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Vacuum Hermetic Fumigation: A review

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ABSTRACT

Methyl Bromide and Phosphine are the most widely used chemical fumigants for insect control in stored grains. Ozone depletion, insect resistance, and residues on grain surface are the problems with the use of chemical fumigants. Zero tolerance for chemical residues under the international trade agreements require alternative solutions for safe and durable storage. Controlled atmosphere (CA)/modified atmosphere storage (MAS), temperature manipulation, hermetic storage, pressure manipulation (hyperbaric and hypobaric), safe fumigants of botanical derivatives and combination of these technologies have been practiced. Each method had certain merits and limitations restricting direct replacement for the existing chemical methods. This review explores chemical disinfection and physical methods with special emphasis on vacuum hermetic fumigation (VH-F). Modern hermetic storage systems utilize ultra-low oxygen and water permeability materials for storage of grains. Depletion of oxygen in the storage systems naturally or through the application of negative pressure (50–100 mm Hg) causes slower metabolic rate and finally cessation of basic metabolism and death of insects in a few days (up to 7 days). The efficacy of VH-F on the lethality of insects depends on vacuum level, stage and type of insects, temperature, CO_2 level and exposure time. Suitability of vacuum hermetic storage systems for various agricultural produces as an alternative to chemical fumigation and the future scope of vacuum hermetic fumigation system are discussed.

Contents

1. Introduction

The world's population has already surmounted to 7 billion and it is expected to reach 8.1 billion in 2025, and 9.6 billion in 2050 (UN, 2014). Depleting and limited resources have drawn the attention of researchers to move towards sustainable and precision agriculture, which aims for higher production with minimum utilization of resources to overcome the global threat of food security in the future (Lipinski et al., 2013; Mohapatra et al., 2015). Food production, distribution, and consumption are a series of events, which together forms a post-harvest system. In this whole series, an unfortunate attribute is associated, that is wastage of large amount of food grains both in field and during storage (Kiaya, 2014). In developing countries, about 10–15% of the total

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production is lost during harvesting, threshing, transport, storage and processing (Neethirajan et al., 2007). Lack of proper storage structure, pest damage during transport, improper handling and unscientific unit operations before reaching to consumers are the major reasons for food losses (Somavat et al., 2014). A survey conducted all over India, reveals that about 4.65–5.99% post-harvest losses of cereals (wheat, paddy, maize, pearl millet and sorghum) occur during various unit operations. In India, storage losses for cereals was 0.75–1.21%, whereas the losses in pulses and oilseeds were observed to be in between 6.36-8.41% and 3.08–9.96%, respectively (Jha et al., 2015).

In the past decades, major focus and investment were allocated to increase food production. 95% of the research expenditure of developing countries was invested in increasing the food productivity and rest in reducing the post-harvest losses (Kader, 2005). The stored product insects and pests are a global problem. Storage pests create both qualitative and quantitative losses in stored agricultural commodities (Neethirajan et al., 2007; Sharon et al., 2014). Losses could be classified as direct and indirect losses. The presence of open or concealed live and dead insects, their droppings and fragments are direct losses; whereas allergens, microorganisms, low market value and parasites transfer to human are categorized as indirect losses (Sahay and Singh, 2004).

Two fumigants, Methyl bromide (MB) and phosphine (PH_3) are globally used for disinfection in food grains storage. Methyl Bromide is a significant ozone depleting substance (ODS). Under Montreal Protocol, 2002, the use and production of methyl bromide was discontinued in developed countries by the year 2005 and worldwide by 2015 (UNEP, 2002). Continuous and discriminate use of phosphine has resulted in the evolution of chemical resistance in insects. Widespread experience has proven that repeated use of the single slow acting chemical in poorly sealed warehouses leads to develop strong resistance by the insects (Simmonds, 1989; Cao et al., 2003; Ahmad et al., 2013; Chadda, 2016). It diverted the focus of research towards development of residue free, organic and environment benign alternative technologies to protect stored produces (Simmonds, 1989; Darby and Caddick, 2007; Navarro, 2012; Kucerova et al., 2013).

Physical measures are safer alternatives as it can be applied directly to stored food. Although a large number of potential alternative methods have been suggested; limitations of each prevent direct replacement of the chemical fumigants. The non-chemical alternatives in use today are not new technologies but it requires adequate monitoring and verification to ensure that treatment's efficacy and proper application (Dowdy, 2002). These methods include controlled atmosphere (CA)/modified atmosphere storage (MAS), hermetic storage, pressure manipulation, temperature manipulation, irradiation, microwave/Radiofrequency treatment, application of inert dust, and combinations of these technologies as hurdles to insect and pest (Das et al., 2013; Finkelman et al., 2004a,b,c; Kucerova et al., 2013; Mohapatra et al., 2015; Navarro, 2006; Subramanyam et al., 2011). The merits and demerits of most physical methods for insect control of stored food grains are listed in Table 1.

The feasibility of using vacuum for safe post-harvest storage was first investigated by Back and cotton, (1925), Bare (1948) and later on by Calderon et al. (1966). Evolution of technologies enables to maintain low pressure in flexible plastic liner in place of massive and rigid vacuum chambers using a vacuum pump that started the abandoned work of vacuum storage of durable commodities (Finkelman et al., 2004a; Navarro et al., 2001, 2002a,b; Rindner et al., 2002). Consequently, a new term was originated for the sealed vacuum flexible container as Vacuum Hermetic Fumigation (VH-F), which is used for low-pressure storage of non-crushable agricultural produces in flexible bags (Finkelman et al., 2004c). Since the review of VH-F is not available so far, this paper is an attempt to archive the research findings.

The interstitial gas composition of a storage structure has dramatic effect on biotic components in a grain ecosystem. Insects, mold, grain, and microorganisms are aerobes, need oxygen for respiration. The biological activities help in depleting oxygen and generate a lethal high carbon dioxide (3–10%) atmosphere for insects (Abalone et al., 2011; Bartosik, 2012; Murdock et al., 2012; Subramanyam et al., 2012). The successful application of lethal atmosphere within a gastight container was used as commercial control tactic for insect infestation in many countries. Gas tightness has paramount importance for successful storage, so this technique was named as hermetic storage. Lack of gas tightness was a global challenge before the development of flexible plastic containers with zipper for hermetic storage. Adequate sealing in plastic containers is comparatively easy than rigid containers. Insect penetration, surface area/volume ratio, cost of sealing and permeability of plastic liner are bottlenecks in rendering the hermetic technology (Navarro, 2012).

2. Hermetic storage

Successful storage is the placement of food grains in suitably sized containers which endowed protection from pests, insects, microbial and physical contamination as well as maintaining the nutritional and processing quality. Generation of modified atmospheres (MAs) inside hermetic bags thorough vacuum, inert gasses and respiration of commodity, have successfully replaced the use of fumigants for quality preservation and insect control of stored materials (Villers et al., 2008; Bartosik, 2012). There are three manners to use hermetic technology viz. Organic storage, Gas Hermetic Fumigation (G-HF) and Vacuum Hermetic Fumigation (V-HF). Organic storage is a simple passive modified atmosphere storage technique, which developed the carbon dioxide enriched environment after a particular time. In G-HF and V-HF, the interstitial atmosphere is replaced by an inert gas (Carbon dioxide; Nitrogen) and vacuum respectively (Villers et al., 2006). Commercially, these terms are used by the USA based GrainPro® named company for their various solutions for hermetic storage. Ultimately the goal of all three manners to develop oxygen deficient (1–2%) ecosystem detrimental to insect and mold growth (Navarro et al., 2003; Villers et al., 2006; Jonfia-Essien et al., 2010). The oxygen concentration depends on insects, infestation level, type, and size of the storage system, stored commodity, the moisture content of commodity, environmental factors etc. It was reduced from 21% to less than 10% within a short period of time. Oxygen levels <10% curtailed the insect growth and germination of seed was above 85% for a period of up to 9 months, whereas non-chemical conventional storage in jute bags reduced germination down to 14% within 3 months (Villers et al., 2008; Bartosik, 2012). For bio-friendly and effective storage in tropical regions, sealed hermetic flexible silo bags are the efficacious solution for preserving moisture content without significant insect proliferation in stored grain (Anankware et al., 2012; Somavat et al., 2014). It is also known as "sealed storage" or "airtight storage" or "sacrificial sealed storage" or "hermetic silo storage" or "harvest bag" or "grain sausage" (Jonfia-Essien et al., 2010). These are available as small portable containers (60 kg to one ton) to large flexible storage structure (five tons to 30,000 tons capacity) (Villers et al., 2008). Storage systems based on the hermetic principle include the following: Bunker storage for conservation of large bulks (10,000–15,000 tons); storage cubes or "Cocoons™" (five to 1000 tons capacity); Silo Bags (200 tons capacity) for on-farm storage and small portable hermetic containers (25 kg–2.5 tons), called "Super Grainbags™", which are suitable for bagged and bulk