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Effectiveness of Hermetic Storage in Insect Control and Quality Preservation of Cocoa Beans in Ghana

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Abstract: This paper reports the development of hermetic storage in Ghana by highlighting the scientific research conducted using GrainPro Cocoons™ in controlling insects and preserving the quality of cocoa beans as an alternative to chemical treatment. Three stacks for hermetic storage and one stack each for conventional storage (without fumigation) and standard storage (with fumigation) were built for sampling and observation. The Cocoon™ stacks were 3.40m (long) × 2.95m (wide) × 2.0m high and contained 220 bags (64 kg per bag) of sun-dried (average of 7.0% moisture content) cocoa beans. Oxygen concentration and temperature inside the stack of cocoa beans were monitored daily. Sampling was done at 0, 3, 6 and 9 week intervals to observe changes in insect density and product quality characterisation. There was a steep decline in oxygen concentration in all Cocoons™ during the storage with the lowest concentration of 0.0% being recorded in all the Cocoon™ from the fifteenth day of storage, maintained throughout the storage period. The temperature was almost uniform inside the Cocoon™ throughout the storage period. After three weeks of storage, the first Cocoon™ was found to be infested with live adults of *Cryptolestes ferrugineus*, *Cryptolestes pusillus*, *Araecerus fasciculatus*, *Lasioderma serricorne*, and *Ephestia cautella* larvae and some fruit flies. However, these live insects were few compared with the high insect population which was dead inside the Cocoons™. Most of the *Lasioderma serricorne* and *Tribolium castaneum* introduced at the beginning of the experiment were dead at the third week; 100% mortality was recorded for all insects at the sixth week of storage. All the cocoa beans inside the Cocoon™ maintained their quality level throughout the storage period; the grade remained the same after nine weeks of storage as it was at the beginning of the experiment.

Key words: GrainPro Cocoon™, hermetic storage, conventional storage, standard storage, cocoa beans, insect control, *Lasioderma serricorne*, *Tribolium castaneum*

Introduction

The production of organic Cocoa beans has been carried out on a small scale in Ghana since its inception some years ago due to certain problems associated with this production[1]. However great efforts are being made to export dry Cocoa beans to sustain and increase the production levels. Because of the desire to produce insecticide free Cocoa beans, much consideration is being given to storing Cocoa beans without or with minimal use of insecticides. Hence the need to investigate the possibility of adopting hermetic storage practices. Hermetic storage is based on the principle of modified atmosphere and no chemical.

Stored product protection is attained by the use of hermetic sealed containers, one of which is the Cocoon™, which provides an airtight environment[2]. The basic principle of hermetic grain protection lies in the fact that from the moment of sealing until the insects consume the volume of oxygen in the Cocoon™, the damage to the grain is negligible[2]. If the insect population is low, the insects may survive causing minimal damage to the produce since it has been established that to obtain a complete kill, the oxygen tension should drop to two percent (2%) or below[3].

Plastic structures suitable for long-term storage, as well as intermediate grain storage for cooperatives and subsistence farmers, for stored products in bags or in bulk, have been developed in Israel[4]. The influence of insulation materials in reducing the intensity of moisture migration under subtropical (Israel) and tropical (Philippines) climates has been investigated[5]. If the storage ecosystem can be sealed to prevent air from entering or leaving it, the respiratory metabolism of insects, moulds and the

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produce itself will lower the oxygen content and raise the carbon dioxide content of the intergranular atmosphere to a level where aerobic respiration is no longer possible[6]. This is the principle behind hermetic storage. However, although it sounds simple in theory, in practice, it is much more complex.

At present, the conventional and standard storage technologies are employed to preserve cocoa beans. This involves stacking bagged beans on wooden pallets inside the warehouse. The uses of deadly pesticides to combat pests of stored products have increasingly become unpopular because of health concerns and the havoc its indiscriminate use brings to the environment. In the past, traditional storage structures provided some protection against storage losses, particularly by insects and rodents, although annual losses that are estimated to be between 5 to 10 percent were previously considered as unavoidable. Attempts to reduce these losses through the introduction of modern storage technologies have frequently failed either because they were socio-economically unacceptable, or inappropriate to local climatic conditions and agro-technical practices[7]. The approach described in this paper involves the modification of existing structures or the construction of new structures in the conventional style but employing modified technologies to improve grain, seed or bean products conservation without being too disruptive to rural life, a concept termed by Guggenheim (1978) as "invisible" technology[8].

Materials and Methods

Dry cocoa beans that were harvested during the 2007/2008 main crop season used in the trials were mainly of grade I and II category. Cocoa beans were sun dried to an average moisture content of 7.0% after fermentation and then bagged in 64kg capacity jute sacks. Outdoor storage trials of 3, 6 and 9 weeks durations were carried-out in the compound of the Research Department, Quality Control Division (COCOBOD), Tema, Ghana. The method of 'airtight' or 'hermetic storage'[9] of grain quality preservation was followed.

Laboratory Rearing of the Target Insect Pests

The target pests were adult *Cadra cautella* (*Ephestia cautella*), *Araecerus fasciculatus*, *Lasioderma serricorne* and *Tribolium castaneum*. A stock of each species was raised in the laboratory of the Research Department of QCD at an ambient temperature range of 25 – 30℃ and relative humidity of 60% – 75%. *C. cautella* was raised on a mixture of ground maize, wheat bran and glycerol in a ratio of 8∶8∶1 (W/W)[10], *T. castaneum* on crushed dry cocoa beans, *L. serricorne* on a mixture of tobacco and dry cocoa beans and *A. fasciculatus* on cassava chips with moderate to high moisture content[11].

Storage Technologies Observed and Experimental Set-up

The storage technologies studied were hermetic storage (HS), conventional storage (CS), and standard storage (SS). The stacks built for HS to demonstrate the effect of these technologies had a uniform dimension of 3.40m × 2.95m × 2.0m length, width and height (LWH) while stacks built for CS and SS to serve as the reference stacks measured 4.0m × 1.0m × 1.50m LWH.

Hermetic Storage Set up

Three GrainPro Cocoon™ made of flexible Polyvinyl Chloride (PVC) plastic liner with a capacity of 220 bags, were set-up outside the building. Wooden pallets were laid-out on the ground and covered with pieces of plywood and cardboard which served as foundation materials to protect the bags during the set-up. Bagged cocoa beans were directly stacked or piled on the lower section of the Cocoon™ and when the desired height was reached, the stack was covered with the upper section of the Cocoon™. During stacking, 15 bags of cocoa beans were randomly selected and sieved to estimate insect pests present in the cocoa beans.

Ten laboratory reared adult *L. serricorne* and *T. castaneum* each were inserted into fifteen miniature jute sacks each containing 2kg dry cocoa beans, which were tied and the whole set up inserted into cotton cloth sacks and distributed randomly in the stack. Thereafter, the lower and upper sections were pulled together closely and zipped with gas-tight multiple tongue and groove zippers. In order to prevent condensation, a Grainshade was stretched over the Cocoon™ at a level of at least 20cm above the top cover. The three Cocoon™ were randomly assigned for destructive sampling at 3, 6, and 9 weeks, respectively.

Conventional Storage (CS) and Standard Storage (SS) Set Up

Two stacks were constructed for CS and SS with an individual capacity of 45 bags, also built outdoors, on double wooden pallets. Ten laboratory reared adult *L. serricorne* and *T. castaneum each were inserted into fifteen miniature* jute sacks each containing 2kg dry cocoa beans which were tied closed and the whole set up inserted into cotton cloth sacks and distributed randomly in the stack. The stacks were individually covered with Herculite gas proof sheets. The CS had no chemical treatment at all but the SS was fumigated using Phosphine (PH_3) gas at an application rate of one tablet per 0. 19 tonne cocoa beans.

Instrumentation

All stacks built for the storage trials were daily monitored for temperature and oxygen (O_2) concentration. The ambient temperature and relative humidity were recorded on a daily interval during the storage trials. A gas inlet valve was attached to the Cocoon™ to monitor oxygen (O_2) concentration inside the structure using a GrainPro oxygen analyser.

Sampling Procedure

Each stack was divided into three blocks and five marked bags per block were collected, sieved and distributed randomly within the stack. Thus, a total of 15 marked bags were sampled per stack. For CS and SS, wherein only one stack was built for observation, samples of two kg each were drawn from the same marked bags at time 0, 3, 6, and 9 weeks of storage. For HS, the marked bags in all three sealed stacks were sampled at time 0 after which only the assigned Cocoon™ for destructive sampling at 3, 6, and 9 weeks, respectively was opened.

Analyses of Samples

Samples gathered were analysed at the Laboratory of the Research Department, Quality Control Division (COCOBOD), Tema, Ghana, for insect mortality and changes in quality of the cocoa beans. Moisture content of gathered samples was immediately measured with an Aqua Boy moisture meter, which was earlier calibrated by oven drying.

Results and Discussion

Bean Quality Characteristics

All the dry cocoa beans stored in the cocoon retained their quality (Table 1). There were some reduction in the total purple color of some of the cocoa beans but differences were not significant enough to cause any change in the grade.

Table 1. Mean quality categorisation of dry cocoa beans after nine weeks storage in the cocoon

Cocoon	Period (weeks)	Sub – Plot	Quality characteristics					GRADE
			TM	TS	TP	AOD	PURITY	
		1	0.2 ± 0.1	5.2 ± 0.4	28.2 ± 1.2	2.4 ± 0.2	64.0 ± 0.9	II
A	3	2	0.6 ± 0.1	2.0 ± 0.2	20.4 ± 0.9	2.2 ± 0.2	74.8 ± 1.0	I
		3	0.0 ± 0.0	3.4 ± 0.3	16.0 ± 0.3	4.0 ± 0.3	76.6 ± 0.7	II
		1	0.0 ± 0.0	5.0 ± 0.4	26.0 ± 1.3	1.6 ± 0.2	67.4 ± 0.9	II
B	6	2	0.2 ± 0.1	2.2 ± 0.3	40.2 ± 0.6	2.8 ± 0.4	54.4 ± 0.4	II *
		3	0.0 ± 0.0	3.2 ± 0.3	38.6 ± 0.7	0.6 ± 0.1	57.6 ± 0.8	II *
		1	0.6 ± 0.2	1.8 ± 0.1	14.2 ± 0.2	2.4 ± 1.0	81.0 ± 1.0	I
C	9	2	0.2 ± 0.1	3.2 ± 0.1	12.2 ± 0.4	3.4 ± 0.9	81.0 ± 0.9	I
		3	0.2 ± 0.1	2.6 ± 0.2	19.0 ± 0.3	2.8 ± 1.6	75.4 ± 1.7	I

± SE; n = 5; TM – total mouldy beans; TS – total slaty beans; TP – total purple beans; AOD – any other defects

Oxygen Concentration

The control (conventional and standard) storage had 21.0% oxygen in the atmosphere. The hermetic storage, likewise, possessed the same concentration of oxygen during the start of the storage period regardless of the plastic enclosure.

There was a steep decline in oxygen concentration in all Cocoon™ during the storage with the lowest concentration of 0.0% being recorded in all the Cocoon™ (Fig. 1). The first 0.0% oxygen concentration was recorded in Cocoon™ "A" on the fifteenth day of storage followed by Cocoon™ "C" on the seventeenth day and Cocoon™ "B" on the eighteenth day. All the Cocoons maintained the 0.0% oxygen concentration till the end of the storage.

In both the conventional and standard experiments the oxygen concentration remained virtually the same. The steep decline in oxygen concentration in all Cocoon™ during the storage is an indication that the organisms including in sects present in the Cocoon™ exhibited significantly high rates of respiration which is a major

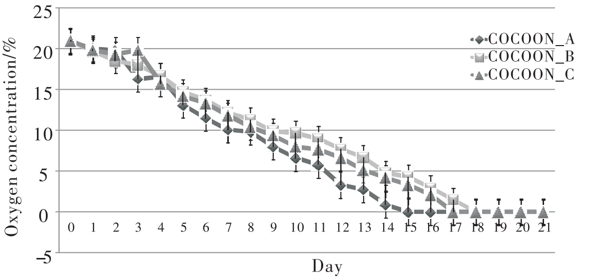

Fig. 1 Daily oxygen concentrations inside the Cocoon™ over the hermetic storage period

factor in the consumption of oxygen. The Cocoon™ prevented gas exchange between the plastic enclosure and the external environment and therefore a depleted oxygen atmosphere was created. Unlike the conventional and standard experiments, the Herculite gas proof sheets used allowed oxygen exchange between the plastic enclosure and the external environment thereby replenishing the oxygen used in the enclosure.

Moisture Content

Regardless of storage methods, the moisture content increased after three weeks of storage from a mean of 7.0% at the setting – up stage to a mean of 7.2%. However there was no change in moisture content with the prolonged storage of nine weeks.

Temperature

The temperature inside the Cocoon™ was not constant but it did not fluctuate significantly (Fig. 2). A mean temperature 28.3℃, 29.1℃ and 29.7℃ were recorded in Cocoon™ "A", "B" and "C" respectively. Comparably, temperatures in the Cocoon™ were lower than that recorded in the conventional and standard experiments.

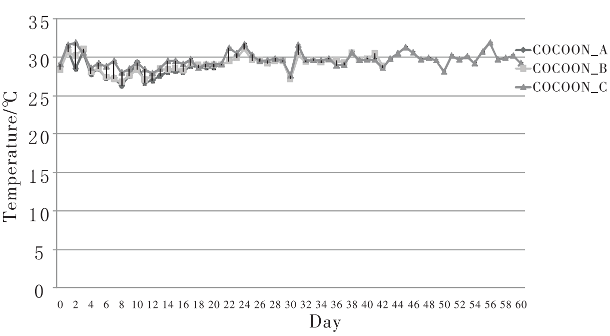

Fig. 2 Daily temperatures inside the Cocoon™ during the hermetic storage period

The temperature inside the conventional and standard stacks fluctuated significantly (Fig. 3) with recorded means of 30.5℃ and 30.6°C respectively. The significant difference in temperature between the two storage methods was likely due to the Grainshade that was stretched over the Cocoon™ at a level of at least 20cm above the top cover. The Grainshade cut off the sun from radiating on the Cocoon™ directly whereas the conventional and standard stacks were exposed to the sun during the day and the sky at night.

Insect Density

Just before building the stacks, the bags of dry cocoa beans that were sieved, then were infested with *Cryptolestes*, *Tribolium castaneum*, *Cadra cautella* (*Ephestia cautella*), *Oryzaephilus mercator Cryptolestes ferrugineus*, *Cryptolestes pusillus*, *Araecerus fasciculatus*, *Carpophilus dimidiatus and Carpopphilus hemipterus*. Predominant among them were *T. castaneum*, *C. ferrugineus*, *C. pusillus* and *O. surinamensis*.

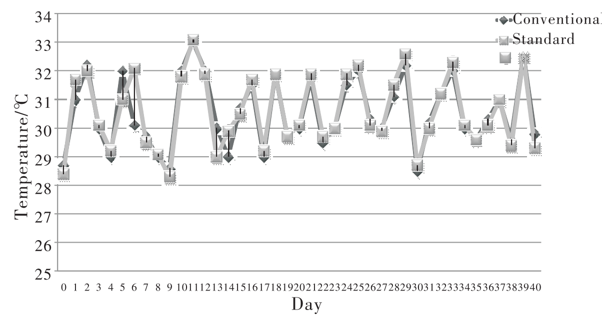

Fig. 3 Daily temperatures inside the control stacks over the storage period

Insect populations significantly increased with time of storage in the conventional storage and in addition to adults, larvae and pupae of both *T. castaneum* and *L. serricorne were found* (Table 2). Insect mortality of 100% was recorded in the standard storage which was fumigated with phosphine. In hermetic storage, not all the *T. castaneum* and *L. serricorne* that were introduced died (Table 3). In addition, a few live insects (adults of *C. ferrugineus*, *C. pusillus*, *A. fasciculatus*, *L. serricorne*, *and C. cautella* larvae and some fruit flies were found at the end of week three moving inside the Cocoon™. The insects were found to be weak and much stressed. It was also observed that high populations of the insects moved outside the bags of cocoa beans and were found dead inside the Cocoon™. However 100% mortality of *T. castaneum* and *L. serricorne* introduced into the Cocoon™ was recorded at the end of both weeks six and nine (Table 3). High populations of insects were found outside the bags of cocoa beans and dead inside the Cocoon™. Thus the Cocoon™ environment had effective control on the insect population in conformity to the findings of other researchers[12].

Table 2. Mean population live stages of *T. castaneum* and *L. serricorne* introduced into the conventional storage stack

Cocoon	Period (weeks)	Sub – Plot	Lasioderma			Tribolium		
			Larvae	Pupae	Adult	Larvae	Pupae	Adult
		1	4.2 ± 0.3	0.0 ± 0.0	12.2 ± 0.3	6.2 ± 0.2	0.4 ± 0.2	15.8 ± 0.3
A	3	2	2.0 ± 0.1	6.2 ± 0.1	12.0 ± 0.0	6.0 ± 0.4	6.2 ± 0.1	20.2 ± 0.1
		3	4.8 ± 0.4	0.0 ± 0.0	14.4 ± 0.1	4.4 ± 0.2	2.0 ± 0.0	18.6 ± 0.1
		1	5.0 ± 0.6	5.0 ± 0.2	22.0 ± 0.2	8.8 ± 0.3	6.4 ± 0.1	32.2 ± 0.3
B	6	2	10.0 ± 0.4	4.0 ± 0.2	26.0 ± 0.3	10.6 ± 0.3	6.0 ± 0.2	30.4 ± 0.2
		3	10.0 ± 0.3	2.0 ± 0.3	28.4 ± 0.4	10.0 ± 0.2	8.4 ± 0.1	36.2 ± 0.2
		1	8.2 ± 0.1	8.4 ± 0.4	38.4 ± 0.2	12.2 ± 0.2	12.4 ± 0.2	58.2 ± 0.1
C	9	2	10.2 ± 0.2	6.4 ± 0.1	38.0 ± 0.2	14.2 ± 0.1	10.4 ± 0.3	48.0 ± 0.0
		3	10.0 ± 0.4	5.0 ± 0.2	36.8 ± 0.1	14.0 ± 0.0	18.0 ± 0.0	56.4 ± 0.1

± SE; n = 5

The high oxygen concentration (21.0%), high temperature and high relative humidity promoted the growth of insects in the conventional storage. This was not the case in the hermetic storage. The much lower (0.0%) oxygen concentration in the three Cocoons made conditions unfavorable for insect growth, confirming the work of Bailey (1965).

Table 3. Mean mortality after nine weeks of storage

Cocoon	Period (weeks)	Sub – Plot	Lasioderma	Tribolium
		1	90 ± 0.2	82 ± 0.2
A	3	2	90 ± 0.1	84 ± 0.4
		3	88 ± 0.2	82 ± 0.2
		1	100 ± 0.0	100 ± 0.0
B	6	2	100 ± 0.0	100 ± 0.0
		3	100 ± 0.0	100 ± 0.0
		1	100 ± 0.0	100 ± 0.0
C	9	2	100 ± 0.0	100 ± 0.0
		3	100 ± 0.0	100 ± 0.0

SE; n = 5

Conclusion and Recommendation

Highly significant increases in insect population occurred in the conventional storage, especially after the week resulting in significant grain damage quality deterioration. Cocoon^{TM} storage resulted in 100% insect mortality at the end of the nine week storage period with no change in product quality.

Based on the results, use of flexible hermetic structures made of gastight plastic liners can be a safe and viable alternative to permanent structures for organic protection of cocoa beans for extended periods and seems to be the most promising method for storing cocoa beans. Besides controlling insect population it is more economical and convenient. Its set-up is the least expensive compared to traditional methods (conventional and standard storages). Flexibility, transportability, ease of erection, simplicity of operation and maintenance and durability are distinct advantages. Their availability in various sizes, capacities and forms can suit a wide range of requirements to fit several levels of storage operations.

The usage of hermetic storage for cocoa beans is highly practical and technically feasible. Hermetic storage would adequately reduce problems on losses in storage and at the same time ensure cocoa bean quality preservation. The Cocoon^{TM} can also be used as a fumigation chamber but will not require the use of sand snakes, gas proof sheets and residual insecticide.

It is recommended, therefore, that hermetic storage technology be promoted to solve the problem of organic storage of cocoa beans.

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