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The use of portable systems to control insect pests by low pressures

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Abstract: The possibilities of using low pressure as a method to control insects have long been suggested and studied. Until now the ability to implement the full potential of this method has been limited, but in recent years flexible mobile chambers made of welded PVC liners have been introduced. Under vacuum, these chambers shrink over the periphery of the commodity and hold it fast. The system is sealed by an air-tight zipper and is able to retain a vacuum or different compositions of modified atmospheres. At the base of the chamber, an inlet and hosing enable connection to a vacuum pump that maintains the prerequisite low pressure. Previous laboratory studies have revealed the effect of 50 ± 5 mm Hg on six important stored-product pests: *Trogoderma granarium* (Everts), *Lasioderma serricorne* (F.), *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Herbst) *Ephestia cautella* (Walker), and *Plodia interpunctella* (Hübner). At 30°C and a relative humidity of 55% the egg is the most resistant stage in all species, the times needed to obtain 99% mortality being 46 h, 91 h, 32 h, 22 h, 45 h, and 49 h respectively. Additional results indicated that at lower temperatures or at higher relative humidities, the times needed to achieve mortality were prolonged. Three parameters are most important in the determination of treatment time required for a given commodity. To control all pests, the range of insect species likely to infest the specific commodity must be drawn up. Treatment time must be based on the sensitivity of the most resistant stage of the most resistant species in this list, which is obtained from knowledge of previous infestations. However, no less important are temperature and the relative humidity in the chamber, both these parameters being determined by the condition of the commodity. Consequently, it is the temperature and moisture content of the commodity, and its insect fauna that determine the duration of treatment. To demonstrate this principle, a range of commodities containing natural and artificial infestations was subjected to low pressure for 5 days exposure, under ambient conditions (Mediterranean summer climatic) and 100% mortality was recorded in all cases. In conclusion, the use of low pressure is now a promising option for insect control in stored commodities without the requirement of potentially harmful chemicals.

Key Words: vacuum, flexible treatment chambers, stored-products, insects

Introduction

The use of low pressures to control insects in post-harvest storage has been studies by Back and Cotton (1925), Bare (1948), and Calderon et al. (1966). It was shown that mortality is caused mainly by the low partial pressure of oxygen that results in hypoxia (Adler et al., 2000; Navarro and Calderon, 1979) and also dehydration due to removal of water vapor under vacuum (Jay et al., 1971; Navarro, 1978).

Several studies were conducted on the effect of low pressures on the mortality of storage insects under various trial regimes (Calderon et al. 1966; Finkelman et al. 2003a), but in order to compare sensitivities under uniform treatment conditions and make these findings available for use by commercial companies we have studied the effect of 50 ± 5 mm Hg on six important stored-product pests: *Trogoderma granarium* (Everts), *Lasioderma serricorne* (F.), *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Herbst) *Ephestia cautella* (Walker), and *Plodia interpunctella* (Hübner) at 30°C and relative humidity of 55%. The egg was found

to be the most resistant stage in all species, the times needed to obtain 99% mortality being 46 h, 91 h, 32 h, 22 h, 45 h, and 49 h respectively (Finkelman et al. 2004a, b).

However, it should be emphasized that all the above experiments were carried out under laboratory conditions.

In the past, the possibility of using low pressures at the large scale commercial level was abandoned due to the requirements for massive, rigid and expensive structures needed to withstand the low-pressures.

Recently a new and innovative technology was introduced for the hermetic storage of durable commodities, and is now in use on an industrial scale (Navarro *et al.,* 1988; 1990; 1994; Silberstein *et al.,* 1998). The structures consist of flexible plastic chambers with manufacture specifications to a level of gas tightness that also enables treatments with modified atmospheres or fumigants without significant gas loss over short exposure times (Navarro *et al.,* 1995). The structures are termed "GrainPro Cocoons™".

In order to adapt this storage system to the application of low-pressure conditions it was necessary to develop an initial commercial product and find solutions to the problematic of air extraction, leak sealing and commodity loading. It was suspected from the outset that certain commodities, when treated with prolonged vacuum, could present a potential problem because they release corrosive out-gassing of vapors liable to contaminate the oils used in most commercially available vacuum pumps. Accordingly, it was found necessary to select and apply oil type filter/pump configurations that would most economically meet the parameters identified for the successful operation of the system. Navarro et al. (2001) was the first to report on a trial set up with an experimental prototype that was conducted in 1999 in Foxboro MA, USA for treatment of cocoa bean pests, and later in Israel (Navarro at el. 2001). Later, Finkelman et al. (2002, 2003b) reported on additional experimental work conducted in Israel and Ivory Coast. In these later trial 15 m^3 capacity cube was used with pressure maintained between 23 to 75 mm Hg for three days and five sets of bioassay tubes were inserted. Again, complete mortality of test insects (All developmental stages of *E. cautella* and *T. castaneum*.) was observed after the 3-days exposure to vacuum. Until the study report on here, the commodity used was cocoa beans due to the high added value of this commodity and support from the industry. However, the potential of vacuum for insect control in durable stored products is not limited to the chocolate industry, and the paper reports on its application to a wide range of commodities.

Materials and methods

Previously established data

Several laboratory studies undertaken on the effect of 50 mm Hg on different stored product insects at different temperatures have been published (Finkelman el al. 2002; 2003b) and Table 1 is a partial summary of previous findings. These findings were used to plan and execute a series of semi-commercial field trials, where to determine exposure time, the following three parameters were taken into consideration:

- *Insect species present.* To control all pests, the range of insect species likely to infest the specific commodity must be drawn up.
- *Sensitivities of species and instars:* Treatment time must be based on the sensitivity of the most resistant stage of the most resistant species in this list.
- *Temperature and moisture content of the commodity:* These abiotic micro-environmental conditions also influence the rate at which mortality takes place under low pressure.

Field trials

The field trials were conducted during 2001 at different food manufacturing factories in Israel. Both vacuum cubes of 7.5 m^3 and V-HF (Vacuum-Hermetic Fumigation) cubes of 34 m^3 capacity, adapted to facilitate low pressure, were used. The low pressure in the cubes was established using a rotary-vane, oil-lubricated vacuum pump (3 hp Becker model U 4.70, Germany) to within the range of 23 and 75 mm Hg for a duration of 5 days. A variety of durable commodities was used as shown in Table 3.

Table 1. The effect of 50 mm Hg on egg mortality at 55% r. h. and 30°C.

Test insects	**LT_{99} values (hours to obtain 99% mortality)**
Trogoderma granarium	46 h
Lasioderma serricorne	91 h
Oryzaephilus surinamensis	32 h
Tribolium castaneum	22 h
Ephestia cautella	45 h
Plodia interpunctella	49 h

As mentioned above, mortality under low pressure is dependent upon the partial pressure of oxygen available for insect respiration. Table 2 indicates the relationship between these two variables.

Table 2. Units used to express atmospheric pressure and their equivalent partial pressure of oxygen expressed in mm Hg and in percentage.

mm Hg (torr)	atmosphere	kg/cm^2	inches Hg	kPa	mbar	**mm Hg Oxygen**	% Oxygen
760	1.00	1.03	29.92	101,325	1,013	159	20.9
600	0.79	0.82	23.62	79,993	800	125	16.5
500	0.66	0.68	19.68	66,661	667	105	13.8
400	0.53	0.54	15.75	53,329	533	84	11.0
300	0.39	0.41	11.81	39,997	400	63	8.3
200	0.26	0.27	7.87	26,664	267	42	5.5
100	0.13	0.14	3.94	13,332	133	21	2.8
50	**0.07**	**0.07**	**1.97**	**6,666**	**67**	**11**	**1.4**
0	0.00	0.00	0.0	0	0	0	0.0

The vacuum cube system

In order to adapt the standard cubes to low pressure use, a quick-release hose and one-directional valve were incorporated. In addition, the system was connected to the pump using flexible 1.5"connecting tubes. The system was designed to be modular enabling the user to connect several cubes to the same vacuum pump, or to disconnect one of the cubes without changing the pressure in the other connected cubes.

The V-HF system

A specially constructed V-HF module of 5.5 m long, 2.6 m wide and 2.4 m high was used to accommodate pallets containing the commodities. The V-HF module consisted of two sections; the upper section that was destined to cover 1.4 m from the top and the bottom

Fig. 1. The Vacuum cube system.

Fig. 2. The V-HF (Vacuum-Hermetic Fumigation) system.

section that had a wall of 1 m high. The commodities were loaded over the bottom section of the module on pallets using a forklift. Then, the top and the bottom sections were zipped together to obtain a sealed structure. At start of the trial, a slight vacuum of 100 Pa was applied to adhere the V-HF liner to the bagged commodities, thus minimizing the free space within the V-HF system. Data loggers to measure temperature and air relative humidity were also placed in each trial on top and bottom of inside the V-HF module.

Bioassay

Five sets of bioassay replicates were placed in each of cubes, each set containing all life stages of either *E. cautella, T. castaneum, O. surinamensis* or *P. interpunctella*. Four of the bioassay sets were located, one on each side of the four cube walls at mid-center height, and one at the top-center. The control bioassay was placed on the top, above the liner of the cube in an open plastic container filled with the commodity being tested. Temperatures at the top and at the f our side faces of the cubes were recorded during the trials using data-loggers (HOBO Pro Series).

Results

The results of the semi commercial trials are given in Table 3. Under the experimental conditions no living insects were found in any of the commodities or test vials after the 5 day exposure period. These trials clearly demonstrate that the use of low pressure is now a promising option for insect control in stored commodities without the requirement of potentially harmful chemicals.

Table 3. Semi-commercial field tests that produced 100% mortality of adult insects under low pressure (23 – 75 mm Hg) for 5 days.

Treated Commodity	Infestation found in the treated commodity	Test insects used in the trials
Oats	*T. castaneum, O. surinamensis*	*E. cautella*
Corn chips	*E. cautella*	*T. castaneum, E. cautella, O. surinamensis,*
Cocoa beans		*E. cautella, O. surinamensis, T. castaneum, P. interpunctella*
Wheat	**S. oryzae, O. surinamensis, T. castaneum*	*O. surinamensis*
Wheat flour	**R. dominica O. surinamensis, T. castaneum*	*T. castaneum, O. surinamensis, E. cautella*
Semolina		*T. castaneum, O. surinamensis, E. cautella*
Almonds		*O. surinamensis, L. serricorne, E. cautella*
Garden peas		**C. chinensis, *S. oryzae, T. castaneum*
Chick peas	**S. oryzae, *C. chinensis, T. castaneum, *R. dominica*	**C. chinensis, * S. oryzae, T. castaneum*
Sunflower seeds		*T. castaneum, L. serricorne , E. cautella*
Semolina		*T. castaneum, O. surinamensis, E. cautella*
Rice	*T. castaneum, *S. oryzae, O. surinamensis*	*O. surinamensis, E. cautella, *S. oryzae*

* *Sitophilus oryzae, Callosobruchus chinensis* and *Rhyzopertha dominica* adults have not yet been subjected to laboratory exposures under 50 mm Hg and at 30ºC.

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