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Vacuum hermetic fumigation for food grains storage

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ABSTRACT

Deregistration of chemical fumigants in stored agricultural produce makes it urgent to find alternative solutions for the safe and durable storage. The ozone layer depletion and developing chemical resistance in pest due to continuous application of methyl bromide (MB) and phosphine (PH_3), respectively, are the major reasons of phasing out of chemical methods. To overcome this global problem, a large number of potential alternative methods have been suggested but limitations prevent direct replacement. These methods include controlled atmosphere (CA), modified atmosphere storage (MAS), temperature manipulation, hermetic storage, pressure manipulation (hyperbaric and hypobaric) and combination of these technologies as hurdles to pest. The previous research proved that hermetic storage of agriculture produce in flexible bag could be an attractive non-chemical and environment benign technology. It can be used in three manners, i.e. organic storage, fumigation with inert gas and vacuum hermetic fumigation (VHF). The vacuum of 50 ± 10 mm Hg was developed inside the hermetic bag which was maintained to this limit using periodic use of rotary vane vacuum pump. Research evidences proved that egg stages were the most resistant stage in insects which take 46 h in *Trogoderma granarium* (Everts) for LT_{99} on 55% r.h. and 30°C interstitial condition. The lethal time for LT_{99} in all stages of insects (i.e. egg, larva, pupa and adult) increases with the reduction in temperature up to a certain limit. The advantages of this approach of vacuum fumigation in flexible bags involve no toxic chemical and short exposure time to LT_{99} in comparison to phosphine in same conditions.

Key words: Food protection, Fumigation, Hermetic, Low pressure storage, Non-chemical insect control, Vacuum, VH-F

Rapid population growth is one of the major global issues. It is expected to reach 8.1 billion in 2025 and 9.6 billion in 2050 (UN Report, 2015). The depleting and limited resources had diverted the research towards the food safety in future. Storage is the major unit operation in the food chain from farmer to consumer table. It is important to store the food in such an environment which plays as safeguard against biotic and abiotic components responsible for the post-harvest losses (Somavat et al., 2014). A survey conducted all over India, reveals that about 2.8–4.7% post-harvest losses of cereals (wheat, paddy, maize, pearl millet and sorghum) occur during various unit operations (Nanda et al., 2012). In addition, to improve the efficiency of the storage some chemical fumigants have to be used. Globally, methyl bromide and phosphine are the major fumigants used in the grains storage. Methyl bromide is an ozone depleting substance (ODS); continuous use of phosphine has developed chemical resistance in the insects (Ahmad et al., 2013). In the era of information technology, the consumer is well aware and demands for the residue free and organic food. Consumer resistance against the use of chemical fumigants in stored products and international trade treaties increase the focus to find green and residue free technology. A number of technologies in combinations or alone has been tested or are under testing for the organic storage of food. 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; each have certain merits and limitations restricting direct replacement for the existing chemical methods (Kucerova et al., 2013). The previous research has proved that hermetic storage of agriculture produce

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Table 1. Atmospheric pressure and their equivalent partial pressure of oxygen expressed in mm Hg and in percentage

Vacuum, mm Hg	760	600	500	400	300	200	100	50
Oxygen, mm Hg	159	125	105	84	63	42	21	11
Oxygen, %	20.9	16.5	13.8	11.0	8.3	5.5	2.8	1.4

Source: Finkelman et al. (2004)

in flexible bag could be an attractive non-chemical and environment benign technology. It can be used in three manners, i.e. organic storage, fumigation with inert gas and vacuum hermetic fumigation (Navarro et al., 2012).

Earlier vacuum hermetic fumigation was abandoned due to unavailability of flexible container for the maintenance of negative pressure. Evolution of technologies enabled to maintain vacuum inside the flexible structure using the vacuum pump periodically (Finkelman et al., 2003). The maintenance of vacuum below 100 mm of Hg helps preserve the quality and quantity of the non-crushable commodities. This ensures 99% mortality of the insects and pests in storage ecosystem (Finkelman et al., 2002). This technology is used for quarantine purpose in infested grains as well as prevention of insect proliferation. In this review, suitability of vacuum hermetic fumigation for storage of grains and future prospects are discussed briefly.

VACUUM HERMETIC FUMIGATION

Vacuum is maintained in the three-layer ultra-low permeability PVC based, sealed, flexible and mobile innovative storage system, equipped with an airtight zipper (Navarro et al., 2001). Using flexible bags, it was practical to maintain sufficiently low pressures (below 100 mm Hg absolute pressure) necessary for 99% insect mortality (LT_{99}) using a commercial vacuum pump (Navarro et al., 2001). Rotary-vane, oil lubricated vacuum pump with oil type filter should be used to avoid the problem of corrosive outgassing of vapours from stored commodity. Commercially, these flexible bags are now available in international and national market as 'VolcaniCubes^{TM}', 'GrainProCocoons^{TM}', MegaCocoons^{TM} or TranSafeliner^{TM} for small and large scale storage (Navarro et al., 2001; Jonfia – Essien et al., 2010). There is a provision of one directional valve and a quick release hose at the base or bottom of bag used to connect vacuum pump with 1.5" pipes. The non-crushable commodities can be stored in bulk or stack of bags on pallets inside the structure. The bag shrinks over the material under vacuum and shaped as stored material (Finkelman et al., 2004). Several studies showed that VH-F has potential of being used for quarantine and pre-shipment (QPS) treatments as a safe alternative to MB with similar exposure time for insect control (Finkelman et al., 2002).

Under vacuum, insect control was caused by the low partial pressure of oxygen in storage ecosystem (Table 1), resulting in hypoxia and also dehydration due to removal of water vapour (Adler et al., 2000). Research evidences proved no significant role of the vacuum itself in insect control (Finkelman et al., 2004).

INSECT CONTROL IN VACUUM HERMETIC FUMIGATION

Finkelman et al. (2002) observed that all life stages of *Ephestia cautella* (Walker) and *Tribolium castaneum* (Herbst) were controlled in the infested cocoa beans (*Theobroma cocoa* L.) stored under 55 ± 10 mm Hg at 30°C and 55 ± 3% r.h. The lethal time needed to obtain 99% mortality (LT_{99}) for all life stages of insect varied between 8 and 96.3 h, for at storage temperature of 18º and 30°C (Table 2). The result also revealed that the egg stage of both the species was the most resistant stage at both 18°C and 30°C temperature. The time for LT_{99} was reduced to about one-third on increasing the temperature from 18º to 30°C.

Finkelman et al. (2002) conducted a field trial with 15 m^3 capacity of Volcani Cube^{TM} for cocoa beans infested with *E. cautella* and *T. castaneum.*

Table 2. The effect of 55±10 mm Hg at 18/30°C and 55 ± 3% r.h. on all stages of *Ephestia cautella* and *Tribolium castaneum*

Development stages	LT_{99} at 18°C, h		LT_{99} at 30°C, h	
	T. castaneum	*E. cautella*	*T. castaneum*	*E. cautella*
Egg	96.3	148.8	53.0	40.7
Larva	36.8	43.6	<28.0	<28.0
Pupa	71.8	26.2	<38.0	<8.0
Adult	29.9	76.7	<28.0	<10.0

Source: Finkelman et al. (2002)

Table 3 Influence of carbon dioxide concentrations on LT_{99} of *Trogoderma granarium* larvae at three different temperatures with 25–29 mm Hg

Temperature, °C	CO_2 concentration, %			
	60	70	80	90
30	38	29	-	29
40	24	28	20	-
45	15	17	15	10

Source: Navarro et al. (2002)

Pressure maintained at 23–75 mm Hg resulted complete mortality in three days' exposure at 28.0 ± 0.5°C and 65% r.h. inside the cube. In another study by Finkelman et al. (2004), the effect of 50 ± 5 mm Hg at 30°C and a r.h. of 55% on six important stored-product pests: *Trogoderma granarium* (Everts)*, Lasioderma serricorne* (Fabricius)*, Oryzaephilus surinamensis* (L.)*, T. castaneum, E. cautella* and *Plodia interpunctella* (Hübner) revealed that lethal time is different for different insects and the exposure times needed to obtain $LT_{99}$was 46 h, 91 h, 32 h, 22 h, 45 h, and 49 h respectively. Additional results proved that egg was the most resistant stage in all species of insects at lower temperatures or at higher relative humidity. Low temperature or high humidity prolonged the exposure times needed to achieve 99% mortality in insect. Navarro et al. (2002) investigated the combination of various treatments of CO_2, and temperature along with vacuum to increase the effectiveness of disinfestation and concluded that by increasing CO_2 concentration, the effectiveness decreased (Table 3). As the CO_2 concentration increased from 60% to 90%, LT_{99} time decreased to about 10 h at 45°C, whereas at 35ºC the LT_{99} value was 29 h. For *E. cautella* and *O. surinamensis* under the same conditions, the LT_{99} values were 3 h and 9 h for the most resistant pupae and egg non-mobile stages respectively. The LT_{99} value for *L. serricorne* adults exposed to low pressures (25 mm Hg) at 30ºC was 15 h, and in case of *T. granarium* larvae it was 172 h. Sensitivity of the most resistant stage of the most resistant insect species determined the treatment or exposure time to low pressure (Navarro et al., 2002).

In a similar work, Kucerova et al. (2013) found that there were significant differences in the susceptibility to low pressure (vacuum) between the adult stages of *Tribolium castaneum* and *S. granarius* insects. *T. castaneum* was approximately 10 times more susceptible to low pressure than *S. granarius*. The lethal exposure times (LT_{99}) for adult *T. castaneum* were 15.1 h at 25°C and 30.8 h at 15°C. In case of adult *S. granarius,* values of LT_{99} were 160.1 h at 25°C and 274 h at 15°C. A higher temperature under a constant vacuum (1 kPa) significantly shortened the exposure time (LT_{99}) necessary to reach 100% mortality in the tested beetles (Kucerova et al., 2013). The eggs of *E. cautella, P. interpunctella, Rhyzopertha dominica,* and *T. castaneum* were exposed to pressures of 50, 75, 100, 200 and 300 mm Hg at 5, 15, 22.5, 30, and 37.5ºC, respectively, for times ranging from 12 to 168 h in a glass chamber. In all four species, the mortality of eggs increased with the increasing exposure time and temperature. Low temperatures and high pressures were observed to be least effective for killing eggs in comparison with high temperatures and low pressures combinations in all species investigated (Mbata et al., 2004). In a similar laboratory experiment by Mbata and Philips (2001), on eggs, larvae and pupae of *T. castaneum, P. interpunctella* and *R. dominica* at 32.5 mm Hg at 25, 33, 37 and 40°C for times ranging from 30 min to 144 h in rigid glass chambers. Pupae stages of *T. castaneum* and *R. dominica* were more tolerant to vacuum than larvae. Higher temperatures and low pressure resulted in further significant reduction in lethal time values.

CONCLUSION

The concept of using vacuum hermetic storage was proved effective in prevention and disinfestations of infestation in stored commodity. Exposure time for complete mortality of insects was less in comparison to phosphine fumigation for same quantity. It is a residue free, safe for storage workers and non-target organisms, environment benign and portable vacuum storage technology. VH-F has potential to replace existing toxic fumigants with high level of consumer acceptance and satisfaction. The vacuum of below 100 mm Hg was to be maintained inside bag using rotary vane vacuum pump. Research on combinations of CO_2, pressure and temperature showed 99% insect control with minimum exposure time. High level of carbon dioxide and lower temperature decreased the exposure time. Egg stages of insects were the most resistant stage. It is adopted in more than 40 countries and possibly to expand even more rapidly in the future.

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