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Development of Hermetic Storage Technology in Sealed Flexible Storage Structures

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Abstract: Restrictions due to the adverse effects of pesticide residues in food and the environment resulted in the imposition of strict limitations on pesticide registration by regulatory agencies. Consumer demand for chemical-free and insect contamination-free products increased the attention to the application of non-residue organic technologies for the protection of stored grain. Among the new gaseous application technologies that have successfully replaced fumigants are the manipulation of modified atmospheres (MAs) through the use of biogenerated MAs, for insect control and for quality preservation of seeds, stored paddy, polished rice, wheat, pulses, cocoa or coffee beans, and high moisture corn. This takes advantage of the atmospheric gas composition produced by the respiratory metabolism of the biological agents of the grain bulk to prevent insect development and suppress microflora activity. Sufficiently sealed structures enable insects and other aerobic organisms in the commodity, and/or the commodity itself, to generate the MA by reducing the O_2 and increasing the CO_2 concentrations. Further moisture levels stay constant preventing mold growth.

Freshly harvested high moisture corn has been successfully stored under hermetic conditions, maintaining its quality prior to subsequent drying or processing into feeds or ethanol. A recent development is the use of MAs in a low-pressure environment. These niche applications of MAs have resulted in very promising treatments with market acceptability.

Hermetic storage for dry commodities is now used in 32 countries for storage of a number of important commodities as discussed and illustrated. The growing number of types of hermetic containers for various needs is documented. This ranges from small portable containers of 60 kg to 1 tonne called SuperGrainbags™ to a series of large flexible storage structures, called Cocoons™, TranSafeliners™ and Bunkers™, ranging from 5 tonne to 30,000 tonne capacity. Economic analysis, as reported by studies and field trials, is provided for representative applications, including rice and cocoa.

Keywords: hermetic, controlled atmosphere, modified atmosphere, pesticide-free, Cocoons™, SuperGrainbags™, TranSafeliners™, molds, insects, grain storage, seed storage, long-term storage, fumigation, disinfestations, organic

1. **Introduction:**

Hermetic storage (HS) technology has emerged as a significant alternative to other methods of storage that protect commodities from insects and molds. This technology, also termed sealed storage, airtight storage, or assisted hermetic storage, is a form of bio-generated modified atmosphere (MA). HS 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[3,20]. Among the advantages of hermetic storage is the generation of a MA in an environmentally safe and sustainable manner eliminating the need for chemical treatments, fumigants, and climate control.

The rapid growth in adoption of HS is due to the increasing demand for environmentally safe and sustainable technologies that are simple to use and are now supported by the greater availability of scientific information and field experience. Some HS units are characterized by their ease of installation, rodent protection, favorable costs, ease of relocation, and very modest requirements for infrastructure[20].

***Figure 1**: 150 Tonne Cocoon™ storing maize in Rwanda.*

Modern HS results from important scientific work done starting in the 1980s at the ARO (Agricultural Research Organization) of the Department of Agriculture in Israel[2,3,5,12,13]. Only in the last several years has HS emerged as an important, widely used alternative method of post harvest storage. This growth is due in part, to increasing concerns about the use of pesticides that endanger the fumigator, the environment, and the consumer.

1.1 **Limitations of Conventional Concrete or Metal Silo Storage**

The modern approach to storage of bulk commodities is based on storage in metal or concrete silos. Technology for storage in silos well serves the world's highly developed economies that are generally located in temperate climates. However, the use of silo technology in hot, humid climates in tropical and semi-tropical regions has produced negative results by causing condensation and humidity damage to the stored commodities[5,6]. (See Appendix I.)

In tropical climates, even commodities that are initially sufficiently dried suffer from three major problems when stored within metal or concrete silos:

1. Condensation leading to fungal and insect growth,
2. Susceptibility to external humidity, which raises the moisture content to unsafe levels,
3. Contamination with fumigants and chemical contact insecticides used to prevent insect infestation.

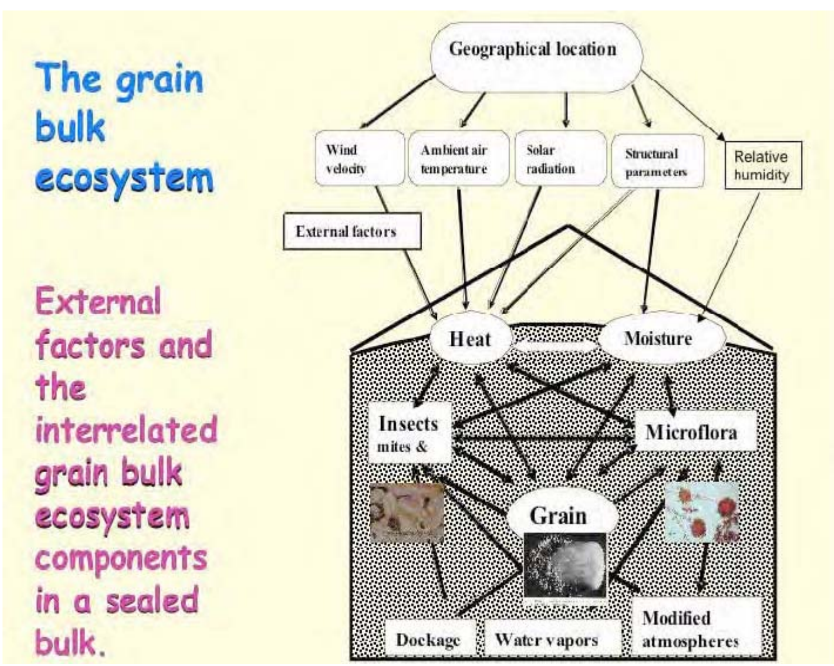

***Figure 2:** The Conventional Silo Ecosystem[10]*

Metal and concrete silo technologies originated in Europe and the United States, whose climates permit the use of built-in ventilation systems to cool the grain during cold seasons, thereby controlling insect activity. However, in tropical climates, aerated silo storage does not prevent moisture condensation and subsequent moisture increase. In such regions, it is necessary to deal with the combined problems of high relative humidity and high temperatures. There is also a growing recognition of environmental effects of fumigants and pesticides and of the growing insect resistance to pesticides in general and in particular to phosphine. Some of these factors are portrayed in Figure 2.

1.2 Applications of Hermetic Storage

The applications for which hermetic technology has been most widely accepted are:

- Long-term storage of cereal grains, primarily rice, corn, barley, and wheat.
- Long-term storage of a variety of seeds to preserve germination potential and vigor.
- Quality preservation of high-value commodities, such as cocoa and coffee.

In addition, still newer applications for HS are emerging, such as safe storage of high-moisture corn; storage of specialized, difficult to store products such as brown rice, rice bran and basmati rice; and the prevention of growth of toxinogenic aflatoxins in corn and peanuts, or ochratoxins in coffee. HS is also used to store oily commodities such as cottonseeds or peanuts to prevent the growth of free fatty acids (FFAs), and resulting rancidity. Hermetic storage as shown in Appendix II is now used in 32 countries.

2. Hermetic Storage Technology

Successful use of hermetic storage is based on the need to achieve one or more of the three following goals:

- Low oxygen, high carbon dioxide atmosphere to prevent infestations (molds and insects), and oxidation
- Preventing entry of moisture
- Protection from rodents

2.1 Low Oxygen Modified Atmosphere

Creation of a sufficiently low oxygen elevated CO_2 MA protects from insects, molds, and oxidation effects. This is done through a natural metabolic process of insect respiration and, in some cases the respiration of the commodity itself. When a level of less than 2% oxygen is reached mortality of all insect stages is achieved rapidly.

Because insects lower their metabolism at low temperatures, a prerequisite for achieving insect mortality due to insect respiration is to have sufficiently high temperature inside the enclosure, typically room temperature of 22^o C or above. The time required for insect mortality depends strongly on temperature. This is true even in the case of cocoa beans and rice, where the consumption of oxygen by both the organisms and the commodity, with their release of CO_2, play a major role. In a few commodities, of which coffee is an example, oxygen levels don't go down significantly because of a generally low level of infestation and the behavior of the commodity itself, but the control of moisture content is the vital element in maintaining quality.

Figure 3 shows the high sensitivity to both temperature and oxygen levels that mortality of many insects exhibit in low oxygen high carbon dioxide atmospheres. Figure 4 shows how insect population growth in a normal atmosphere relates strongly to temperature typically peaking at about 28ºC. Growth of molds, on the other hand, as seen in Figure 5, in normal atmosphere, is a strong function of ambient relative humidity.

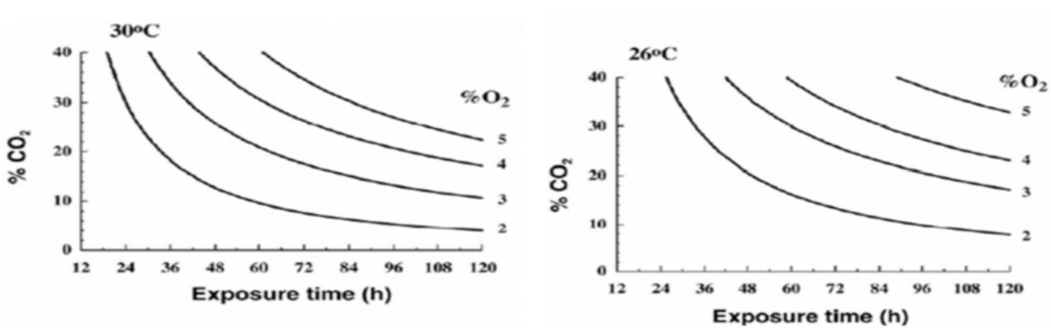

Figure 3: *Exposure times vs. CO_2 levels with 95% mortality for Tribolium castaneum at 57% r.h. at 26°C and 30°C*[15]

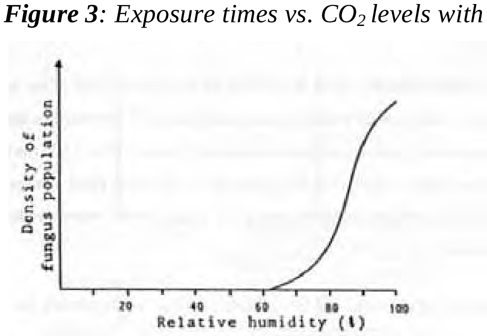

Figure 4: *Typical insect density vs. temperature.*

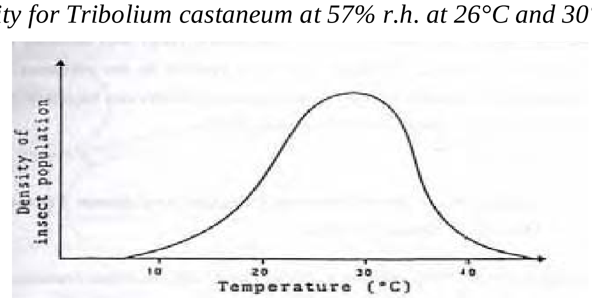

Figure 5: *Typical fungus density vs. humidity*

2.2 Prevention of ingress of water vapor

By preventing the entry of water vapor into a hermetically sealed container, adequately dried commodities are protected from external humidity, preventing a rise in their moisture content beyond their critical moisture level.

2.3 Protection from Rodents

Properly designed hermetic storage is highly rodent resistant. Rodent resistance is provided in the case of large hermetic enclosures such as Cocoons by using tough, slippery materials such as flexible PVC (typically 0.83 mm thick), and tensioning straps, which prevent rodents from getting a tooth hold.

2.4. Preservation of Germination and Vigor in Stored Seeds

Many studies in various countries including Mexico and Bangladesh have shown that HS maintains germination of 85% or more for periods up to 9 months, while conventional storage in jute bags reduces germination down to 14% to 76% within 3 months[17,20]. This has led to adoption of HS by some leading international rice seed producers.

For the last 10 or so years, the International Rice Research Institute (IRRI) in the Philippines has extensively tested HS of rice seeds and paddy[9]. Rice storage also was the subject of a careful economic study at PhilRice in 2006. This study[17] compared the performance and economics of HS of rice seed to three other methods: conventional (unprotected) storage, air conditioned storage, and refrigerated storage. The PhilRice study concluded that conventional storage was least expensive and adequate for up to three months; but after three months, loss of germination capability prevented conventional storage from meeting the 85% germination level required for certified seed. The three remaining methods: hermetic storage (HS), air-conditioned storage (ACRS), and cold room storage (CRS) all performed substantially the same. However, major differences in capital and operating costs were documented and are described in Section 5. As seen in Table 1 and 2 below, germination percentage and insect density were compared at three-month intervals, during a nine-month period. Insect infestation and moisture content were also compared. The study's conclusion was that for storage for nine months or more, the HS process provided equal or better performance as compared to previously used techniques but at a lower overall cost. Figure 6 shows similar performance for peanuts in Vietnam.

Figure 6: *Germination % vs. time for peanuts*

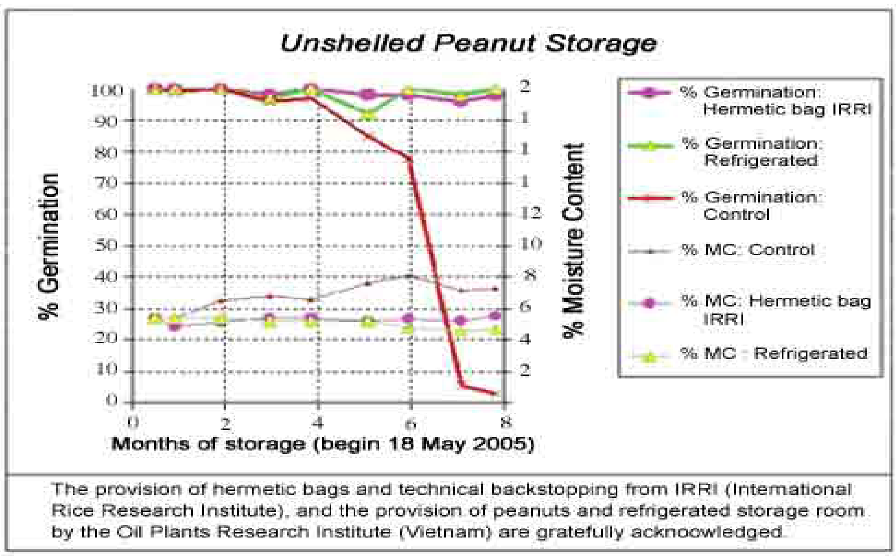

Table 1. Mean percent germination rate of Mestizo 1 (PSB Rc72H) hybrid paddy seeds stored under different storage technologies and durations

	Storage duration (months)			
Method	0	3	6	9
HS	96.16	96.47	93.30	86.15
CRS	96.80	97.57	92.95	89.60
ACRS	94.30	94.75	88.13	85.82
CTRL	92.87	92.92	76.38	74.70

Table 2. Mean percent adult insect density per kg sample of Mestizo 1 hybrid paddy seeds stored under different storage technologies and durations.				
	Storage duration (months)			
Method	0	3	6	9
HS	1.13	3.82	3.22	8.42
CRS	0.96	0.38	0.64	0.56
ACRS	0.84	0.76	8.58	38.27
CTRL	0.35	16.95	79.40	147.84

IRRI has promoted the use of portable SuperGrainbags for seed storage in a number of countries including East Timor, Vietnam, Philippines, and parts of Africa. Seeds have been stored on an industrial scale in India, Philippines, and Indonesia using either 60-kg bags with the SuperGrainbag liners, or the much larger Cocoons. SuperGrainbags have been found to provide equivalent protection to the much larger Cocoons, with the exception of protection against rodents. More recently, 1 tonne capacity SuperGrainbags have been introduced for efficient mechanized handling.

2.5. Quality Preservation – Aroma and Flavor

Sealed hermetic containers preserve the quality of aromatic dried plant material such as spices. It seems that HS traps the aromatic volatiles that are emitted by each commodity and maintains the aroma and flavor of such commodities as coriander, turmeric tuber, red chili pepper, coffee, cocoa and basmati rice.

3. Current Types of Flexible Hermetic Storage

In order to fill differing requirements of scale and other needs for the variety of users, HS is now used in a number of different forms. Most often these use the purely organic effect of the respiration of commodity and insects to create the desired low oxygen MA. However, a few specialized applications require more rapid disinfestation, such as in 3 days for dried figs[8]. In these, oxygen levels are reduced more rapidly, either by purging with CO_2 (Gas Hermetic Fumigation "G-HF"), or by applying a significant vacuum (Vacuum Hermetic Fumigation "V-HF"). In either case, the process quickly reduces oxygen content to below 1% to 2%[8, 14].

The most widely used form of HS is the Cocoon. It is produced in capacities ranging from 5 tonnes to 1000 tonnes. Cocoons, used for storing bagged grain, are made from specially formulated flexible PVC, and sealed with a special zipper originally developed for use by astronauts.

Figure 7: *Scale model MegaCocoon™ being sealed – Philippines, 2008.*

Figure 8: *TranSafeliner™ being installed in a transport container, 2008.*

A newer type of Cocoon called the MegaCocoon™ has been introduced for larger scale storage up to 1050 tonnes, with initial installation in South Sudan (Figure 7). Much larger storage, called Bunkers, have been used for multi-year storage in such places as Israel and Cyprus[12].

The highly transportable SuperGrainbag, (Figures 11 and 12), maintains quality, even with long transport times and humid environments[15]. More recent SuperGrainbags now handle much larger loads – up to 1 tonne capacity. Users also wish to protect their bagged or bulk commodities when shipping long distances in 20- and 40-foot standard shipping containers. To meet this need more economically, the TranSafeliner was introduced in 2008 (figure 8). The TranSafeliner provides HS during transport using the same type of ultra low permeability coextruded plastic as is used in the SuperGrainbag.

Using the same materials the SuperBunker™ was also introduced in 2008, to provide lightweight, one-season storage for thousands of tonnes, at storage costs as low as $10/tonne.

It is also possible, as demonstrated in the Philippines and China, to safely store corn with moisture content up to 35% for use as animal feed. This approach allows exceeding the normal safe moisture content limit of 12.5%. The corn ferments due to the release of alcohol and ethanol. This is well accepted by cattle, and increases the nutritional value of the corn. The following table compares high moisture corn (26%) versus standard, showing the benefits of high moisture storage under anaerobic conditions[7].

Table 3: Analysis of Corn After 3 months of Hermetic Storage compared with AACC Values: (26% initial moisture level)

	Moisture Content, % wet basis	Ash, % dry basis	Crude Protein, % dry basis	Crude Fat, % dry basis	Crude Fiber, % dry basis
Experimental High Moisture Corn **	10.06	1.87	12.23	5.35	2.70
AACC*	16.0 (7-23)	1.4 (1.1-3.9)	9.5 (6-12)	4.3 (3.1-5.7)	9.5 (8.3-11.9)

NOTE: *AACC values from White PJ & Johnson LA, 2003. Corn Chemistry and Technology, American Association of Cereal Chemists. Range values are in parenthesis.
** Wet corn was hermetically stored for 3 months, and then it was dried using a flat bed dryer[7].

According to Professor G. Ashbell, Feed Conservation Technology Specialist of the Food Technology International Consultancy, Beit Yehoshua, Israel: "Preservation of fodder in anaerobic conditions is a well-known technology for many generations. This technology is the key of silage making. In cases with difficulties related to drying possibilities during harvest season it is possible to store corn with high-moisture content as high as 35% moisture. … As long as the fermentation process is carried out under anaerobic conditions the possibility of mold development is eliminated."

"There should not be any problem in feeding livestock with corn that were preserved under anaerobic conditions. … the slight fermentation is an excellent characteristic that improves the nutritional value of the corn for the livestock."

4. Examples of Current Large Scale Applications

4.1 Overview

Today hermetic storage of maize, as well as sorghum, beans, and rice is used on a large scale in a number of countries, such as Ghana, Philippines, Rwanda, South Sudan and Sri Lanka. In Rwanda a total of several hundred large Cocoons, such as those seen in Figures 1, 9 and 10, are used for long-term storage. A Rwandan Ministry of Agriculture report on long-term corn storage concludes (as translated)[4]:

> "... after more than 30 months of storage in some units, we observed the following:
> • The insects present in the grains during initial storage were all dead and no re-infestation was recorded.
> • In most cases the grains remained identical in appearance and preserved their germination potential."

Figure 9: *150 tonne Cocoon™ being closed, corn storage, Rwanda, 2007.*

Figure 10: *Hermetic warehouse storage of corn, Rwanda, 2007.*

4.2 Hermetic Storage of Rice

As a result of extensive studies at the International Rice Research Institute (IRRI), the benefits of storing both rice and rice seeds in HS are now well understood and in widespread use, particularly in Asia. Cocoons are currently in use in sizes from 5 tonnes to 1000 tonnes capacity. IRRI itself has adopted the use of SuperGrainbags, now available with capacities of 10- to 1000-kg. Their permeability to oxygen, depending on the model at 23º C, ranges from 3 to 55 cc/m^2/day. SuperGrainbags serve as liners for either polypropylene or jute outer bags. A group of such liners made from an ultra-low permeability, co-extruded, multi-layer plastic using an inner layer of a proprietary gas barrier is shown at IRRI in Figure 11. SuperGrainbag liners are reusable. Figures 11 and 12 show the 60 kg. capacity versions.

Figure 11: *SuperGrainbags with paddy seed, IRRI, Los Banios, Philippines*

Figure 12: *SuperGrainbag as a liner in a polypropelene container for rice seed at IRRI*

The Cocoons shown in Figure 13 are used in a warehouse of the National Food Authority of the Philippines, to store rice paddy safely for up to one year. Figure 14 shows outdoor storage of 150 tonnes of milled rice, also at the National Food Authority. Hermetic storage applications for rice and/or rice seed are currently found in such countries as: Cambodia, East Timor, Indonesia, India, Pakistan, Philippines, Sri Lanka, and Vietnam.

Figure 13: *Outdoor storage Cocoons*

Figure 14: *Cocoon filled with milled rice, outdoors*

4.3 Hermetic Storage of Corn

Second only to rice, corn (maize) is the commodity most widely stored hermetically. Cocoons in the hundreds are used in Rwanda, Ghana and the Philippines for storing both shelled and unshelled corn. These large flexible HS units are generally used at the village level, but are also used as strategic reserves to prevent famine at the district level.

Small farmers use SuperGrainbags, typically of 60 kg capacity for farm storage. The SuperGrainbag can be hung or kept in a metal drum, or other rodent-resistant outer container. In 2007, 100,000 SuperGrainbags were delivered to Ghana for a variety of uses, including household use.

4.4 Medium and Large Scale Storage of Wheat and Barley

Hermetic storage on a large-scale of wheat in "Bunkers" with capacities ranging from 10,000 to 30,000 tonnes was first introduced in the early 1990's, as shown in Figure 15. Hermetic storage of wheat stored at or below its critical moisture content of 12.5 %, provides storage without significant degradation of quality, including maintenance of baking qualities, for up to 4 years[6]. In Cyprus Bunkers allowed quality preservation of barley for 3 years, with total losses of 0.66% to 0.98%, and with germination remaining above 88%.

Figure 15: *GrainPro Bunker™ storing wheat in Israel*

Storage of wheat in Cocoons and/or Bunkers has reduced losses due to insects or molds to a small fraction of 1% per year. Storing without the need for pesticides is an increasingly important advantage, not only for organically-grown but also for conventionally grown wheat both for environmental reasons and because of the growth of pesticide resistant insects[6,13].

4.5 Hermetically Stored Pulses (Beans)

Bean storage is subject to invasive pests such as *Callosobruchus maculatus* and *C. chinensis*, which are controlled through HS. In Rwanda and Ghana, storage of beans in Cocoons has permitted groups of farmers to hold their crops off the market while waiting for more favorable market prices. Both of these countries have large seasonal price variations, as described in Section 5, leading to major financial benefits for farmers who use HS to postpone sales to a more advantageous time.

4.6 Cocoa Storage Under Tropical Conditions

The safe storage of cocoa under tropical conditions requires special considerations. Cocoa's critical moisture level of 6% at 30º C is often exceeded in storage, 7-8% moisture content is common. Particularly problematic in cocoa bean storage are the deleterious effect of molds, microflora, and oxidation. Oxidation leads to the increase of Free Fatty Acids (FFAs), which have a major impact on the quality of cocoa (rancidity). When cocoa beans are stored hermetically, oxygen levels typically go down to 2% or less within as little as a week, thereby protecting the commodity against insects, oxidation effects and the growth of molds [5,10].

This rapid decline in oxygen level, as seen in Figure 16, is, however, a strong function of moisture level. For instance, the ARO has reported that cocoa with % moisture content of 8.2% at 26ºC, reaches 1% oxygen and 30% CO_2 levels in less than 10 days, while at lower moisture content of 5% a level of 8% O^2 and CO^2 level of 10% was only attained in 21 days[10].

In March 2008, the Ghanaian Cocoa Board completed a 6-week trial on three 1-tonne Cocoons loaded with cocoa at initial moisture content of 6.7% humidity. By the end of the trial, oxygen levels in all 3 Cocoons had reached 0%. "When the Cocoon was opened, it was seen that *Tribolium castaneum, Ephestia cautella, Cryptolestes* spp., *Oryzaephilus surinemensis, Araecerus* spp. were dead at the bottom of the Cocoon when the beans were being packed out. All insects introduced [for test purposes] in the prototype bags were also dead."

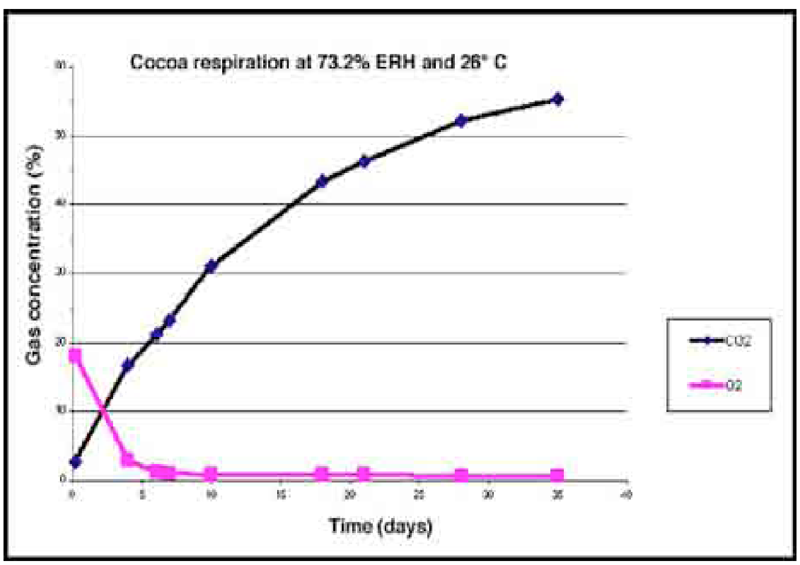

Figure 16: *Changes in modified atmosphere, as time for cocoa beans, 73.2% ERH (Equilibrium Relative Humidity)[11]*

4.7 Coffee Quality Preservation

Although it is still widely believed that coffee is sensitive to high temperature and requires aeration for cooling, field data from various countries, including Costa Rica, shows that preventing the penetration of external humidity alone has proved sufficient to protect coffee bean quality for up to 9-months[1].

Coffee is a yearly crop, requiring the ability to safely store for close to a year. In hot humid climates, deterioration in storage is very significant. In a trial performed by Café Britt in Costa Rica in 2005, they compared HS of coffee using Cocoons to coffee stored in ordinary jute bags or bins. The following conclusions were made by its professional cupper after 5 months of storage: "The [cup average] quality remained at 4.0 [5-point scale] for those in the Cocoon and dropped to 3.0 for unprotected coffee beans. The superiority of coffee stored in hermetic Cocoons became very noticeable."[1]

Coffee is now stored commercially both in the portable SuperGrainbags and in the larger Cocoons. The smaller SuperGrainbags are used both for storage to preserve high-quality coffee and also for long transit time shipments without refrigeration[18].

Producers, traders, and roasters in Australia, Costa Rica, East Timor, Ethiopia, Jamaica, Hawaii, Peru, and the continental United States now practice HS for their green coffee bean storage and transport.

5. Economics of Hermetic Storage

Studies conducted in several different countries have compared the economics of hermetic and other forms of storage. The earlier cited study performed at the Philippine Rice Research Institute (PhilRice), is particularly interesting. It compared four forms of seed storage, namely an unprotected control (CTRL) stored conventionally in a warehouse in bags, hermetic storage (HS), cold room storage (CRS), and air-conditioned storage (ACRS). Unprotected storage was found least expensive for up to three months, but by six months was inadequate for preserving germination capacity. The same report also concludes that after six months, the ranking from most to least cost effective of the three remaining technologies was: #1 Hermetic Storage ($2.52/20 kg bag); #2 Air Conditioned Room ($2.63/20 kg bag); and #3 Cold Room Storage $4.20/20 kg bag). By nine months, the three methods provided similar and adequate germination rates, but CRS and HS provided the lowest insect count, and, as seen in Table 4, by month 6, HS provided the lowest total cost.

Field experience in Africa has shown that Cocoons are being used successfully where previous storage attempts using metal or concrete silos failed[19]. Because of moisture ingress and moisture migration in these relatively high humidity environments, silos have not been satisfactory and often lie empty and unused. As seen earlier in Figures 5 and 6, this is caused when unprotected molds and insect losses become a major factor in the presence of elevated temperature and humidities. Using conventional storage for multiple month storage in much of Africa with their hot and humid climates, losses due to insects alone can be as high as 25%. Appendix I shows the relevant factors.

Table 4. Cost comparison, in Philippines of using four storage methods for preserving Mestizo 1 (PSB Rc72H) hybrid paddy seeds (Using $1 = 50 pesos)

PARTICULARS	STORAGE PERIOD (Months)							
	THREE Months				SIX Months			
	CTRL	HS	CRS	ACRS	CTRL	HS	CRS	ACRS
INVESTMENT COST (U.S. Dollars)	82,250	1,744	12,820	16,230	82,250	1,744	12,820	16,230
OPERATING EXPENSES								
Fixed Cost,	18,095	488	2,820	3,570	18,095	488	2,820	3570
Variable Cost	6,896	16	728	250	12992	16	1.376	379
TOTAL OPERATING EXPENSES	24991	504	3.548	3,820	31,086	504	4,196	3,950
CAPACITY, # OF BAGS	10,000	200	1,000	1,500	10,000	200	1,000	1,500
COST PER BAG, (US$)	2.50	2.52	3.55	2.55	3.11	2.52	4.20	2.63

CTRL = unprotected control stored conventionally in a warehouse in bags; HS = hermetic storage; CRS= cold room storage; and ACRS = air-conditioned storage.

In the case of a high value crop such as cocoa, weight loss of 1% to 2% per month during six-month storage periods has been shown. At a current value of $3,245 per tonne (on July 1, 2008), this monthly loss is worth $64.90 per tonne, while in HS no weight loss is observed. The cost of HS using Cocoons ranges from $20 per tonne to $80 per tonne (depending on size), with a useful life of 10-15 years, resulting in a per year depreciation of $1.33 to $8/tonne/year.

The value of being able to store crops safely for months after harvest in order to take advantage of much higher prices is illustrated in a study performed in Rwanda on beans, sorghum and corn. This study, as seen in Table 5, shows the following results after 68-132 days of storage, resulted in a payback on the Cocoons averaging 97 days[4].

Table 5 – Rwanda Storage Financial Results for Several Crops

District	Location	Group	Commodity	Number of 10-tonne Cocoons	Total Profit In USD	% Profit	Days Storage	Final O_2 % Range
Gatsibo	Kabarore	Karenge	Beans	10	8182	75.00%	120-132	1-4.2
Kayonza	Mukarange	Nyagatovu	Sorghum	2	-1364	-11.11%	95-96	4-6
Gatsibo	Kabarore	Karenge	Beans, Corn	4	1818	21.05%	65-68	3.6-4.2

6. Future Evolution in Use of Hermetic Storage

Because of the continuing growth in the number of uses for hermetic storage and its resulting modified atmosphere, many countries beyond those listed in Appendix II, that have not yet benefited from this process, will undoubtedly do so in the near future. Moreover, still newer forms and applications of HS are being continuously developed. One of the most promising emerging applications is the ability to store bumper harvests of corn for human consumption in HS for relatively short periods of time, such as 8 weeks, at up to 35% humidity versus the normal safe limit of 12.5%, or storage for many months for use as animal feed. This has now been done in Mindanao in the Philippines and allows the spreading out of the drying season through short-term storage under moist conditions.Whether based on sun drying, or use of mechanical dryers, HS of high moisture corn for animal feed eliminates a common bottleneck in drying capacity often responsible for large losses.

Future scientific study is needed to determine the extent to which the preservation of taste, aroma, and quality in commodities such as hermetically stored coffee and cocoa depends primarily on achieving a low oxygen high CO_2 environment (as in the case of cocoa), maintaining constant moisture content (as in the case of coffee) or whether, in addition, there is also, as suspected, a protective effect from numerous volatiles trapped inside the sealed environment.

7. Conclusion

Hermetic storage is a sustainable, cost effective, user-friendly and environmentally benign technology that makes the use of pesticide and fumigants in post harvest and seed storage unnecessary. The technology has already been adapted for the protection of many different commodities in quantities ranging from that of conventional grain bag size to many thousands of tonnes. Applications of hermetic storage are very likely to expand even more rapidly in the future, as the available forms of hermetic storage continue to increase and more users experience and understand the advantages of this “green” technology.

Appendix I – Comparison of Hermetic Storage Vs Conventional Silos in Tropics, from Feed Technology Update[19]

Item of comparison	**Hermetic ("Cocoon™") storage**	**Conventional metal or concrete bin silos**
Control measures if infestation occurs	Control by depleted O2. Gas analyzer enables follow up on infestation level, detection of leak	Grain will have to be unloaded and treated with phosphine (PH3)
Fumigation	Not needed	Required every 6—12 weeks
Condensation at 14% MC	No, if "GrainShade" provided with Cocoon is used properly	High risk storage if above 1 month and grain does not remain sufficiently dry (low moisture content (MC)
Protection from rodents	Protected	Protected
Length of storage	1 to 5 years	1—3 months depending on climate, silo material (metal or concrete), the extent of the exposure of the roof to absorb solar energy, and initial MC of the commodity
Moisture level of commodity	Remains constant	Moisture content will rise significantly
Aeration	Not needed	Is required in temperate climates, but it is ineffective in tropics due to lack of cold nights
Life span of the structure	10—15 years	20—25 years (if metal is painted periodically against corrosion, and concrete with adequate maintenance)
Set up	Can be quickly set up at any location, indoors or outdoors	Needs concrete floor, access road, construction time
Infrastructure required	None	Road, electricity
Auxiliary equipment	None	Bucket elevator, fans, "sweeper" auger
Price per MT (investment)	US$20—US$80	US$100—250 (including infrastructure and handling equipment)
Mobility (ability to move/dismantle silos and move them to another area)	Excellent	Impossible once set up
Hazards	Rodents (but can easily be prevented)	Dust explosion, caking due to excess of moisture content, condensation
Safe storage duration	Proven under tropical conditions for long term storage	Storage may not be safely extended above 1—3 months

Appendix II – Countries and Commodities where Hermetic Storage is in Use

COUNTRIES

Australia, Bangladesh, Botswana, Brazil, Cambodia, China, Costa Rica, Cyprus, Dominican Republic, East Timor, El Salvador, Ghana, Guatemala, Honduras, Israel, India, Indonesia, Jamaica, Laos, Pakistan, Peru, Philippines, Rwanda, Sri Lanka, Sudan, Thailand, Turkey, Uganda, United States, Vietnam, Zimbabwe

COMMODITIES STORED

Barley, Bran, Coffee, Cocoa, High-moisture Corn, Figs, Maize, Narcissus bulbs

Rice (basmati, bran, milled, paddy, organic)

Seeds of Peanuts, Sorghum, Wheat and Hybrid Rice

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