

HERMETIC STORAGE: A NOVEL APPROACH TO THE PROTECTION OF COCOA BEANS

W. JONFIA-ESSIEN, SHLOMO NAVARRO¹ and P. VILLERS²

Research Department, Quality Control Company Ltd. (COCOBOD), P. O. Box CO 247, Tema, Ghana

¹Food Technology International Consultancy Ltd., Israel

²GrainPro, Inc., 200 Baker Avenue, Concord, MA 01742

Corresponding author: wajonfiaessien@gmail.com

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ABSTRACT

Hermetic storage has provided a successful storage method for protection of commodities without fumigants or need for refrigeration for insect control and quality preservation of stored products. Hermetic storage is achieved in specially constructed plastic structures for the preservation of cereal grains and other commodities. Plastic structures suitable for long-term storage systems, as well as intermediate storage of grain have been developed and applied. These storage systems based on the hermetic principle were designed for (1) storage at the farmer-cooperative and small trader level with 10 - 1000 tonnes capacity for enclosing stacks termed CocoonsTM, (2) small scale storage suitable for small portable containers of 60 kg to 2 tonnes called SuperGrainbagsTM and (3) quality preservation, insect control and prevention of condensation during shipment of commodities in shipping containers known as TranSafelinersTM. Hermetic storage is based on the principle of generation of an oxygen-depleted, carbon dioxide-enriched interstitial atmosphere caused by the respiration of the living organisms in the ecological system of a sealed storage. A sufficiently low oxygen and elevated CO₂ atmosphere is created through a natural metabolic process based on insect respiration and, in cases where the commodity has sufficiently high moisture, the respiration of the microorganisms within a sealed storage system. Applications for which hermetic technology has been most widely accepted are long-term storage of cereal grains, primarily rice, corn, barley, wheat and a variety of seeds to preserve germination potential and vigor and quality preservation of high-value commodities such as cocoa and coffee. Under field conditions in a cocoa bean storage facility in Makassar, Indonesia, a hermetically sealed flexible structure containing 6.7 tonnes of cocoa beans at an initial moisture content of 7.3% and relative humidity of 70% was monitored for oxygen concentration and quality parameters of the beans. The measurements showed a decrease in oxygen concentration to 0.3% after 5.5 days. No insects survived the oxygen depleted biogenerated atmosphere. Similar trials were carried out in Ghana by COCOBOD in which 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. At the sixth week of storage 100% mortality of insects was recorded in the CocoonTM. All the cocoa beans inside the CocoonTM maintained their quality category throughout the storage period and the grade remained the same after nine weeks of storage as it was at the beginning of the experiment.

Key Words: Coffee, cocoa beans, hermetic storage, insects, modified atmospheres, quality preservation, seeds, storage

RÉSUMÉ

Le stockage hermétique constitue une méthode satisfaisante de stockage pour la protection des produits sans recours aux fumigènes et à la réfrigération, pour le contrôle des insectes et la préservation de la qualité des produits stockés. Le stockage hermétique est réalisé par la construction des structures en plastique, spécialement pour la conservation des grains de céréales et autres denrées. Des structures en plastique appropriées aux systèmes de

stockage de grains à long aussi bien qu'à moyen terme ont été développées et appliquées. Basés sur le principe hermétique, ces systèmes de stockage étaient conçus pour (1) le stockage au niveau de coopératives de fermiers et de petits commerçants avec une capacité de 10 - 1000 tonnes pour enfermer des piles ont nommé CocoonTM, (2) stockage à petite échelle appropriée aux petits conteneurs portables de 60 kg à 2 tonnes appelés SuperGrainbagsTM et (3) la préservation de la qualité, lutte contre les insectes et la prévention de la condensation lors du transport des produits dans des conteneurs connus sous le nom de TranSafelinersTM. Le stockage hermétique est basé sur le principe de génération d'oxygène appauvri, un atmosphère interstitiel enrichi en dioxyde de carbone par la respiration des organismes vivant dans le système écologique du stockage scellé. Il en résulte un atmosphère suffisamment déficient en oxygène, avec un taux élevé de CO₂ par suite du processus naturel de métabolisme basé sur la respiration des insectes et, dans les cas où les produits ont une humidité suffisamment élevée, la respiration des microorganismes dans le système de stockage hermétique. Les applications de la technologie hermétique les plus largement acceptées sont le stockage à long terme des grains de céréales principalement le riz, le maïs, l'orge, le blé et la préservation de la viguer et du potentiel de germination de semences variées, ainsi que la préservation de la qualité des produits de grande valeur tels que le cacao et le café. En conditions de terrain dans une installation de stockage de fèves de cacao à Makassar en Indonésie, une étude a été faite sur la concentration de l'oxygène et les paramètres de qualité des grains dans structure flexible hermétiquement fermée contenant 6,7 tonnes de fèves de cacao ayant une teneur initiale en eau de 7,3% et une humidité relative de 70%. Des mesures effectuées ont montré une diminution de 0,3% de la concentration en oxygène après 5,5 jours. Aucun insecte n'a pu survivre à la biogénération de l'atmosphère appauvri en oxygène. Des essais similaires ont été menés au Ghana par COCOBOD, par lesquels trois piles pour le stockage hermétique et une pile de stockage conventionnel pour chacun (sans fumigation) et le stockage standard (avec la fumigation) étaient construits pour l'échantillonnage et l'observation. À la sixième semaine de stockage, 100% de cas de mortalité des insectes était enregistré dans le CocoonTM. Toutes les fèves de cacao à l'intérieur du CocoonTM maintenaient leur catégorie de qualité tout au long de la période de stockage et la qualité est restée la même après neuf semaines de stockage tel qu'il était au début de l'expérience.

Mots Clés: Atmosphères modifiées, café, préservation de qualité, insecte de stockage, semence

INTRODUCTION

A new approach to cocoa bean storage, "hermetic storage" (HS), has been investigated in both laboratory and field studies to protect them both in storage and in transit, and is now in commercial use in Africa, Asia and Latin America. Hermetic storage is a type of modified atmosphere (MA) that has now been applied for the protection of stored agricultural commodities including cocoa beans, coffee, rice, corn, pulses and seeds (Navarro *et al.*, 1984; 1993; 1995; Varnava and Mouskos, 1997; Navarro, 2006; Sabio *et al.*, 2006). It is also called "sealed storage" or "air-tight storage" or "sacrificial sealed storage" or "hermetic silo storage". This method takes advantage of sufficiently sealed structures that enable insects and other aerobic organisms in the commodity or the commodity itself to generate the MA by reducing the O₂ and increasing the CO₂ concentrations through respiratory metabolism. 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. Hermetic storage provides protection of cocoa beans without the need for chemicals, cold storage chambers or refrigeration, and maintains a constant moisture level in the cocoa beans regardless of the exterior air composition.

Infestation is a major problem and therefore the beans are frequently fumigated using phosphine or methyl bromide (MB). Fumigants are widely used for pest control both in cocoa beans and also in other stored products to prevent quantitative and quality losses caused by insect pests. However, increased public concern over the adverse effects of pesticide residues in food and the environment has led to their partial substitution with alternative control methods. Consequently, non-chemical and environmentally user-friendly methods of pest control in the post harvest sector are becoming increasingly important. MB should have been phased out in developed countries by 2005 and will be phased out in developing countries by

2015, because of its contribution to stratospheric ozone depletion (UNEP, 2002). In contrast, phosphine remains popular, particularly in developing countries, because it is easier to apply than MB. However, some insects have developed resistance to phosphine in some countries over the last decade (Cao *et al.*, 2003; Savvidou *et al.*, 2003).

Storage problems prevail in the presence of adequate oxygen and temperature. This presents and promotes the growth of insect population and in the presence of high relative humidity molds develop to cause quality deterioration resulting in an increase in free fatty acids (FFAs), rancidification of flavour and mycotoxins. These postharvest problems are eliminated through the lethal effect of a low O₂/high CO₂ atmosphere produced through respiration processes. Under hermetic conditions, stored commodities with intermediate moisture contents generate modified atmospheres due to the respiration of the microflora and the commodity itself. The objective of this study was to provide data on the novel approach of using hermetic storage based solely on biogenerated modified atmospheres as an insect control, and quality preservation method for stored cocoa beans and other stored agricultural products.

Storage structures and enclosures developed for hermetic storage. Modern hermetic storage systems (HS) for cocoa and other commodities use special low permeability flexible plastic enclosures. These hermetic storage containers have evolved to store a variety of dry commodities in the range of 60 kg to 10,000

tonnes. They became commercially available starting in the early 1990's, and today are in use in more than 38 countries in a variety of configurations.

In order to fill the growing range of requirements, hermetic storage is used in a number of different forms. Most often, these systems rely purely on biological effect of respiration of the commodity and of infesting insects to create the desired low oxygen modified atmosphere. However, a few specialised applications require more rapid disinfestation, such as in 3 days for dried figs (Ferizli and Emekci, 2000). In these, oxygen levels are reduced more rapidly, either by purging with CO₂ (Gas - Hermetic Fumigation "G-HF"), or by applying a significantly high vacuum (Vacuum - Hermetic Fumigation "V-HF"). In either case, the process can quickly reduce oxygen content to below 1% to 2% (Navarro *et al.*, 2002; Villers *et al.*, 2006).

The most widely used form of HS is the CocoonTM (Fig. 1). It is manufactured in capacities ranging from 5 to 300 tonnes. Cocoons, used for storing cocoa and other commodities, are made from specially formulated flexible 0.83 mm thick PVC with permeability to oxygen of 400 cc m⁻² day⁻¹ and to water vapour of 8 g m⁻² day⁻¹. They are sealed with an airtight zipper originally developed for use by astronauts.

A newer type of Cocoon called the MegaCocoonTM has more recently been introduced for larger scale storage of up to 1050 tonnes, with initial installations in Sudan (Fig. 2). For smaller unit containers of 60 kg to 90 kg capacity, a 150 g weighing highly transportable SuperGrainbagTM (SGB) is used (Fig. 3). The SGB



Figure 1. Outdoor storage in cocoonsTM, Philippines, 2008.



Figure 2. 1050 Tonne MegaCocoon™, Sudan, 2009.



Figure 3. Hermetically sealed SuperGrainbag™ with corn seeds inside a woven polypropylene bag.

is a 3-layer coextruded plastic with thickness of 0.078 mm, $3 \text{ cc m}^{-2} \text{ day}^{-1}$ permeability levels for oxygen and for water vapour of $8 \text{ g m}^{-2} \text{ day}^{-1}$. These features of SGB maintain commodity quality, even with long transport times and in humid environments.

More recently using the same material, the SuperGrainbags-HC™ has become available for use with mechanized loading, which handles up to a 2-tonne capacity for bags or bulk storage (Fig. 4). To protect bagged or bulk commodities against damage and deterioration when shipping across intercontinental distances in 20- and 40-foot standard shipping containers, the TranSafeliner™ was introduced in 2008 (GrainPro, 2008) (Fig. 5). The TranSafeliner provides hermetic storage during transport in a standard shipping container using the same type of ultra low permeability co-extruded plastic used in the SuperGrainbag (Fig. 3) (Villers *et al.*, 2008). These various forms of hermetic storage are now used for a number of different commodities. The

most common current uses other than for cocoa are for the protection of paddy, milled rice, brown rice, corn, wheat, sorghum, pulses, seeds of many types, and coffee. The hermetic barrier materials used are most often either the 0.83 mm thick PVC Cocoon™ shown in Figure 1 with a permeability to oxygen of $400 \text{ cc m}^{-2} \text{ day}^{-1}$ and to water vapor of $8 \text{ g m}^{-2} \text{ day}^{-1}$, or the 0.078 mm co-extruded polyethylene with a proprietary ultra low permeability barrier material as middle layer such as shown in SuperGrainbags™ (Fig. 3) with a permeability to oxygen ranging down to $3 \text{ cc/m}^2/\text{day}$, and to water vapor of $8 \text{ g m}^{-2} \text{ day}^{-1}$.

Preservation of stored cocoa beans. The problem of moisture in non-hermetic storage is well understood. Intermediate moisture contents of stored commodities at equilibrium with relative humidity of 65 to 75% of stored commodities are inevitable in tropical climates (Transport Information Service, 2009). Under hermetic conditions, stored commodities with intermediate



Figure 4. One tonne SuperGrainbags-HC™ storing paddy with woven inside protective polypropylene bag.



Figure 5. TranSafeliner™ being installed in a standard shipping container, 2008.

moisture contents generate modified atmospheres due to the respiration of the microflora and the commodity itself. Data were compiled for insect control and for quality preservation of stored cocoa beans by employing a novel approach through the use of bio-generated modified atmospheres as a methyl bromide alternative. The respiration rates of fermented cocoa beans at equilibrium relative humidities of 73% at 26°C in hermetically sealed containers depleted the oxygen concentration to <0.3% and increased the carbon dioxide concentration to 23% within 5.5 days. This hermetically sealed flexible structure contained 6.7 tonnes of cocoa beans at moisture content of 7.3%. It was monitored for oxygen concentration and quality parameters of the beans (Fig. 6). No insects survived the oxygen

depleted bio-generated atmosphere. These encouraging results reveal the possibility of utilising bio-generated atmospheres in integrated pest management (IPM) for quality preservation by preventing the development of moulds, FFA and mycotoxins and insect control of cocoa pests. (Navarro *et al.*, 2007). Hermetic liners for 20 ft. containers such as the TranSafeliner™ are now increasingly used for maintaining quality in international shipments of cocoa beans and coffee.

Laboratory data on hermetic storage of cocoa.

Cocoons were first used for cocoa storage in Indonesia in 2005, and in the same year were the subject of a detailed laboratory study in Israel at its Agricultural Research Organization (ARO).

The study's report describes hermetic storage as a method of quality preservation of stored cocoa beans methyl bromide a novel approach through the use of bio-generated modified atmospheres. The respiration effect of fermented cocoa beans from Makassar, Sulawesi, Indonesia, was determined under laboratory conditions. Initial insect populations found in these cocoa beans samples consisted of *Carpophilus* spp., *Ahasverus advena*, *Cryptolestes* spp. and *Psocids*. The effects of cocoa beans at equilibrium relative humidities (r.h.) of 59, 68, and 73% were determined at 26°C in hermetically sealed 1-liter capacity jars containing 500 g of the commodity. At the equilibrium r.h. of 73%, the respiration of the cocoa beans depleted the oxygen concentration to <1% and increased the carbon dioxide concentration to 23% within six days. However, to obtain similar oxygen depletion for drier cocoa beans at 68% equilibrium r.h., a duration of 23 days was required, while for the sealed cocoa beans in equilibrium with 59% r.h. the oxygen concentration after 23 days had only decreased to 10.8% (Navarro *et al.*, 2007).

Field experience from Indonesia. The field trial was carried out in a warehouses located in

Makassar (Ujung Pandang), Indonesia from June to November 2005. The trial consisted of storing locally available bagged cocoa beans in a gas-tight sealed flexible GrainPro Cocoon of 15 m³ capacity. The Cocoon accommodated 108 jute bags of cocoa beans each of 62.5 kg capacity. The initial moisture content (m.c.) of the Cocoon™ was determined on ten samples taken from the bottom, middle and top layers of the stack. The average m.c. of each sample was taken at the start of the trial in June and at the end of the trial.

The initial moisture content of 7.3% (70% equilibrium r.h.) was monitored for oxygen concentration and quality parameters of the beans. The measurements showed a decrease in oxygen concentration to 0.3% after 5.5 days (Fig. 6). An ambient temperature of 30°C was maintained through out the six months period. The cocoa bean samples showed a slight increase in moisture content from 7.3 to 7.7%, thus 70 to 73% equilibrium r.h. Such an oxygen depleted atmosphere was sufficient to control the existing insect population and no live insects were recorded in the ten cocoa bean samples at the opening of the Cocoon in November.

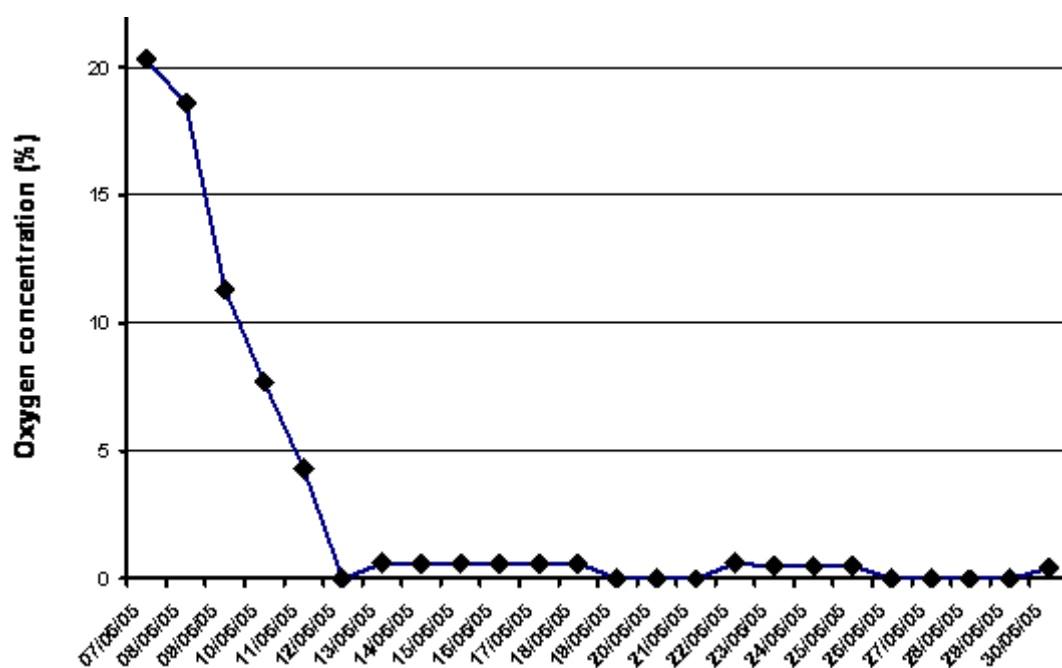


Figure 6. Changes in oxygen concentration in cocoa beans, Makassar, Indonesia, 2005 (Navarro *et al.*, 2007).

Field experience from Ghana. Three stacks for hermetic storage and one stack each for conventional storage (without fumigation) and standard storage (with fumigation) were built for the experiment. The Cocoon stacks were 3.40 m long x 2.95 m wide x 2.0 m 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 weeks intervals for insect density and quality characterisation. A steep decline in oxygen concentration was observed in all Cocoons during the storage with a concentration of 0.0% being recorded in all the Cocoons from the fifteenth day of storage and this was maintained throughout the storage period (Fig. 7). The temperature was almost uniform inside the Cocoon throughout the storage period. After three weeks of storage, the first Cocoon was infested with live adults of *Cryptolestes ferrugineus*, *Cryptolestes pusillus*, *Araecerus fasciculatus*, *Lasioderma serricorne*, and *Ephestia cautella* larvae and some fruit flies. However, most of the insects died inside the Cocoons. Most of the *Lasioderma serricorne* and *Tribolium castaneum* introduced at the beginning of the experiment were dead at the third week and 100% of all the types of insects were dead by the sixth week of storage (Table 1). All

the cocoa beans inside the Cocoon maintained their quality category throughout the storage period and the grade remained the same after nine weeks of storage as it was at the beginning of the trial. (Jonfia-Essien *et al.*, 2008a).

This was not the case in both the control/conventional and standard experiments in which the oxygen concentration remained virtually the same. The steep decline in oxygen concentration in all Cocoons during the storage is an indication that the organisms including insects present in the Cocoon exhibited significantly high rate of respiration, which is a major 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.

The Ghana Cocoa Board also evaluated the use of hermetic SuperGrainbag (SGB) liners inside conventional jute bags of 70 kg and after 30 days of storage, 100% mortality of populations of insects were observed in all cocoa beans stored in SGB liners except one single bag in which a few individual insects were alive (Jonfia-Essien *et al.*, 2008b).

Other major applications of hermetic storage. Starting in 2003, the International Rice Research Institute (IRRI) proved that hermetic storage of paddy and rice seed using 5 tonne Cocoons

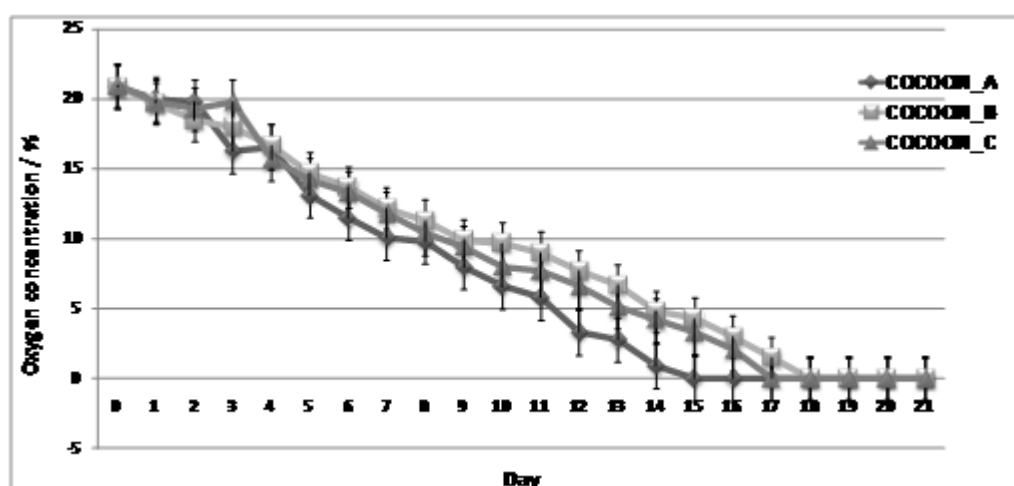


Figure 7. Daily oxygen concentrations inside the Cocoon™ over the hermetic storage period of cocoa beans stored in Ghana (Jonfia – Essien *et al.*, 2008a).

TABLE 1. Mean mortality after nine weeks of storage of cocoa beans stored in Ghana (Jonfia – Essien *et al.*, 2008a)

Cocoon	Period (weeks)	Sub-plot	<i>Lasioderma serricorne</i>	<i>Tribolium castaneum</i>
A	3	1	90 ± 0.2	82 ± 0.2
		2	90 ± 0.1	84 ± 0.4
		3	88 ± 0.2	82 ± 0.2
B	6	1	100 ± 0.0	100 ± 0.0
		2	100 ± 0.0	100 ± 0.0
		3	100 ± 0.0	100 ± 0.0
C	9	1	100 ± 0.0	100 ± 0.0
		2	100 ± 0.0	100 ± 0.0
		3	100 ± 0.0	100 ± 0.0



Figure 8. Cocoa in SuperGrainbag-HC, 1 tonne, Singapore, 2009.

produced results equivalent to storing under air conditioned conditions or refrigerated storage for periods of up to a year. Later, IRRI showed safe storage in the smaller SuperGrainbags (60 kg) (Rickman and Aquino, 2004; Villers and Gummert, 2009). Other studies on hermetic storage of rice and corn seed in Mexico, Thailand, Bangladesh, and Cambodia showed similar results for periods of 90-280 days with germination rates at the end of the period from 95 to 98.3%. SuperGrainbags are now used on a large scale by Bayer CropSciences for rice seed storage in the Philippines, India, Indonesia and Brazil.

Coffee storage using Cocoons or SuperGrainbags up to a year while maintaining quality has been used since 2005 (Aronson *et al.*, 2005). This process protects coffee against deterioration of quality as determined by cupping tests and is now used in some 12 countries.

Hermetic corn storage on a large scale (Fig. 1), has been used in such places as the Philippines, Rwanda and Thailand (Villers *et al.*, 2008). In Ghana, several hundred thousand are

sold at retail for small farmers for corn, sorghum and bean storage.

Beans and sorghum stored in large Cocoons™ for up to one year have been used on a large scale in Rwanda and Ghana (Villers *et al.*, 2008). Field trials in Costa Rica have shown that beans stored hermetically in Cocoons for 3 months not only are well preserved and insect-free but the otherwise doubling of required cooking time after 3 months of conventional storage is eliminated. More recently, in 2009, initial trials in Kerala, India have shown promising results in storing tea, maintaining essential constant moisture content as well as taste, color and texture for 4 months (private communication from Avinish). Indian subcontinent regional sales manager, GrainPro Inc.

CONCLUSIONS

Hermetic is a successful storage method for the protection of commodities, replacing fumigants for insect control and for quality preservation of

stored products. Hermetic storage is achieved in specially constructed plastic structures. Plastic structures suitable for long-term storage systems, as well as intermediate storage of grain have been developed and applied. 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 operation.

The use of hermetic structures made of gastight flexible plastic liners can be a safe and viable alternative to permanent rigid structures for organic protection of cocoa beans for extended periods and it seems to be the most promising method for storing cocoa beans. Aside from controlling insect population it is more economical and convenient. The usage of hermetic storage for cocoa beans is highly practical and technically feasible.

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