Worldwide developments in ultra hermetic™ storage and solar drying technologies

De Bruin, T. #[1], Villers, P.*[2], Navarro, S.[3]
[1]GrainPro Philippines, Inc., Subic Bay Freeport Zone, Zambalas, 2222 Philippines
[2]GrainPro, Inc., 200 Baker Avenue, Suite 309, Concord, MA 01742 United States
[3]Green Storage Ltd., 5 Argaman St. Rishon Letsion, 7570905 Israel

*Corresponding author, Email: pvillers@grainpro.com
#Presenting author, Email: tdb@grainpro.com

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Abstract

Ultra Hermetic™ storage and solar drying of commodities is providing safe, pesticide-free storage and drying in over one hundred countries. This paper provides an overview of recent major innovations in the use of pesticide-free Ultra Hermetic storage and of drying technologies for a wide array of crops, including rice, maize, pulses, coffee, cocoa, peanuts, and many types of seeds, and the positive implications of these innovations for loss prevention and public health and safety. Innovations have been driven by rapidly growing use of hermetic storage and drying solutions all over the world, for both indoor storage and rugged outdoor typhoon- and flood-resistant storage. A case study of the hermetic storage of seeds, as well as the results of scientific studies of coffee and cocoa stored hermetically without refrigeration or pesticide use, are described. The paper also presents important recent data on the prevention of aflatoxin growth in stored crops, demonstrating that widespread use of Ultra Hermetic storage technology can play an important role in both preventing growth of aflatoxins in storage and in producing safer, healthier food supplies while promoting public health, especially in tropical locations. In specialized applications such as peanut and other oily nut storage, adjunctive use of injected CO_2 or of oxygen absorber packets can accelerate reaching a low oxygen atmosphere. Recent developments in solar drying technology can now provide continuous 24-hour drying. These innovations have been spurred by the widespread growth of Ultra Hermetic storage, now used in 103 countries, and of advanced solar drying technology. Important scientific and product improvements made in both these technologies include large flood- and typhoon-resistant storage units, as well as man-portable, insect-resistant Ultra Hermetic liners for transport and 24-hour/day solar dryers. Ultra Hermetic storage technology is used frequently for high-value crops such as coffee, cocoa, and seeds, but also is widely employed for major staple crops such as rice, maize, wheat and pulses. Other expanding areas of application include spices, sorghum, cassava, peanuts and silage crops.

Keywords: hermetic storage, ultra hermetic™, modified atmosphere, long term storage, flexible storage, and solar drying

1. The worldwide storage problem

Why is the use of Ultra Hermetic storage growing so rapidly? The answer is that it meets some very important needs, the most crucial of which is the elimination of heavy grain losses in hot, humid climates during multi-month periods of storage (Villers et al., 2006b). Losses in East Africa reaches and even exceed 25% loss (Fig. 1), but with the use of Ultra Hermetic storage, can be reduced to less than 1% per year. Ultra Hermetic storage also reduces major public health hazards caused by the growth of aflatoxin-producing molds in stored crops, including maize and peanuts, as discussed in Section 2.3.

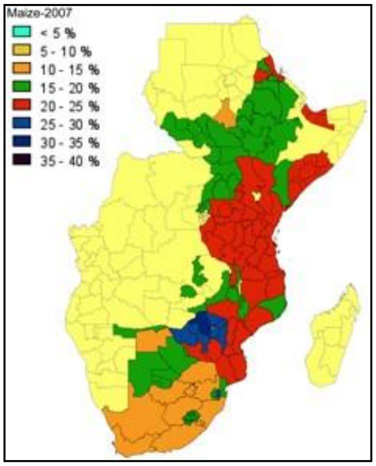

Figure 1 Post-harvest losses of maize, East Africa. (World Bank, 2011)

Figure 2 First generation Solar Dryer.

In general, dry commodities intended for human consumption can be stored safely only if they are dried to a point at or below their critical moisture level, which varies by commodity but which is defined an in equilibrium with 65% r.h. However, the high operating and capital costs of fossil fuel for mechanical dryers is too expensive for much of the developing world. For this reason, there is increasing worldwide demand for efficient solar dryers, which also protect commodities from the rain while drying, as seen in Figure 2 with GrainPro’s Collapsible Dryer Case (CDC™) solar dryers. The newly developed advanced Solar Bubble Dryer™ (SBD) shown in Figure 3 leverages solar gain and allows 24-hours/day drying to accelerate the drying process through forced convection. Two small fans powered either by available electricity or by electricity generated by an optional solar panel creates a constant airflow across the SBD drying surface 24 hours a day. (Rojas-Azucena, 2014).

Figure 3 Solar Bubble Dryer with optional, solar panels.

Figure 4 Man-portable SuperGrainbag, inside a protective bag.

Two different forms of Ultra Hermetic storage are being used to provide safe transport of dry commodities, particularly for intercontinental transport. One is the man-portable bag called the SuperGrainbag (SGB)™ with either a twist and tie or zipper closure, available in various sizes from 25 kg to 1½ tonne capacity (Fig. 4 and 5).

Figure 5 1-tonne capacity SuperGrainbag-HC.

Figure 6 GrainPro TranSafeliner.

The other is the TranSafeliner™ for shipping containers (Fig. 6), an Ultra Hermetic liner that lines a standard, 20 or 40-foot container. Both the SGB and the TranSafeliner are made of the same thin, ultra-low permeability material: a coextruded plastic with a proprietary barrier layer. The proprietary low permeability barrier layer reduces permeability to oxygen to only 3 cc/m^2/day. 500 times lower than that of other available plastics.

2. Improved resistance to insect penetration in man-portable bags

A series of experiments conducted in 2012 at the Technological University, Monterey, Mexico, showed that the newest SuperGrainbag, the co-extruded, multilayer SGB-IV-R, protected successfully against penetration from relevant, major post-harvest insect pests such as Larger Grain Borers (LaGBs), Lesser Grain Borers (LeGBs) and Cowpea Weevils (CWs). In this experiment the patented, SGB-IV-R liners (72 cm x 130 cm) were filled, respectively, with maize, wheat and cowpeas with grains fresh from the field plus added target insects. (Garcia-Lara, 2010). These pests were known to have penetrated previous SuperGrainbag versions.

The SGB-IV-R is now used worldwide; its remaining limitation is that its stored commodities are protected from LaGB or LeGB attacks inside the bag but not from outside. Problems arise with improper sanitation, since these insects are attracted when grain is left scattered around the stored bags. In time, they can make holes because they are not in an unbreathable oxygen atmosphere, unlike insects within the airtight bags.

3. Recent scientific data

3.1. Coffee studies

Along with general growth in the applications and forms of Ultra Hermetic storage, have come a variety of new specialized scientific studies, including an important series of studies on the storage of coffee by Professor Flavio Borem at the Universidad Federal de Lavras in Brazil. He compared the performance of coffee stored both in hermetic 1-tonne, and smaller 69-kilogram GrainPro SuperGrainbags with storage in plain, jute bags. He also compares the performance of hermetic storage used alone to hermetic storage with the addition of injected CO_2. He writes: “The coffee packaged in jute sacks had the highest frequency of flavor classified as poor. Conversely, the flavors classified as good, very good or excellent were predominant in the other types of packaging” (Borem et al., 2013). Quantitative scores are shown in Table 1.

Table 1 Quantitative Value for Coffee Quality after 12-months of storage (Borem et al., 2013).

Mean values of the overall score of the coffee beans after 12 months of storage.		
Big-bag (one-tonne hermetic)	Position	Score
With CO_2	Upper	80.00a
With CO_2	Middle	80.80a
Without CO_2	Upper	78.09a
Without CO_2	Middle	78.06a
Other treatments:		
GrainPro (SuperGrainbag, no CO_2)	GrainPro	78.98a
Jute sack alone	Jute sack	73.03b

Professor Borem also writes: “The color of the coffee bean is related to beverage quality and is an important factor in the valuation of the product. Color variation in green coffee beans is a strong indication of the occurrence of oxidative processes and natural enzymatic biochemical transformations that will alter the composition of the precursors responsible for the flavor and aroma of the beans, resulting in reduced beverage quality. The present study shows that after 12 months of storage, the beans packaged in hermetic big-bags and GrainPro sacks maintained similarly high frequencies of classification as ‘current crop’.”

He further demonstrated that coffee storage in hermetic packaging preserved desirable coffee aromas, while frequencies of sweetness and acidity attributes for the coffees packaged in jute sacks were predominantly low. “Undesirable flavors and aromas predominated in the coffees packaged in jute sacks” (Borem et al., 2013).

3.2. Seed storage studies

Seed storage experiments in Peru by Bayer Crop Sciences (Bayer Crop Sciences, 2012) confirmed the results of previous studies published by the International Rice Research Institute (IRRI) on rice seeds (Villers and Gummert, 2004), and of other seeds in various parts of the world. All show that Ultra Hermetic storage can preserve many types of seeds as well as refrigerated storage but without the energy consumption and capital investment required by refrigeration. Comparative data from CIMMYT on maize seeds in Mexico is shown in Figure 7, also showing the need for proper drying before storage (Das et al., 2010), while Figure 8 shows results for cotton seed (Bayer Crop Sciences, 2012). Dr. Sabio’s study shows that Ultra Hermetic storage can achieve the same results as air-conditioned storage minus the capital and operating cost (see also Section 5).

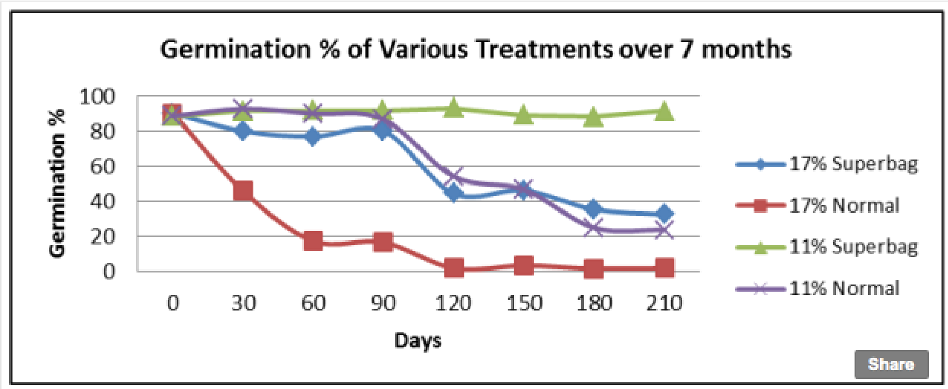

Figure 7 Comparative data on maize seeds of 11 and 17% moisture content from CIMMYT, Veracruz, Mexico (2010).

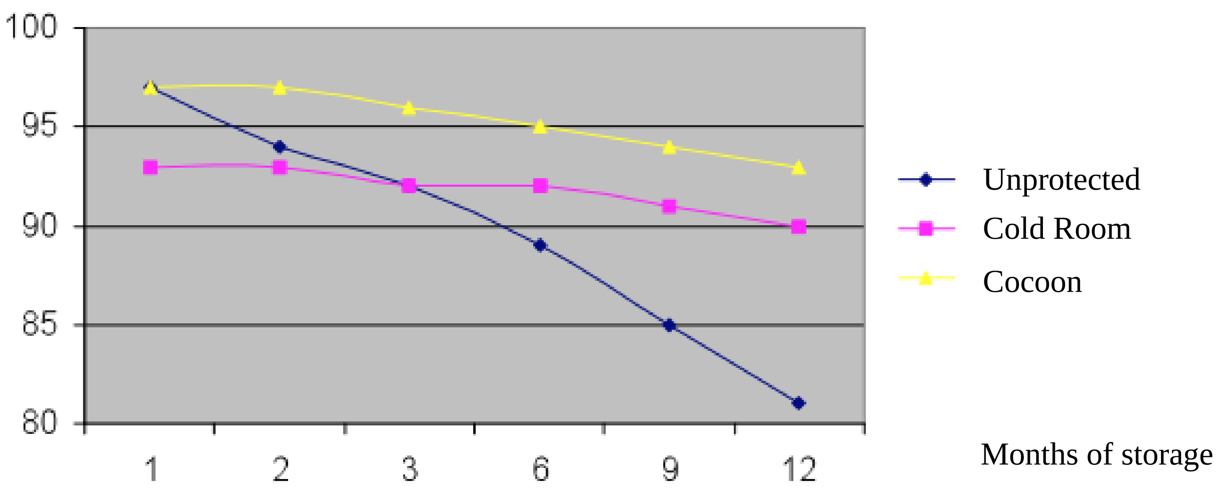

Figure 8 Cotton seed germination for 12-month storage, Peru, 2012.

Table 2 Comparison of 4 methods of paddy seed storage. (Sabio et al., 2006)

Method	Storage duration (months)			
	0	**3**	**6**	**9**
Hermetic (HS)	1.13	3.82	3.22	8.42
Cold Storage (CRS)	0.96	0.38	0.64	0.56
Air Conditioned (ACRS)	0.84	0.76	8.58	38.27
Control (CTRL)	0.35	16.95	79.4	147.84

Mean percent adult insect density per kg sample of Mestizo 1 hybrid paddy seeds stored under different storage technologies and durations.

3.3. Aflatoxin effects and prevention

As reported by Dr. J. H. Williams of the University of Georgia, USA, a survey of local African markets shows that 40% of the commodities found there exceeded permissible levels for aflatoxins in foods (in excess of the international standard of 10 to 20 ppb), putting an estimated 4.5 billion people in developing countries at risk. As further reported by Dr. Williams, a cross-sectional study conducted in Ghana shows that immune systems of recently HIV-infected people are significantly modified if they have above-median levels of natural exposures to aflatoxins. Moreover, "People with a high aflatoxin biomarker status in the Gambia and Ghana were more likely to have active malaria" (Williams, 2011). In 2010, 10% of the Kenya maize crop was condemned because of excessive aflatoxin levels. It is known that high aflatoxin levels in the bloodstream, by depressing the immune system, facilitate cancer, and HIV and stunt the growth of children (Gong et al., 2014). Likewise, excessive aflatoxin levels cause failure-to-thrive in farm animals such as chickens and turkeys (Oladele, 2014).

An increasing amount of scientific research has been devoted to learning more about dealing with the aflatoxin problem and possible solutions, including the use of genetically modified seeds formulated for resistance to aflatoxins or of biological controls such as AflaSafe, now used in Africa. However, a neglected part of solving the aflatoxin problem continues to be preventing the growth of aflatoxin levels in stored commodities exposed for prolonged periods to high temperatures and to relative humidity above 65%. These conditions are commonly found in the tropics, while in temperate climates the same problems can be controlled largely with ventilation during cooler nights and lower winter temperatures. In the tropics, conventional storage for more than two months causes rapid growth of aflatoxins, as shown in field studies by Icrisat in Mali (Table 3) (Waliyar, 2002). More recent, from Millennium Villages using unpublished data sampling 2000 farmers in Ruhiira, Uganda as analyzed by the Dept. of Food Science, Matere University in, confirms the Mali data (Fig. 9).

Table 3 Increase in aflatoxin concentration during storage. (Icrisat in Mali) (2013)

Village	Aflatoxin content (ppb)		
	At harvest	1 month in storage	2 months in storage
Bamba (5)	101.3	168.9	275.5
Gouak (5)	61.4	118.0	174.7
Kolokani (5)	119.2	352.6	400.0
Sido (5)	53.7	93.6	166.2

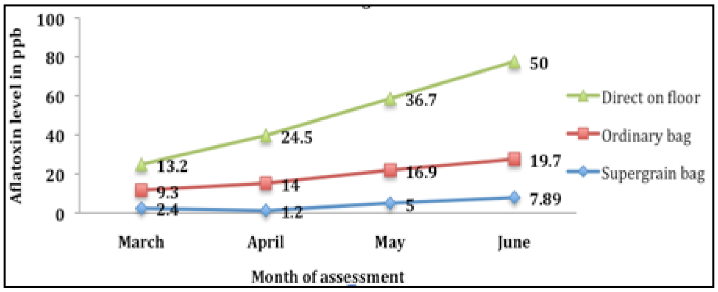

Figure 9 Aflatoxin growth in maize in different storage conditions in Ruhiira, Uganda, Millennium Villages study, 2013.

Peanuts are often contaminated with aflatoxins before storage, but (unlike most grains) may take as long as 30 days or so to reach a 3% oxygen level in Ultra Hermetic storage (Navarro et al., 2012). This is too long a period to prevent major increase of aflatoxin levels. For this reason, one of two forms of accelerant is used. For field operation and portable bags, an oxygen-absorbing sachet weighting 65 g per 69 kg capacity is sufficient. For large storage units or volume production, injecting carbon dioxide to drive out the air is adequate (Villers, 2014).

Table 4 shows mold growth densities measured in CFUs after 90 days (Navarro et al., 2012). The table shows two orders of magnitude difference in mold density for crops stored in conventional (the Control) vs. hermetic storage, using carbon dioxide injection. Hermetic storage alone, even without injected carbon dioxide, still shows a five-fold improvement vs. the Control. Unfortunately, in this particular study, aflatoxin-producing molds turned out to be largely absent in the mold mix, and therefore the data of Table 5 does not include direct measurement of the growth of aflatoxin, as distinct from all molds (CFU). Table 5 shows the significant improvement with hermetic storage alone and even greater improvement with the early addition of carbon dioxide in controlling the growth of rancidity-producing FFAs (Free Fatty Acids).

Table 4 Showing aflatoxin growth in maize (7% moisture content) (Navarro et al., 2012).

Test Parameters	**Initial**	**After 90 days**			
		Hermetic with 3% broken peanuts	**Hermetic plus CO2 with 3% broken peanuts**	**Control clean peanuts**	**Control with 3% broken peanuts**
% Moisture Content	5.97+/- 0.0 3	7.20 +/- 0.21	6.60 +/- 0.40	6.33 +/- 0.53	6.60 +/- 0.26
FFA (% oleic acid)	0.36 +/- 0.0 1	0.70 +/- 0.17	0.43 +/- 0.07	0.57 +/- 0.03	1.50 +/- 0.12
CFU molds	$3*10_2$	$1.7*10_3$ +/- $1.2*10_2$	$9.7*10_1$ +/- 28	$1.3*10_4$ +/- $9*10_3$	$4*10_4$ +/- 10_3

3.4. Cocoa storage studies

Cocoa beans deteriorate rapidly in hot, humid climates in conventional storage. But if properly dried to 7% moisture content, they can be well-preserved, and the growth of rancidity-producing Free Fatty Acids can be effectively controlled for up to 160-days with the low-oxygen, high CO_2

atmosphere of hermetic storage in GrainPro Cocoons, as used extensively by the Cocoa Board of Ghana (Cocobod). According to an unpublished report by Gorkeh-Seykan, head of Quality Control at the Board (Gorkeh-Seykan, 2013), their experiments conducted in 2008 in Tema, Ghana, with both stored stacked bags of cocoa beans in Cocoons (Fig. 10), 60 kg bags of cocoa in SuperGrainbags (Fig. 4), or using TranSafeliners for gas-tight lining of shipping containers (Fig. 6), all showed that the resulting low oxygen/high carbon dioxide atmosphere was able to eliminate the insect population in less than two weeks. The Cocoon trials involved three stacks for hermetic storage and one stack each for conventional storage without fumigation and compared with standard storage with fumigation. At the sixth week of storage, 100% mortality of insects was recorded in the Cocoon. All the cocoa beans inside the Cocoon maintained their quality category throughout the storage period. After nine weeks of storage, the grade remained the same in hermetic storage as it was at the beginning of the experiment (Jonfia-Essien et al., 2010).

Figure 10 Cocoa in a hermetic Cocoa Board of Ghana (CocoBOD) Cocoon, Tema, Ghana. (Jonfia-Essien, 2008)

4. Role of strategic stores

Countries in many parts of the world are recognizing the importance of maintaining adequate reserves to stabilize commodity prices. Large fluctuations in prices have a devastating impact on the poor and, not too surprisingly, create social unrest. Countries such as the Philippines and Nigeria have adopted the goal of achieving self-sufficiency in key crops. In the Philippines, the goal is self-sufficiency in rice using a large number of Cocoons with up to 150-tonne capacity each. In Nigeria, the goal is elimination of the need for foreign grain imports. Since harvests vary and only occur once or twice a year, maintenance of large stores is a strategic necessity maintained in private or government hands. However, in too many countries, including in the widely publicized case of India, conventional long-term storage causes rapid deterioration and massive loss of stored commodities (New York Times, 2012). This is where the use of large size, Ultra Hermetic storage, such as 1,000-tonne Cocoons™, 1,050-tonne Mega Cocoons™ and up to 15,000-tonne Hermetic Bunkers™ such as are used for long-term storage in Cyprus, Jordan and Israel, have been shown to play an important role in driving storage losses down to less than 1% per year, while also substantially suppressing the growth of aflatoxins (Fig. 11).

Figure 11 Cocoons of 150 tonnes in Philippines.

Figure 12 Cocoon II – For low-cost indoor storage of 4 to 36 tonnes.

5. Current forms of Ultra Hermetic storage

Forms of Ultra Hermetic storage are increasingly specialized. Patented (0.078mm thick) coextruded plastic liners for smaller-sized bags provide an extremely low permeability to oxygen, and therefore to many other gases, namely 500 times lower than with conventional plastic alternatives such as polyethylene and causes rapid and reliable asphyxiation of all air-breathing organisms. Insect, microorganism and commodity respiration reduces oxygen levels to below 3%, and carbon dioxide levels typically reach 15%, when low permeability results in insect and other respiration rates to be greater than residual rates of oxygen infiltration.

The same coextruded plastic material furnished with a simple outer cover (Cocoon II, Figure 12) is a new lower cost solution with a shorter life span than standard Cocoons designed for indoor use. It uses materials similar to those of the TranSafeliner™ that provide protection during intercontinental shipments.

Fully loaded Cocoons have now been shown other recent innovations include a new, portable oxygen meter, which increases the life of the oxygen sensor from one year to five years; and a new, inexpensive aflatoxin field test kits for rapid field measurements to make sure grains that go into storage are below the permissible 10- to 20-ppb international standard.

Other, non-Ultra Hermetic technologies also are in use. In Africa, they include the Purdue PICS bag (Purdue Improved Cowpea Storage), which is used to combat the Cowpea Weevil. In some areas, so-called "hermetic bags" made of plain polyethylene have been introduced claiming equivalent performance, although they are 500 times more permeable and have very different commodity preservation characteristics. "Silo bags" made of plain polyethylene use specialized machinery to stuff grains in long tubular arrangements (up to 100 meters long). They are being used in Argentina and a number of other countries.

6. Economic comparisons, Ultra Hermetic storage versus alternatives

Studies conducted in several different countries have compared the economics of hermetic with other forms of storage, such as a study performed at the Philippine Rice Research Institute (PhilRice). 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 (HS) ($2.52/20kg bag); #2-Air Conditioned Room (ACRS) ($2.63/20kg bag); #3-Cold Room Storage (CRS) ($4.20/20kg bag). By nine months, the three remaining methods provided similar and adequate germination rates, but CRS and HS provided the lowest insect count. By month six, HS provided the lowest total cost (Sabio, et al., 2006; Villers and Gummert, 2009) (Table 5).

Table 5 Cost comparison of using, conventional, hermetic, cold room and air-conditioned room storages for preserving Mestizo 1 (PSB Rc72H) hybrid paddy seeds (Using $1 = 50 pesos).

PARTICULARS	STORAGE PERIOD (Months)							
	THREE (3)				SIX (6)			
	CTRL	HS	CRS	ACRS	CTRL	HS	CRS	ACRS
INVESTMENT COST (U.S. Dollars)	82,250	1,744	12,820	16,230	82250	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, BAG	10,000.00	200.00	1,000.00	1,500.00	10,000.00	200.00	1,000.00	1,500.00
COST PER BAG, (US$)	2.50	2.52	3.55	2.55	3.11	2.52	4.20	2.63

In general, storage cost of Ultra Hermetic containers varies from under $10/tonne for multi-year Bunkers to $20/tonne for 10- to 15-year life 1050-tonne capacity MegaCocoons. For smaller units, reusable TranSafeliners™ cost is $6/tonne to $8/tonne, and small 60 kg to 2-tonne reusable SuperGrainbags™ from $13/tonne to $31/tonne. Figure 13 shows cost comparison for 4 methods of storing green coffee.

Inputs	
Cost SuperGrainBag (FOB)	1.85
Cost jute bag	2.5
Cost Al.foil 15 kg	0.7
bags per 20' container	320
weight 20' container in KG	19200
Price 20 MT Cocoon (FOB Manila)	2650
Price TSL 20' container (FOB)	120
Bag woven PP	0.25
Storage cycles per year	2
Years depreciation Cocoon	10
Output calculated per 20' cont	
Jute bags	800
Cocoon +TSL+PP bags	332.5
Alum Foil *)	896
SuperGrainbag inside PP bag	672

*) not including price for cartons

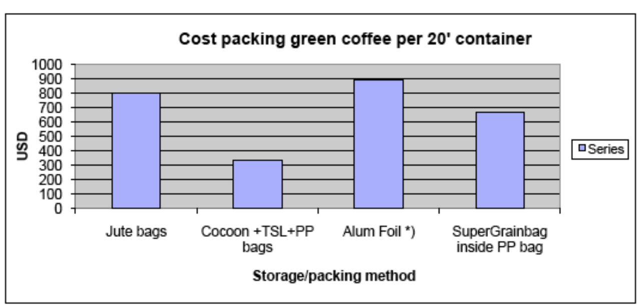

Figure 13 Comparative Cost Calculations Dorman (VolCafe Kenya) (in USD) (De Bruin, 2012).

7. Conclusion

Pesticide-free, Ultra Hermetic storage and its companion technology solar drying, have been shown to be effective in eliminating the heavy losses of quantity and quality resulting from traditional storage of dry commodities in hot, humid countries by drastically reducing these losses from an all-too-common 25% to less than 1% per year. As a result, Ultra Hermetic storage in its many forms has already reached and is being used in 103 countries to protect a growing number of dry commodities as described in this paper. In addition to large reduction of losses, there are significant environmental advantages to the use of hermetic storage. These include the elimination of pesticides for food preservation and of refrigerated storage for preservation of seeds for germination. Further, hermetic storage prevents significant growth of aflatoxins, a major public health hazard.

Certain industries, such as high quality coffee producers, have largely adopted Ultra Hermetic storage as their *de facto* standard (C & CI, 2011). Large-scale storage of rice, pulses and maize is increasingly popular, with availability of Cocoons in capacities of 150- to 1,000-tonnes, man-portable formats as represented by the SuperGrainbag, and a number of offerings in between, with the 1-tonne GrainSafe and the less expensive one-tonne SuperGrainbag HC-1 being preferred options.

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