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Recent Developments in Hermetic Storage Technology Using Sealed Flexible Storage Structures

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Abstract: Restrictions due to the adverse effects of pesticide residues in food and the environment have resulted in the imposition of strict limitations on pesticide registration by regulatory agencies. Consumer demand for chemical-free and insect contamination-free products has increased the attention for 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 production 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, coffee beans, cocoa beans, and high moisture corn. Biogeneration takes advantage of the atmospheric gas composition produced by the respiratory metabolism of the biological agents of the grain bulk which prevents insect development and suppresses microflora activity. Sufficiently sealed structures enable insects and other aerobic organisms in the commodity, and/or the commodity itself, to generate an MA by reducing the O_2 and increasing the CO_2 concentrations. 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 or use of CO_2 to accelerate the process. These niche applications of MAs have resulted in very promising treatments with market acceptability. As discussed and illustrated, hermetic storage for dry commodities is now used in 31 countries for storage of a number of important commodities. The growing number of types of hermetic containers for various applications 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.

Key words: hermetic, controlled atmosphere, modified atmosphere, pesticide-free, Cocoons, SuperGrainbags, TranSafeliner, molds, insects, grain storage, seed storage, long-term storage, fumigation, disinfestations, organic, V - HF, G - HF.

Introduction

Hermetic storage technology has emerged as a significant alternative to other methods of storage that provide means of commodity protection from insects and molds, especially in hot and humid climates. This technology, also termed sealed storage, airtight storage, or assisted hermetic storage is a form of biogenerated modified atmosphere. 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[1,2,3]. Hermetic storage generates a modified atmosphere in an environmentally safe and sustainable manner that eliminates the need for chemical treatments or fumigants.

Modern hermetic storage results from important scientific work carried out at the Agricultural Research Organization in Israel[4]. Only in the last several years has hermetic storage emerged as an important, widely used alternative method of post harvest storage. This is due, in part, to increasing concerns about the use of residual pesticides which endanger the fumigator, the environment, and the consumer, as well as to growing field experience.

1 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, pulses, 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.

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1.1 Low Oxygen Modified Atmosphere to Eliminate Infestations

A sufficiently low oxygen and elevated CO_2 atmosphere is created through a natural metabolic process based on insect respiration and/or the respiration of other microorganisms within a sealed storage system. When a level of less than 2% oxygen is reached mortality of all insect stages is achieved rapidly[1]. When needed, this process can be accelerated by the use of "Vacuum – Hermetic Fumigation" (V – HF) or "Gas – Hermetic Fumigation" (G – HF), using injected CO_2.

1.2 Prevention of Ingress of Water vapor

By preventing the entry of additional water vapor into a hermetically sealed container, dried commodities are protected from humidity. This prevents a rise in their moisture content beyond their critical moisture level, thus overcoming the limitations that make conventional silos unsatisfactory in tropical climates[5].

1.3 Protection from Rodents

Properly designed hermetic storage, because of its slippery surface, when kept taut, is highly rodent resistant. Rodent resistance is provided 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[6,7,8].

1.4 Preservation of Germination and vigor in Stored Seeds

The International Rice Research Institute (IRRI) in the Philippines has extensively tested and recommends the use of hermetic storage for rice seeds and paddy[9]. A PhilRice study compared: hermetic storage (HS), air-conditioned storage (ACRS), and cold room storage (CRS). All performed substantially the same. The study concluded that for storage for nine months or more, hermetic storage provided better performance as compared to previously used techniques but at a lower overall cost, and that after 3 months conventional storage (CTRL) was inadequate to meet the certified seed 85% germination requirement[10] (Tables 1 and 2).

1.5 Quality Preservation Aroma and flavor

Sealed hermetic containers preserve the quality of aromatic dried plant material such as spices. Hermetic storage traps the aromatic volatiles that are emitted by such commodities and maintains the aroma and flavor of such commodities as coriander, turmeric tuber, chili pepper, coffee (Fig. 1), cocoa and basmati rice[1,11].

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	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

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
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ACRS	0.84	0.76	8.58	38.27
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2 Examples of Current Large Scale Applications

2.1 Overview

Hermetic storage of maize, as well as sorghum, beans, and rice is currently used on a large scale in a number of countries such as Ghana, Philippines, Rwanda, South Sudan and Sri Lanka. Cocoons™ are used for long-term storage in Rwanda (Figures 2 and 3). A Rwandan

Fig. 1 Storing high quality coffee using GrainShade to prevent moisture migration and preserving its quality.

Ministry of Agriculture report on long-term corn storage concludes "after more than 30 months of

storage insects present in the grains were all dead and no re-infestation was recorded; grains remained identical in appearance and preserved their germination[12]."

Fig. 2 Corn storage in a Cocoon™ of 150 tonnes in the process of sealing, Rwanda, in 2007. (Courtesy of GrainPro Inc.)

2.2 Hermetic Storage of Rice

As a result of extensive studies at IRRI[9] and later by PhilRice[10], over the last 10 years, the benefits of storing both rice and rice seeds in hermetic storage are now well understood and in widespread use, particularly in Asia. The Cocoons shown in Figure 4 are used in a warehouse of the National Food Authority of the Philippines, to store rice paddy safely for up to one year. Hermetic storage applications for rice and/or rice seed are currently found in such countries as: Cambodia, East Timor, Indonesia, India, Pakistan, Sri Lanka, and Vietnam[13].

Multi-tonne storage containers called Cocoons are currently in use in sizes from 5 tonnes to 1000 tonnes capacity. IRRI itself has also adopted the use of the portable hermetic storage liners called SuperGrainbags™, now available with capacities of 10 to 1000 kg. SuperGrain Bags serve as liners for either polypropylene or jute outer bags (Figure 5). Recently, a hermetic liner for 20' and 40' shipping containers called TranSafeliner™ became available (Figure 6).

Fig. 3 Hermetic warehouse storage of corn, Rwanda, in 2007 (Courtesy of GrainPro Inc.)

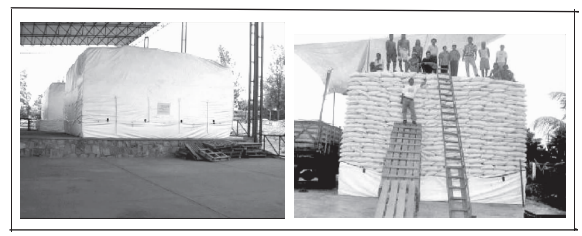

Fig. 4 Cocoons™ in the Philippines warehouse of National Food Authority

Fig. 5 Supergrain Bags™, filled with paddy seed. IRRI, Los Banios, Philippines

Fig. 6 TranSafeliner™ installed in 20 – ft. shipping container, 2008. (Courtesy GrainPro Philippines, Inc.)

2.3 Hermetic Storage of Corn

Cocoons are widely used in Rwanda, Ghana and the Philippines for storing both shelled and unshelled corn, typically in capacities ranging from 50 to 150 tonnes. Similar results were obtained for corn when stored in 60 kg capacity SuperGrain Bags. The large flexible hermetic storage units are generally used at the village level, but also as strategic reserves to prevent famine at the district level[1,13,14]. In 2007,

100,000 Super Grain Bags were delivered to Ghana for a variety of uses, including household use.

2.4 Medium and large Scale Storage of Wheat and Barley

Hermetic storage 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 Fig. 7. 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[15,16,17]. In Cyprus such Bunkers allowed quality preservation of barley for 3 years, with total losses of 0.66% to 0.98%, and with germination remaining above 88%[17].

Fig. 7 GrainPro Bunker™ storing wheat in Cyprus.

2.5 Hermetically Stored Pulses (beans)

Beans in storage are subject to invasive pests such as *Callosobruchus maculatus* and *C. chinensis*, which are controlled through hermetic storage In Rwanda and Ghana, storage of beans in Cocoons of 20 to 150 tonne capacity has permitted groups of farmers to hold their crops off the market while waiting for more favorable market prices[12].

2.6 Cocoa Storage under Tropical Conditions

Cocoa's critical moisture level of 6% at 30 ℃ is typically exceeded in storage, often at 7% – 8%. This leads to the growth of molds. When cocoa beans are stored hermetically, oxygen levels are typically depleted to less than 2% within as little as a week, thereby preventing the growth of molds (as well as protecting against insects and oxidation effects)[18]. In a 6-week trial by the Ghanaian Cocoa Board, three Cocoons were loaded with cocoa. By the end of the trial, oxygen levels in all 3 Cocoons had reached 0% and complete insect mortality was observed.

2.7 Coffee Quality Preservation

Field data from Costa Rica shows that preventing the penetration of external humidity alone has proved sufficient to protect coffee bean quality for up to 9-months[11]. Coffee is now stored commercially in portable SuperGrainbags, or in larger Cocoons for storage to preserve quality, and also, for long transit – time shipments in shipping containers without refrigeration[19], using SuperGrainbags, or TranSafeliners™. Hermetic coffee storage of green coffee beans is now practiced in Costa Rica, East Timor, Ethiopia, Jamaica, Hawaii, Peru, and the continental United States. A recent U.S. scientific study of coffee and its processing effects concludes, "overall it appears that under standard warehouse conditions, long – term storage in GrainPro [hermetic storage], compared to jute, may preserve coffee much better, leading to moisture content in the desired range and ultimately to better cup scores"[20]

3 Economics of Hermetic Storage

Studies performed by PhilRice[10] compared four forms of seed storage: unprotected control stored in a warehouse in bags (CTRL), hermetic storage (HS), cold room storage (CRS), and air-conditioned storage (ACRS). The report calculated the total storage cost of the three technologies meeting the certified seed 85% germination threshold, and of the unprotected control (CTRL): CTRL $ 2.50/20 kg bag; HS $ 2.52/20 kg bag; ACRS $ 2.63/20 kg bag; CRS $ 4.20/20 kg bag. By nine months, all three remaining methods provided similar and adequate germination rates, but CRS and HS provided the lowest insect count, and by month 6, hermetic storage provided the lowest total cost (Table 3).

Field experience in Africa has shown that Cocoons are being used successfully where previous storage attempts using metal or concrete silos failed[5]. 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 due to the damage caused by insects, while in hermetic storage no weight loss is observed[18]. The cost of hermetic storage using Cocoons, ranges from $ 20 per tonne to $ 80 per tonne, with a useful life of 10 – 15 years, resulting in a per year depreciation of $ 1.33 to $ 8/tonne/year. The value of storing crops safely for months after harvest to take advantage

of much higher prices is illustrated in a study performed in Rwanda on beans, sorghum and corn, which resulted in an average payback of 97 days[21].

Table 3. 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 ($ US)	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[10].

4 Conclusions

Hermetic storage is a sustainable, cost effective, user-friendly and environmentally benign technology that renders post-harvest use of pesticide, fumigants, and climate control 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.

References

[1] Navarro, S. Modified Atmospheres for the Control of Stored – Product Insects and Mites. In: Insect Management for Food Storage and Processing, Second Edition. Heaps, J. W. Ed., AACC International, St. Paul, MN, 2006. pp. 105 – 146

[2] Villers, P., De Bruin, T., Navarro, S. Development and Applications of the Hermetic Storage Technology. In: I. Lorini et al. (eds) Proceedings of the 9th International Working Conference on Stored Products Protections Campinas, Sao Paulo, Brazil, ABRAPOS, 2006. 719 – 729 pp

[3] De Bruin, T., 2006. A User's Introduction to Hermetic Storage How it Works. (unpublished). GrainPro Document Number SL2322TDB0506 – 4. GrainPro, Inc. Concord, MA USA

[4] Navarro, S. and Donahaye, E. Innovative Environmentally Friendly Technologies to Maintain Quality of Durable Agricultural Produce. p. 205 – 262. In: S. Ben – Yehoshua (Ed.), Environmentally Friendly Technologies for Agricultural Produce Quality, CRC Press, Taylor & Francis Group, Boca Raton, FL. 2005

[5] Villers, P., De Bruin, T., Navarro, S. Safe Storage of Grain in the Tropics. Feed Technology Update. Vol. 1, Issue 3, 2006

[6] Navarro, S., Varnava, A. and Donahaye, E. 1993. Preservation of grain in hermetically sealed plastic liners with particular reference to storage of barley in Cyprus. Pages 223 – 234. in: Navarro, S. and Donahaye, E. ed., Proceedings International Conference on Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd., Jerusalem

[7] Navarro, S., Donahaye, E. and Fishman, S. 1994. The future of hermetic storage of dry grains in tropical and subtropical climates. Pages 130 – 138. in: Proceedings of the 6th International Working Conference on Stored – Product Protection. E. Highley, E. J. Wright, H. J. Banks, and B. R. Champ Eds., April 1994, Canberra, Australia. CAB International, Wallingford. United Kingdom

[8] Navarro, S., Donahaye, E. J., Caliboso, F. M. and Sabio, G. C. 1998. Outdoor Storage of Corn and Paddy Using Sealed – Stacks in the Philippines. In: Proc. 18th ASEAN Seminar on Grains Postharvest Technology, 11 – 13 March 1997, Manila, Philippines Pages 225 – 236

[9] Rickman, J. F. Aquino, E. 2004. Appropriate Technology for Maintaining Grain Quality in Small – scale Storages. CAF2004 International Conference on Controlled Fumigation in Stored Products 8 – 13 August 2004 Gold Coast, Australia

[10] Sabio, G. C., Dator, J. V., Orge, R. F., Julian, D. D. T., Alvindia, D. G., Miranda, G. C., Austria, M. C. 2006. Preservation of Mestizo 1 (PSB Rc72H) Seeds Using Hermetic and Low Temperature Storage Technologies. GrainPro Docu-

ment SL2329GCS1206. 2006
[11] Aronson, S., Raudales, R., Trubey, R., and Villers, P. 205. Breakthrough in Storing High Quality Coffee. Tea & Coffee Trade Journal, Vol. 177/No. 11. November, 2005
[12] Rwandan Ministry of Agriculture (MINAGRI), 2006. "Systeme de Stockage au Rwanda: 36 mois d'experience" MINAGRI. Kigali, Rwanda
[13] Montemayor, R. 2004. Better Rice in Store. *World Grain*, November, 2004
[14] Navarro, S., Donahaye, E., Caliboso, F. M., and Sabio, G. C. (1995). Application of modified atmospheres under plastic covers for prevention of losses in stored grain. Final Report submitted to U. S. Agency for International Development, CDR Project No. C7 – 053, August 1990 – November 1995. 32 pp
[15] Navarro, S., Donahaye, E., Kashanchi, Y., Pisarev, V., and Bulbul, O. 1984. Airtight storage of wheat in a P. V. C. covered bunker. Pages 601 – 614. In: Proc. Intl. Symp. Practical Aspects of Control1ed Atmosphere and Fumigation in Grain Storages. B. E. Ripp, H. J. Banks, D. J. Calverley, E. G. Jay, and S. Navarro, Eds., Elsevier, Amsterdam
[16] Navarro, S., Varnava, A. and Donahaye, E. 1993. Preservation of grain in hermetically sealed plastic liners with particular reference to storage of barley in Cyprus. Pages 223 – 234. in: Navarro, S. and Donahaye, E. ed., Proceedings International Conference on Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd., Jerusalem
[17] Varnava, A. and Mouskos, C. 7 – Year Results of Hermetic Storage of Barley Under PVC Liners: Losses and Justification for Further Implementation of This Method of Grain Storage. In: Donahaye, E. J., Navarro, S., and Varnava, A. [Eds.] Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, 21 – 26 April 1996, Printco Ltd., Nicosia, Cyprus, 1997. pp. 183 – 190
[18] Navarro, S., deBruin, T., Montemayor, A. R., Finkelman, S., Rindner, M., and Dias, R. (2007) Use of biogenerated atmospheres of stored commodities for quality preservation and insect control, with particular reference to cocoa beans. In: S. Navarro, C. Adler, J. Riudavets, V. Stejskal (Eds.), *Proceedings of the Conference of the International Organization for Biological and Integrated Control of Noxious Animals and Plants* (*IOBC*). West Palaearctic Regional Section (WPRS) (OILB SROP) Working Group on Integrated Protection of Stored Products Bulletin Vol. 30 (2), 2007, Prague, Czech Republic, September 20 – 23, 2005
[19] GrainPro "SuperGrainbags™: taking cocoon technology to sea", Coffee & Cocoa International, February/March 2006 issue, page 41. GrainPro document # PU2001PV0406, GrainPro, Concord, MA USA, 2006
[20] Harris RLW, Miller A., "Keeping it Real: Storing & Preserving Green Coffee Part 2 of 2", Roast, 2008, July/August, 31 – 38
[21] "Economic Study: Storage of Beans, Sorghum and Corn in Rwanda", Tom de Bruin, GrainPro Document # SL2351TDB0608, 2007. GrainPro, Inc. Concord, MA USA