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Above:150MT Cocoon™ storing maize in Rwanda. Cover photo by courtesy of Grainpro

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Safe storage of grain in the tropics

A comparison of hermetic storage in flexible silos versus rigid metal or concrete silos

By Philippe Villers, Tom de Bruin, and Dr. Shlomo Navarro

In modern hermetically sealed "silos" such as Cocoons (as shown in Figure 1), the bagged grain is stored under modified atmospheric conditions, insulated from the ambient atmosphere by means of a special fabric that serves as a gas barrier.

Fig. 1:
300MT Cocoon with GrainShade storing paddy in the Philippines

The metabolism of the organisms in the stored products, including insects found in grains, creates a Modified Atmosphere (MA) with high CO_2 and low O_2 conditions. The low-permeability, flexible PVC material used in the Cocoons both prevents changes in humidity and protects the stored grains from rodents.
This MA controls the insect population, prevents development of fungi (molds) and slows down oxidation. The unique design and PVC material of the Cocoon protect the commodities from rodent attack. With the use of a Cocoon, all quality aspects of the grain, seeds or other dry agricultural products are protected without the need for fumigation or aeration.
By contrast, in non-hermetic, traditional metal or concrete silos, grain is loaded into the silos by several means, including the use of bucket elevators. Once the grain is stored in non-hermetic conditions, it is exposed to atmospheric oxygen and external humidity, and therefore, insect infestation cannot be controlled without the use of toxic pesticides.
Metal and concrete silo technologies originated in Europe and in the United States, where temperate climates, particularly in winter, permit the use of ventilation systems built into the silos to cool the grain during the cold season. Most storage pests are not active at temperatures of less than 20°C.
A properly built conventional silo is effective in protecting against rodents but in tropical climates, does not prevent moisture condensation and subsequent moisture increase within the stored commodities.

Table 1 – Comparison of Hermetic Storage Vs Conventional Silos in Tropics

Item of comparison	Hermetic ("Cocoon™") storage	Conventional metal or concrete bin silos
Control measures if infestation occurs	Control by depleted O_2. Gas analyzer enables follow up on infestation level, detection of leak	Grain will have to be unloaded and treated with phosphine (PH_3)
Fumigation	Not needed	Required every 6—12 weeks
Condensation at 14% MC	No, if "GrainShade" provided with Cocoon is used properly	High risk if storage is above 1 month and grain is not sufficiently dry (low moisture content (MC)
Protection from rodents	Protected	Protected
Length of storage	Unlimited	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 due to condensation
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 set up at any location	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$50—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 extended above 1—3 months

Background information

Problems of metal or concrete silos for long-term storage in the tropics: In tropical climates, even if the commodity is sufficiently dry, it suffers from two major problems if stored within metal or concrete silos:

1. Condensation occurring below the roof of the silos and at the top layers of the grain bulk, leading to fungal and insect growth.

2. Contamination with fumigants and chemical contact insecticides necessarily used to prevent insect infestation.

Cylindrical metal or concrete silos were designed for storing grain in bulk. Grain in a silo is protected against rain, but not protected against change in moisture content (which is accompanied by rapid mold development), oxidation, or insect infestation.

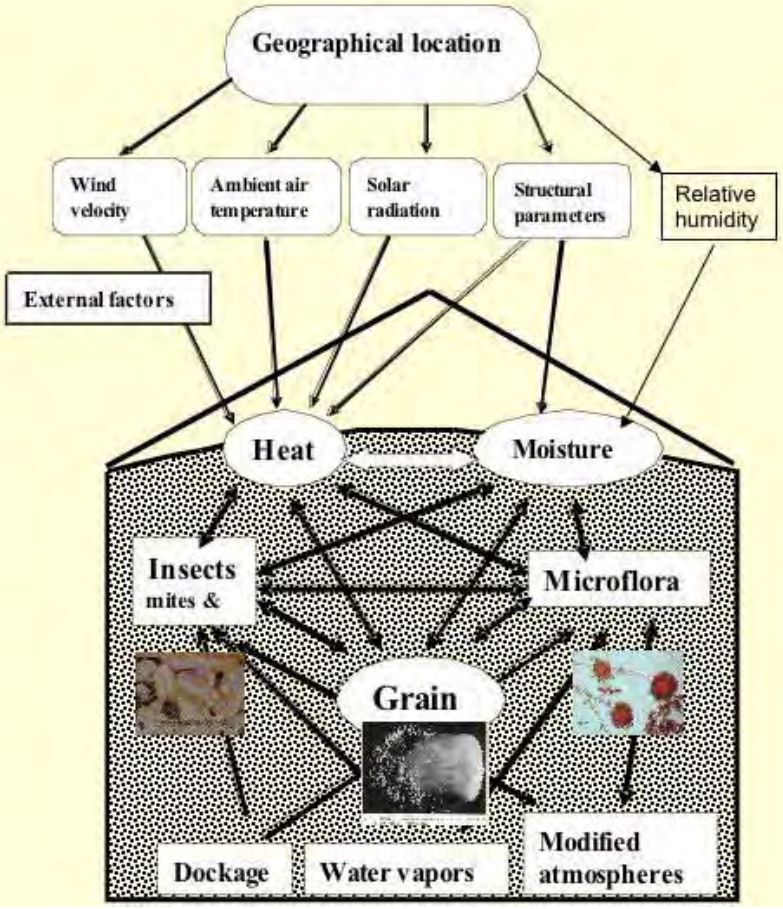
"Conventional silos operate successfully in continental, temperate and subtropical climates where a cold season exists".

Conventional silos operate successfully in continental, temperate and subtropical climates where a cold season exists.

Figure 2. Diagram showing factors having an impact on stored grain

The grain bulk ecosystem

External factors and the interrelated grain bulk ecosystem components in a sealed bulk.



The temperature of grain stored in **non-tropical climates** rises because of high moisture content (MC) or insect infestation but can be reduced by mechanical aeration - using fans that take advantage of the cold air available during the night or during the cold season. If well managed, aeration can control insect populations, which are suppressed at temperatures below 18°C.

Humidity and Condensation

Condensation in metal or concrete silos is the result of heat build-up at the headspace of the grain bulk, followed by cooling. This is caused both by direct sunshine on the roof and the walls of the silo and by high prevailing daytime temperatures. Warm air has the capacity to hold more water than cold air and, aided by convection currents, warm headspace air in the silo absorbs moisture from the grain by adjusting its relative humidity to that of the grain. This moisture is transferred to the headspace air from the grain inside the silo through diffusion and "convection currents". (Remember the principle: *warm air rises, cold air goes down!)*

At night the ambient temperature drops and so does the temperature in the headspace of the silo. As the temperature goes down, the air in the headspace which has become over-saturated with moisture then releases its excess of water. This is known as condensation drops or "sweating."

These drops settle at the roof of the silo and will eventually drip onto the top surface layer of the grain bulk and along the walls. Wet grain at the top of the bulk forms, a phenomenon called "caking." The grain becomes moldy and black, heats up during the warm day and, if not removed in time, can ignite due to spontaneous combustion. By contrast, a Cocoon is designed to have no headspace and to be protected from large temperature gradients.

Infestation

Because in metal and concrete silos in tropical climates the grain bulk cannot be properly cooled (unless refrigeration is applied), infestation is a common feature. Infestation usually occurs in spots where large populations of insects also develop; however, uniform distribution of the infestation is also possible. Infestation generates more heat and thus creates favorable conditions for further insect and mold development.

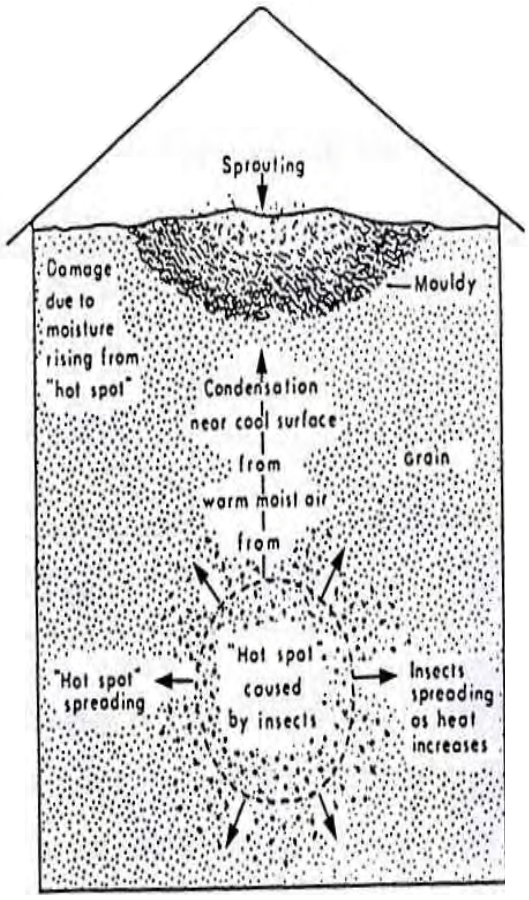


Figure 3: Hot spot and its impact on grain

Moisture absorption

The commodity should be stored dry at a safe moisture content (MC). For corn, this is set at 12.0% (which is in equilibrium with 60% relative humidity) because molds develop at higher relative humidities.

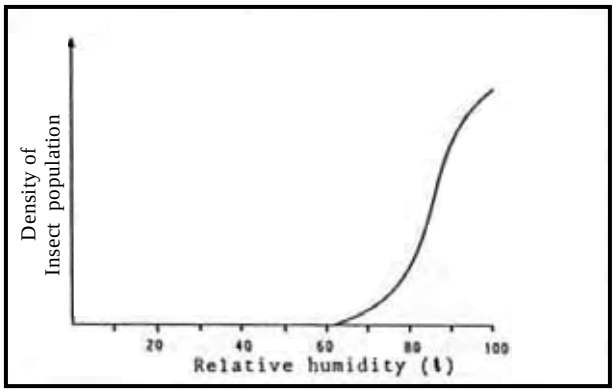


Figure 4: Effect of relative humidity on mold density

Silos in the tropics

In the tropics average temperatures are around 30°C and the relative humidity fluctuates between 70-90%. The water vapor capacity of this warm and humid air is high, particularly when the headspace heats to 50°C. This air, at a relative humidity of 65%, may contain as much as 62g of water per m^3 air.

When this air cools to a temperature of 30°C, its maximum water vapor capacity drops to 29 g water/ m^3 air. The excess of water vapor condenses on the roof (inside the silo) and each m^3 air releases about 33 g of water for each day/night cycle.

Although day and nighttime temperature differences are very limited in tropical climates (usually not more than 5°C), the problem arises due to heating of air at the headspace of the silo. The exposed metal roof temperature can easily heat up to 60 °C or more, aggravating the condensation. Thus, a commodity stored at 14% MC (at 70% RH) in a silo in the tropics is exposed both to high relative humidity and high temperature. Operation of the ventilation system is generally ineffective since the cooling effect of air with a day/night temperature difference of 5°C is extremely low. In addition the ventilation system helps to expose the commodity to air with a high relative humidity (RH), thus increasing the MC of the commodity.

As a result, insects easily develop in the grain (optimal temperatures for storage pest development is 28-35°C). In addition, when the MC increases, molds and related aflatoxin easily develop.

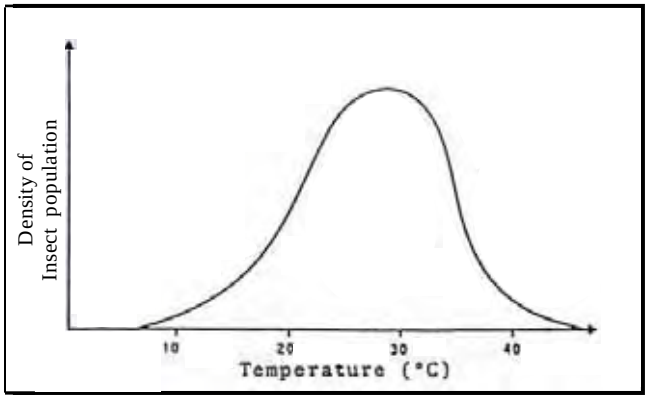


Figure 5: Effect of temperature on insect infestation

Eventually, heat build-up at the roof and walls will result in condensation which, under tropical conditions, cannot be prevented due to inability to cool the grain sufficiently.

What about existing silos in the tropics?

Many traditional metal and concrete silo complexes exist in the tropics, often built without sufficient understanding of the unique problems of storing grain in that environment. As a result, in some countries such as Nigeria, millions of dollars worth of storage capacity is standing idle.

In the Philippines, a number of silo complexes acquired for storing paddy are unused due to the problems mentioned above. For example,

feed millers have had severe problems of caking of corn in their silos, requiring them to clean the silo walls at great expense. Although it is possible to hermetically seal conventional silos, the expenses involved are substantial. Silo roofs have to be insulated and walls may have to be painted white to reduce heat absorption. A solution is needed to cope with air expansion due to fluctuation of temperature.
Hermetic storage in flexible liners called Cocoons* such as those shown in Figure 6 below, offers an alternative solution.

Fig. 6 - 150MT Cocoon™ storing maize in Rwanda

It preserves the quality of the grain and is a totally environmentally user-friendly and green solution. Applying the existing hermetic technology to new metal silos to create Hermetic Silos™ for bulk grain storage is also possible using the same flexible PVC as in Cocoons. However, retrofitting existing silos in this manner would be quite difficult.The use of (patented) hermetic storage using Cocoons, as described above, is now used in some 20 countries for applications as varied as:
1) long-term safe seed and grain storage without refrigeration; **2)** preserving taste and aroma of coffee, cocoa and spices; and **3)** using either vacuum or purging with CO_2 or Nitrogen for rapid fumigation of high-value commodities as different as figs and historically important museum pieces.

Fig. 7 - IRRI Rice Seed in SuperGrainbags

Recently, (as seen in Figure 7) the introduction of a novel type of low cost hermetic liners for conventional bags, called SuperGrainbags™, allows 50Kg bags of grains or seed to benefit from hermetic storage.

For further information contact Tom Debruin:
tom@grainpro.com *or visit:*
www.agri.gov.il/Envir/envir.html and
www.grainpro.com
For a list of references contact Dr. Shlomo Navarro, Agricultural Research Organization
snavarro@volcani.agri.gov.il

About the authors:
Philippe Villers is President, GrainPro Inc., Concord, MA 01742 U.S.A.; Tom de Bruin is Vice President, Sales & Marketing, GrainPro, Inc., Quezon City, Philippines and Dr. Shlomo Navarro is Principal Scientist, Dept of Food Science, Agricultural Research Organization, Bet-Dagan, Israel.