchus maculatus (Johnson and Valero, 2003). Freezing at 15°C for at least 48 h has also been reported to be effective in the control of Indian meal moth in dried fruits and nuts where diapausing larvae are potentially present (Johnson et al., 2007). Application of low temperatures to control stored product insects also is one of the physical control methods that affects by reduction of development rate in pest population, decrease feeding and fecundity by reduction in life cycle.

Temperatures between 25 and 15ºC results in fewer eggs laid, slower development, less movement and longer life spans. For most insects, 20°C is the limit at which they can complete development (Table 1) (Fields, 1992). Sitophilus granarius (L.) is an exception to this general rule, as it can complete its development at 15°C. Mites, such as Acarus siro L can develop at 7°C. It is well known that lower temperature lowers the rate of development. For example, at 18.2°C Sitophilus oryzae (L.) takes 15 weeks to complete a generation, a female will lay 4 eggs/week and will give rise to 4 females in 10 week. Whereas at 29°C, it will take 4 weeks to go from egg to adult and a female will lay 344 eggs and will give rise to 2,110 females in 10 week. Chilled aeration has been used in a limited way for many years in Australia, Europe and more recently the USA (Rulon et al., 1999).

**Table 1.Response of Stored-Product Insect Pests to Temperature (adapted from Fields, 1992)**

| Zone | Temperature(°C) | Results |
|---|---|---|
| Lethal | Above 62 | Death in <1 min |
| | 50 to 62 | death in <1 h |
| | 45 to 50 | death in <1 day |
| | 35 to 42 | Populations die out, mobile insects seek cooler environment |
| | 35 | Maximum temperature for reproduction |
| Suboptimum | 32 to 35 | Slow population increase |
| Optimum | 25 to 32 | Maximum rate of population increase |
| Suboptimum | 13 to 25 | Slow population increase |
| | 13-20 | Development stops |
| Lethal | 5 to 13 | Slowly lethal |
| | 1-5 | Movement ceases |
| | -10 to -5 | Death in weeks, or months if acclimated |
| | -25 to -15 | Death in <1 h |

Obviously the lower the temperature, the faster the insects die. The shape of the curve is usually a "J" shaped (Figure 1). The supercooling of stored-product insects varies between -22°C for the larvae of Ephestia kuehniella (Zeller) or a high of -8°C for the larvae of Tenbrio molitor (L.) (Fields, 1992). At temperatures below the development threshold, insects will eventually die. The length of time this takes depends on many factors; temperature, insect species, life stage, moisture content of the grain and acclimation to cold. There are several good reviews covering the effects of temperature on stored-product insects (Fields and Muir, 1995; Mason and Strail, 1998; Burks et al., 2000). Therefore, there is a great advantage to lowering the grain temperature below the optimal temperature for growth as soon as possible after harvest.

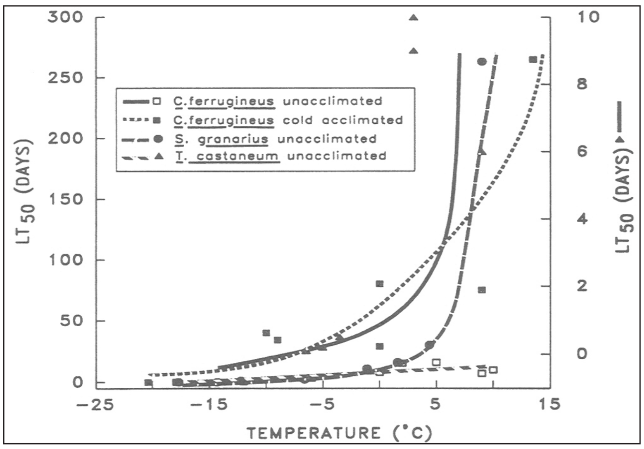


**Figure 1.The Lethal Time for 50 % of the Population for Some Stored Product Insects at Temperature below their Development Threshold (from Fields, 1992).**

## Microwave and Radio Frequency

Microwave is a type of electromagnetic energy that provides rapid heating (Karabulut and Baykal, 2002). When the material with water molecules is subjected to microwave radiation that rapidly changes direction, the water molecules rotate into alignment with the direction of electrical field. The water molecules friction produces the internal heat of the material (Halverson et al., 1998). The microwave radiation has lower frequency than X and gamma rays, which does not cause any damage to food products (Johnson, 1998). However, in low electric field intensity, it can enhance food products to a high temperature in a short time, which may be lethal to the insect. Additionally, microwave radiation is effective by a disorder in structure and function of nervous cells, coagulation of protein in different tissues, abnormal development within both cephalic and thoracic appendages in larval and pupa stages, decreased reproduction rate in adults, reduction body weight, prevention metamorphosis and sterility of males (Neven, 1994; Nelson, 1996).

Microwave and radio frequency are more rapid methods of heating horticultural commodities (Wang and Tang, 2001; Neven and Rehfield, 1995). Microwave has been successful for treating logs (Nzokou et al., 2008), rice (Zhao et al., 2007), and stored products (Shayesteh and Barthakur, 1996). Radio frequency treatments have been very successful in treating dried fruits and nuts (Wang et al., 2007). The advantage of microwave and radio frequency treatments is that they can be performed on a large scale and in flow-through systems, and treatment times can be very short, normally in the span of a few minutes.

Microwave radiation has specific advantages including:

(a) the control of all developmental stages of storage pests, (b) short time for an effective control, (c) having no side hazardous effects on storage products and (d) creation susceptibility of treated insect to the type of stress such as controlled atmosphere and cold (Halverson et al., 1998; Wang and Tang, 2001). Therefore, thermal treatment methods involve, microwave radiation have been investigated as an alternative to chemical fumigation (Karabulut and Baykal, 2002).

Microwave radiation can be used in combination with low temperature for controlling of stored product pests (Ikediala et al., 2000).

## Controlled Atmospheres

Controlled Atmosphere (CA) or Modified Atmosphere (MA) means the alteration of the levels of atmospheric gases beyond those levels found at standard temperature and pressure (Neven, 2010). Most CA treatments are conducted at low temperatures because the low oxygen, elevated carbon dioxide levels slow fruit metabolism and allow for longer cold storage without increasing chilling damage (Kader and Ke, 1994). For the most part, low temperature CA is effective against arthropods because it allows the commodity to be stored at low temperatures for a prolonged period, and the arthropod incurs chilling mortality. The low temperature suppresses insect respiration, the CA does not have as much of an effect on insect mortality. However, ultra low $O_2$ treatments or very high $CO_2$ treatments at low temperature have been shown to be more effective at low temperatures (Neven et al., 2009).

## Ozone Fumigation

Ozone ($O_3$) is an allotrope of oxygen, which can be generated by UV-light and electrical discharges in air. Ozone has a half-life of 20-50 min., rapidly decomposing to diatomic oxygen, a natural component in the atmosphere. It offers several safety advantages over conventional post harvest pesticides. There are no stores of toxic chemicals, chemical mixing hazards or disposal of left over insecticides or containers (Law and Kiss, 1991). Ozone, a known sterilant, can be used as an insect control agent in food commodities at levels less than 45 ppm (Abd El-Aziz, 2011).

Active research is going on to exploit ozone as a potential quarantine treatment for controlling stored product pests (Hollingsworth and Armstrong, 2005).

Ozone can be generated and used to kill insects, although it reacts with caulking in bins and may bleach grain. Ozone also lowers levels of microflora on seed. It is suggested for use in railcars at low temperatures and low humidity (McClurkin and Maier, 2010). It is also effective in killing insects at 1800 ppm for 120 minutes and can be applied in specially modified augers (McDonough et al., 2010).

## Elevated Temperature

The use of elevated temperatures or heat treatments for managing stored-product insects associated with food-processing facilities and museums is becoming popular as an alternative method (Fields, 1992). Heat treatment of structures involves raising the ambient temperature of food-processing facilities to between 50 and 60$^{o}$C, and holding these temperatures for at least 24 h (Roesli et al., 2003). Although heat treatment of structures has been known since the early 1900s very little quantitative data have been collected on the temperature time mortality relationships of stored-product insects associated with food-processing facilities. An understanding of temperature time mortality relationship of insects is important for determining minimum temperature time combinations for killing 99 or 99.9% of a species.

It has been recognised as nonchemical tactics that were environmentally benign for controlling stored-product insects and mites (Hallman and Denlinger, 1999). Stored product insect pests, unlike most other insect pests, live in an environment that can be physically manipulated by humans. Therefore, temperature manipulation of stored-product habitats can slow the increase in populations or eliminate them completely (Fields, 1992).

## Novel Treatments

There are a number of treatments that are being developed that do not fall into any generalised category. These include high pressure washing and surface vacuum to remove surface pests (Neven et al., 2006), high hydrostatic pressures (Neven et al., 2009), metabolic stress disinfection and disinfestation (MSDD) (Lagunas et al., 2008), plasma discharge (Donohue and Bures, 2008), and pulsed electronic fields (Hallman and Zhang, 1997). None of these treatments have been approved for applications further research is needed.

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