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Aflatoxin Growth *versus* Safe Pre- and Post-Harvest Drying and Storage

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Abstract

Discussed are field tested solutions including Ultra Hermetic storage™ contributing to solving the dual global issues of reducing food losses and protecting food safety during drying and storage of grains in a world of growing climate change.Data is provided on post harvest losses, on the public health hazard posed by aflatoxins, and how these problems are aggravated by hot, humid climates. Field data on drastically reducing growth of aflatoxins in storage is described. The storage requirements for moisture control and oxygen levels are specified for pesticide-free storage using airtight storage, including hermeticity requirements needed. Such systems are now used in 107 countries. Benefits include major storage loss reduction – typically to less than 1% for up to 1-year of storage even in the tropics, as compared to typical losses up to 25%, and the inhibition of growth of aflatoxin-producing molds. Data on the application of the same technology to safe, multi-month seed storage without refrigeration as documented by the IRRI and others. Quantitative data is presented. Comparison of conventional storage, air-conditioned and refrigerated storage with Ultra Hermetic storage is provided.Also described are the available forms of both Ultra Hermetic Storage and improved solar drying for cost effective solutions to improve both farmer income and nutrition during what many developing countries refer to as the "starving season". This helps solve food insecurity with increased abilities to preserve commodities in good condition for up to a year or more, as well as facilitate exports by meeting international standards.

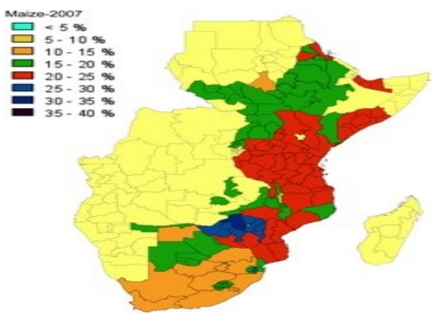
Keywords

Aflatoxins
Cocoon™
Hermetic Storage
Solar Drying
Ultra Hermetic™

GRAIN STORAGE PROBLEMS IN HOT, HUMID CLIMATES AND NEW SOLUTIONS

The preservation of crops in post-harvest storage and ensuring of food safety are worldwide problems, but particularly acute in hot, humid climates found in large parts of Africa (Villers et al., 2006), Southeast Asia and Latin America (Bajaj, 2012). Solutions require preventing high storage losses from insect infestation (Das and Atlin, 2010), various oxidation effects, the growth of mold-producing aflatoxins (Kang, 2011), and loss of seed germination capacity. (DeBruin et al., 2012). Losses in conventional post-harvest storage for multiple months can exceed 25%, as documented by the World Bank for the storage of maize in East Africa in Figure 1. (Zorya et al., 2011).

Figure 1: 2001 Report on post-harvest losses of maize in East Africa



The effect of high temperatures on insect density during grain storage in tropical climates is shown in Figure 2, and the mold-producing effect of high humidity in commodity storage is shown in Figure 3 (Villers et al., 2006).

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Figure 2: Typical insect density vs. temperature

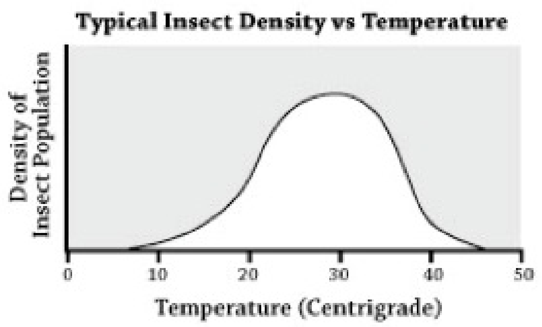
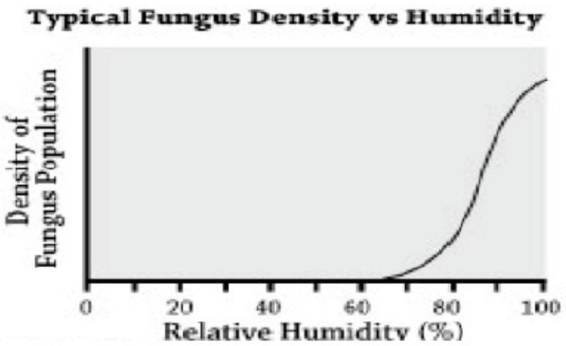


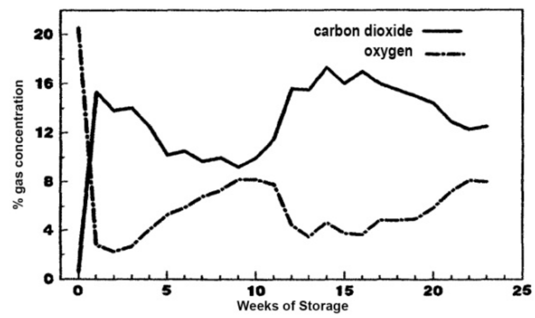
Figure 3: Aflatoxin - producing molds – typical fungus density



A proven solution to the three problems of insect infestation, aflatoxin growth and loss of seed germination capacity during storage in hot, humid climates has been found to be Ultra Hermetic™ storage. This modern method of post-harvest storage is an organic way of creating an unbreatheable low-oxygen/high-carbon dioxide storage atmosphere through the respiration of insects without the use of pesticides (DeBruin et al., 2014). Currently Ultra Hermetic storage is most commonly used to store rice, maize, beans, wheat, and peanuts as well as high value crops such as seeds, coffee, chia nuts and cocoa beans. In the tropics, in the case of seeds, it preserves seeds as well as refrigerated storage, but without the energy requirement.

An Ultra Hermetic™ storage environment is defined as occurring when the rate of residual infiltration of air into the storage unit is less than the rate of respiration produced by insects, other microorganisms, and sometimes the stored commodity itself. The result is an unbreatheable atmosphere. These airtight conditions can be met by use of specially manufactured modern flexible plastics, which can be 500 times more airtight than generally available single layer plastic compositions. For most commodities, low oxygen/high CO_2 conditions occur typically within 10-15 days (or less) at room temperature or above, and more slowly at lower temperatures. During that time, the container's atmosphere becomes unbreatheable as oxygen levels due to respiration alone generally drop to (or below) 3%, and carbon dioxide levels rise to around 15% or more (Figure 4) (Navarro S, Donahaye E, et al, 1990). Under these conditions, all air-breathing life forms die and aflatoxin-producing mold growth is inhibited.

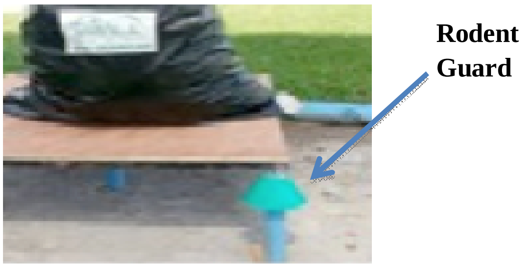
Figure 4: Average carbon dioxide and oxygen concentrations in a GrainPro Cocoon™ storing wheat.



In a few crops, such as peanuts, however, the process of achieving this reduced oxygen and high carbon dioxide condition takes much longer, sometimes as long as 30-days (Waliyard et al., 2002) (Navarro et al., 2011). In such cases, the injection of carbon dioxide or insertion of small, commercial oxygen-absorbing packets is used to accelerate the process. With carbon dioxide injection, air is allowed to escape, with the injected carbon dioxide acting as a piston. With insertion of oxygen-absorbing packets, composed generally of iron filings and clay, oxygen is absorbed directly, creating a slight vacuum. In the special case of green or parchment coffee, insect densities are too low to create low oxygen conditions. However, when protection from humidity, entrance of additional oxygen and outgassing of volatiles are prevented, the result is excellent preservation of coffee quality for a year or more (Aronson et al., 2005). Currently in limited use, 69 kg capacity SuperGrainbags for storing roasted coffee, after the beans have been resting for 48 hours before sealing, allows the bulk of the generated CO_2 to escape. This has been proven effective for storage.

In many countries rodent protection is also an important issue. For this reason adequate protection techniques are needed, and rodent protection has been implemented in Ultra Hermetic containers. In the case of larger units such as Cocoons, this is achieved by tensioning straps to insure that the tough, slippery PVC used is taut enough to prevent rodents from gaining a "tooth hold". Further, a paved surface, wire mesh, or a 5 cm layer of loose material such as sand is used underneath the large container to prevent rodent access from there. In smaller sizes a locally made platform is used during storage with inverted plastic cones known as "rodent guards" mounted on each support or "leg" (Figure 5). These have proven to be effective. Also, in some bulk storage units, this sometimes permits emptying by gravity.

Figure 5: GrainSafe Mini™ 250 kg with rodent guards underneath



SAFE SEED STORAGE USING ULTRA HERMETIC STORAGE

A major problem in multi-month storage of seeds prior to planting, whether farmers' own seeds or high performance hybrid commercial seeds, especially in hot, humid climates, is maintaining a high and predictable seed germination percentage. This is especially true when not protected by expensive and energy-consuming, air-conditioned or refrigerated storage. However, in recent years, it has been found that for a multiplicity of seeds equally good results are achieved from storing in airtight (Ultra Hermetic) storage. (Sabio et al., 2006) This approach is now used on a commercial basis by both local and regional seed producers from Philippines and Kenya, to Brazil and in Africa for farmers' saved seeds or commercial hybrids. The approach for use with paddy, milled rice and rice seed has been extensively studied by the International Rice Research Institute (IRRI) and is recommended by IRRI worldwide. (Villers et al., 2009).

An example is shown below (Tables 1 and 2) (Sabio et al., 2006) of the storage of high-performance hybrid rice seed, variety, Mestizo 1, by the Philippine Bureau of Postharvest Research and Extension (PBPRE) and the Philippine Rice Research Institute (PhilRice). It shows germination rates using different storage technologies. In Mexico, CIMMYT has also studied the benefits of hermetic storage in the field for maize and maize seeds. (Das and Atlin, 2010).

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

	Storage duration (months)			
Method	0	3	6	9
Hermetic Storage	1.13	3.82	3.22	8.42
Cold Room Storage	0.96	0.38	0.64	0.56
Air Conditioned Storage	0.84	0.76	8.58	38.27
Control (unprotected)	0.35	16.95	79.40	147.84

Table 2 - Mean percent germination rate of Mestizo 1 (PSB Rc72H) hybrid paddy (unmilled) seeds stored under different storage technologies and durations

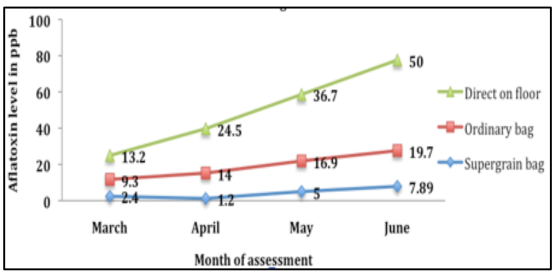
	Storage duration (months)			
Method	0	3	6	9
Hermetic Storage	96.16	96.47	93.30	86.15
Cold Room Storage	96.80	97.57	92.95	89.60
Air Conditioned Storage	94.30	94.75	88.13	85.82
Storage	92.87	92.92	76.38	74.70

Various other studies of rice seed stored hermetically in Bangladesh and Cambodia (100 – 398 days) (Quasem and Rahman, 2001), of maize seed in Mexico, Thailand, and Bangladesh (90 – 280 days) (Moreno et al., 1988) (Sukprakarni C 1998) (Allied Agro Ind. Dhaka); and of barley and wheat in Cyprus and Israel (120 – 900 days) (Calderon et al., 1989) showed seed germination of 81 – 95% after 90 days versus 1% to 95% for conventional storage and the above findings are summarized in a table (Villers, 2002). Another study of peanut seeds from Vietnam showed after 8 months a 98% germination rate when stored hermetically versus a 4% germination rate when stored unprotected. (Navarro et al., 2012) Other studies by Bayer Crop Sciences in 2012 for maize and cottonseed have shown similar benefits (Bayer Crop Science, 2013). The comparative effectiveness of Ultra Hermetic storage versus alternatives, as shown in Table 2 (Sabio et al., 2006), is believed to be due to seed and insect respiration that creates an unbreatheable low-oxygen, high-carbon dioxide atmosphere that normally kills all air-breathing forms of life. Further, both humidity and oxygen on the outside cannot enter, preventing the growth of molds that require oxygen and high humidity, thereby preserving germination potential and seed vigor. Lacking adequate protection from air-conditioned, cold storage or Ultra Hermetic storage, frequently causes overuse of the relatively expensive seeds at additional cost and also, as reported by IRRI in Cambodia, results in unpredictable crop density ranging from overcrowding to sparse.

AFLATOXIN ISSUES AND MULTI-MONTH STORAGE

Growth of aflatoxin-producing molds is a major problem in many stored commodities including maize, rice and peanuts (Gong et al., 2004), (Hell et al., 2010), (Ediage et al., 2004). Aflatoxin-producing molds affect public health by damaging the human immune system with serious consequences (Jiang et al., 2008), (Williams, 2011), (Williams et al., 2004). Dramatic increases in aflatoxin levels occur under conventional storage conditions suitable for mold growth such as high humidity combined with high temperature. Recent field data provided by Millennium Villages in Ruhira, Uganda, illustrates these effects as depicted in Graph 1. (Private communication, Millennium Villages 2014), and similar results in various towns in Mali are shown in Table 3 (Waliyar et al., 2002). Neither aflatoxin-producing nor other molds die in Ultra Hermetic storage conditions, but they are denied both humidity and oxygen. As a result, their growth rates become minimal and hence the increase in aflatoxin levels is small (Villers, 2014).

Graph 1: Aflatoxin growth in maize in different storage conditions in Ruhira, Uganda. (Millennium Villages study, 2013)



Dr. J.H. Williams, of the University of Georgia (USA), has written that "for a long time, aflatoxin as a public health hazard was largely ignored, until 2010, with rejection of 10% of the Kenyan maize crop for excessive aflatoxin level (international standard of 10-20 ppb)" (Williams, 2011). The World Food Program "P4P", which in 2010 rejected large amounts of local maize in Kenya because of excessive aflatoxin contamination, has documented the problem of excessive aflatoxin levels in maize (Kang'ethe, 2011). Since then, the aflatoxin contamination problem has been studied extensively.

Table 3: Increase in aflatoxin concentration during storage (Acrisat -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

Dr. Williams also cites a survey of local African markets showing that 40% of the commodities found there exceeded permitted levels of aflatoxin in food (above 10-20 ppb, and in some cases far above). He writes that an estimated 4.5 billion people in developing countries are at risk of uncontrolled or poorly controlled exposure to aflatoxins, and when random samples were collected, up to 40% of commodities in local African markets exceed allowable levels of aflatoxin in foods (Williams, 2011), (Jolly et al., 2006, 2009). The values in the international standard currently established for maximum permissible aflatoxin contamination levels (10 to 20 ppb) are based on a number of analytical and epidemiological studies of aflatoxin effects on both human and animal immune systems levels. Statistical evidence shows impact on such public health issues as resistance to HIV (Jiang et al., 2008), cancer and the causing of stunted growth in children (Gong et al., 2004), (Turner et al., 2003, 2007), as well as high mortality rates in domestic animals such as poultry (Oladele, 2014), (Williams, 2011), (Williams et al., 2004).

Available data, such as those shown in Graph 1 and table 3, suggest that freshly harvested crops, while often meeting the international contamination standard of 10-20 ppb, when dried and then stored multiple months in hot and humid climates, they will experience exponential growth of aflatoxin levels if not protected by airtight storage with low oxygen and low humidity or by more expensive air conditioned/refrigerated storage (unpublished data, Millennium Villages, 2014). In response to this public health danger, a good deal of effort has gone into reducing aflatoxin contamination (Hell et al., 2010). Farmer-friendly, inexpensive field test kits for measuring aflatoxin levels are increasingly available. Selective or genetic breeding of crops or use of biological approaches such as AflaSafe can also improve eventual aflatoxin levels. AflaSafe works by deliberately introducing non aflatoxin-producing mold species to compete with the aflatoxin producing related species. This technology is now used in Africa. (USAID Feed the Future Newsletter, 2014), (Sumner and Lee, 2012). It is unfortunate that very little attention has been given to the above findings and the dramatic increase of aflatoxin levels during multi-month storage. The overwhelming portion of aflatoxin research to date has been devoted to reducing aflatoxin levels prior to harvest time. This research may be more scientifically interesting, but potentially it may well be more important to conduct further studies on preventing aflatoxin growth in drying and storage. Ultra Hermetic storage to prevent excessive aflatoxin levels after storage is now both affordable and available, but this method is only used on a limited scale and has not been the subject of major scientific studies.

ROLE OF SOLAR DRYING

Advanced solar dryers can insure adequate drying before storage without using fossil fuels. Advanced solar dryers unlike drying on patios, paved and unpaved roads, are designed to be rain-protected, either by folding like a suitcase (Collapsible Dryer Case™, Figure 6) or by a permanent low profile tunnel utilizing solar gain (Solar Bubble Dryer™, Figure 7). (DeBruin T, Villers P, et al, 2014), (Rojas-Azucena RNM, 2014).

Figure 6: Collapsible Dryer Case™ Courtesy GrainPro, Inc., 2014)

Figure 7: Solar Bubble Dryer™ (Courtesy GrainPro, Inc., 2014)

FORMS OF ULTRA HERMETIC STORAGE IN CURRENT USE

If Ultra Hermetic™ storage is effective, how is it actually used in the field? (Alvindia et al., 1994), (Jonfia-Essien et al,, 2008, 2010). Over the last 20 years, a variety of forms of Ultra Hermetic™ storage have been developed and used for a variety of drying and storage purposes. Patented Ultra Hermetic storage containers include from flexible, plastic, containers such as the Cocoons™ (Figure 8) made from 0.8mm food grade PVC with capacities from 1-tonne to 1,000-tonnes. In small sizes, the 0.078 mm thick, 50 to 90 kg capacity, man-portable SuperGrainbags™ (Figure 9) or the new significantly lower cost SuperGrainbag Farm™ (Figure 10) are widely used. For transoceanic shipments, TranSafeliners™ (Figure 11) are used as liners inside standard 20’ or 40’ shipping containers. Also available, a lower-cost alternative to older “tin silos,” the airtight 250 kg capacity GrainSafe Mini™ (Figure 12 like the older tin silo, has a capability of continuous “in and out”.

Figure 8: Cocoon™ (5 to 1,000 tonnes)

Figure 9: Super Grainbag™ 70-90 kg

Figure 10: SuperGrainbag Farm™ with protective outer bag

Figure 11: TranSafeliner™ for 20' and 40' shipping containers

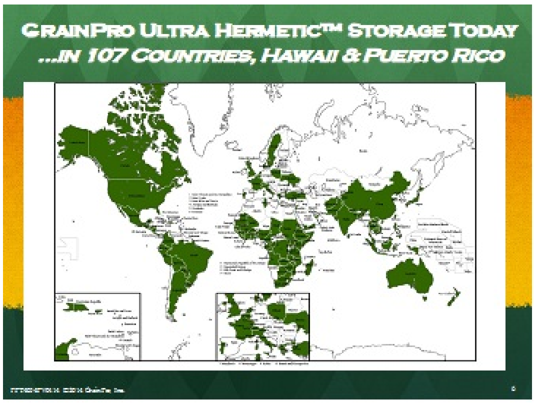
Figure 12: GrainSafe Mini™ 250 kg with Rodent Guards

It is designed to be a modern alternative to the partial airtightness of tin silos, which require pesticides and do not control aflatoxin growth. Other, less hermetic storage, bags of 50 to 69 kg capacities are also available such as the Purdue University PICS bags (Baoua, 2014), which have been used successfully on a substantial scale with some commodities, primarily in Africa. (Baoua et al., 2014). Large scale tube storage with specialized loading machines is also used such as the large Argentine Silo Bag with lengths up to and beyond 100 meters.

Key commodities stored with losses less than 1% per year using Ultra Hermetic™ technology include grains such as maize, rice, beans and peanuts, high value commodities such as coffee, cocoa, chia, and many types of seeds. (Navarro et al., 1996). Users range from small growers to traders, exporters, strategic reserve organizations, and frequently coffee and cocoa roasters or processed food manufacturers.

The hermetic technology, underlying these products, is successful in dealing with the four threats, particularly in tropical climates: These are: high storage losses, growth of aflatoxins and loss of seed germination capacity, as well as rodent damage. Ultra Hermetic storage is used at scales ranging from small to substantial in 107 countries (Figure 13 shows countries where Ultra Hermetic storage has been introduced). The 0.078 mm thick material used for the man-portable Ultra Hermetic bags uses a special form of polyethylene with a proprietary barrier layer that makes the bags 500 times more airtight than normal plastics of comparable thickness (SuperGrainbag leakage rate for oxygen is 3cc/m^2/day). As mentioned earlier, other bags made of plain polyethylene provide a limited amount of protection and are available at a lower cost; however they have permeability to oxygen of about 2000cc/m^2/day.

Figure 13: Courtesy of GrainPro, Inc., 2014



SAFE DRYING USING COMMERCIAL PORTABLE SOLAR DRYERS

To safely store commodities for multiple months – storage of “dry” commodities -- requires drying to the “critical moisture content” or less before multi-month storage. Generally, this point varies from 7% to 14% moisture content (depending on the commodity) (DeBruin et al., 2014). It is defined as the level of the commodity’s moisture content, which is in equilibrium with 65% relative humidity.

In industrialized countries, drying is often done using fossil fuels such as gas- or oil-fueled dryers. In the developing world, scarce wood supplies are still used frequently. This is contrary to what is needed to help arrest growing carbon dioxide levels in the atmosphere and their resulting grave climate change effects. In addition, fossil-fueled dryers are commonly unaffordable both in capital cost and operating expenses in much of the developing world and instead, sun-drying on paved patios or paved or unpaved road surfaces is still widely used. Such sun drying methods suffer from re-wetting when it rains as well as contamination from many sources. As a result, portable solar dryers, such as the rain-protected Collapsible Drying Case (CDC™) have begun to be used more widely (Figure 5). The more advanced but more expensive fully-enclosed Solar Bubble Dryer™ (SBD™) and using solar gain also protects against rain and can reduce both required drying time and growth of aflatoxin during drying (Figure 6).

CONCLUSION

Pesticide-free Ultra Hermetic storage is an environmentally friendly, pesticide-free and energy-conserving technology that is effective in dramatically reducing post-harvest losses and protecting seed before planting without causing environmental damage. In an era of global warming, resulting in lower crop yields and increasing water shortages, storage loss reduction is essential and use of Ultra Hermetic technology can reduce storage losses to less than 1% per year. Its widespread use in Africa, alone, would eliminate this continent’s need for grain imports. Similarly, the under-recognized public health hazard of excessive aflatoxin levels in hot, humid climates remains ubiquitous and yet often preventable with the combined use of environmentally friendly solar dryers and Ultra Hermetic post-harvest storage.

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