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AIRTIGHT GRANARY FOR USE BY SUBSISTENCE FARMERS

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ABSTRACT

An airtight flexible plastic granary of 600-kg nominal capacity was tested for on-farm storage of grain. The granary was designed to provide food security for rural communities. It has the advantage of sealed storage that obviates the need of employing residual insecticides and fumigants.

To test the efficacy of the granary, an artificial infestation composed of adults of the rice weevil *Sitophilus oryzae* (L.), of the lesser grain borer *Rhyzopertha dominica* (F.) and of the flour beetle and *Tribolium castaneum* (Herbst) (6 insects/kg) were added from laboratory cultures to maize at average moisture content of 12.6%. Insect survival, gas composition, and temperature of the maize were recorded. Maize temperatures were within the range of 34ºC to 23ºC. Oxygen concentrations dropped to 0.2% within 13 days and carbon dioxide rose to 12%. For the following 50 days, oxygen and carbon dioxide concentrations remained stable. A moist pocket of maize at the top of the granary was found to be at moisture content of 14.6% that contributed to maintain this atmosphere. In spite of favorable temperatures for development of insects, at the end of two months storage, the initial insect populations of *S. oryzae, R. dominica* and *T. castaneum* were successfully controlled without the use of pesticides.

INTRODUCTION

The maintenance of high nutritive characteristics, and viability in stored cereal grains and seeds such as corn, paddy rice and legumes, has always posed problems to small-scale farmers in developing countries throughout the world. The existing on-farm, predominantly traditional storage practices are frequently inadequate to protect grain and seeds from attack by insects and moulds, which are favored by the ambient conditions of hot and humid climates. At a commercial level, seeds can be preserved in cold storage and food grain can still be protected by chemical treatments. However, such storage technologies are rarely available or affordable to small-scale farmers because of the high investment cost, and even where admixture of grain with insecticides and fumigation, is employed by farmers, these treatments can pose serious safety hazards, particularly in situations where little or no extension infrastructure is set-up to instruct farmers in correct usage.

Much research has been devoted to improving storage technologies at the commercial level, and although it has been long recognized that there is an urgent need for a safe, pesticide-free, and economically viable grain and seed farm-level storage technology to be developed, this avenue of research has been largely ignored. Yet the need for food-security in the developing world is always most acute in the rural communities. We have attempted to redress this imbalance. Our approach has been to implement the ecologically friendly technology of sealed storage, which we have developed and is already well established at the farmer-cooperative and commercial levels, and to modify and adapt it to the needs and pocket of the small-scale farmer (Navarro and Caliboso 1996). The objective of this presentation is to reveal how our storage concept called the "GrainSafe" silo was formulated, through a process of "trials and errors", taking into account the pre-conditions and constraints required to keep this concept within the bounds of socio-economic acceptability of the end-users in different countries.

MATERIALS AND METHODS

The rationale

Two approaches to improving village storage have been applied in the past: (i) to tactfully modify existing storage structures; and (ii) to provide new structures (Guggenheim 1978). Our approach was an amalgam of the two. Many traditional silos are raised above ground on a platform to protect the grain from rodents, farm animals and sometimes flood water. So why not use these platforms, which are part of the farmers' way of life and expertise, and place our hermetically sealed structure on the platform already *in-situ*?

Secondly, the peaked roof required to protect silos from the heat of the sun and prevent rainwater from accumulating above the grain, is best made by the farmer from freely available matting or vegetable fibers. Consequently our efforts were concentrated on designing the actual storage "bag" that would be sandwiched between the locally made floor and roof, thereby drastically reducing cost.

The design of a storage bag appears to be a simple enough procedure, but only after the structure has been manufactured, loaded with grain and trial tested, are the weak points revealed. Consequently we set out with the knowledge that we would need to make, and extensively test, at least three versions before we could approach an optimum design for field testing abroad. This report describes our findings and decisions for change during the first three trials. A report on the fourth trial was presented at the 7th IWCSPP, in Beijing China in 1998 (Navarro *et al.,* 1999), and the structural configuration in the last trial served as a specification sheet for the manufacture of additional GrainSafe units that have since been field-tested elsewhere.

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The basic design

The bag: The basic concept of the structure lies in the development of a hermetically sealable "big-bag" in which the grain is stored. Respiration by stored-product insects inside the bag changes the composition of the inter-granular atmosphere to an extent where the insects are no longer able to survive. The first consideration was capacity. For sealed storage there is a negative correlation between storage volume and rates of oxygen (O_2) ingress into, and carbon dioxide (CO_2) egress away from the intergranular storage atmosphere. This is due to the increasing ratio of volume: surface-area as the size increases. Consequently, for a given permeability of plastic liner, the smaller the storage volume the more difficult it is to retain an atmosphere lethal to stored-product insects. It was decided to conduct the trials using the already proven liner developed together with Haogenplast Projects Ltd., for construction of the Volcani cubes. This is a PVC based liner 0.83 mm thick with permeability of 407 $mL{\cdot}m^2/24$ h for O_2, 2,355 $mL{\cdot}m^2/24$ h for CO_2, 8 $g{\cdot}m^2/24$ h at 38ºC and 90% r.h. permeability to water vapour, and zero permeability to liquid water.

The sheath: The bag in itself when filled with grain has no fixed shape, and therefore must be retained within rigid walls. The idea we used was to take a rectangular piece of rigid but pliable plastic that could be bent, and its edges joined to form an open-ended cylinder. This could then be set on the platform and the bag placed inside. This has the considerable advantage that both bag and plastic board are cheap, light-weight and can be rolled or folded for ease of transportation.

Loading and unloading sleeves: The sleeves must be arranged so that they are conveniently placed for loading and unloading but also can be effectively sealed when not in use.

TRIAL 1

GrainSafe design version 1

A flexible PVC based bag of 500 kg nominal capacity for maize was tailored in the form of a cylindrical liner 50 cm high and 1.3 m diameter (664 L). It was equipped with an upper conical sleeve for loading and a lower conical sleeve for unloading, both with 40 cm minimum diameter apertures. The bag was placed on a wooden platform ~ 60 cm above ground provided with a central hole through which the lower sleeve was inserted to facilitate unloading by gravitation from beneath the platform. The procedure for sealing the lower sleeve was by folding it over and securing it with masking tape. To maintain the shape of the bag a strip of rigid black polypropylene (PP) board 70 cm high was curved into a cylindrical sheath and held in position with four vertical wooden slats and three horizontal steel cables that fitted into grooves 25 cm apart. The grain consisting of 500 kg of uninfested maize at 12.6% m.c. was loaded into the liner from the upper sleeve using a bucket. After insertion of monitoring equipment, the upper sleeve was also sealed by making a series of folds and securing with masking tape. An inverted bucket was placed on top of the silo to raise the level above the PP wall and a straw roof was laid over the top and held in place with a large stone placed on top of the bucket.

Infestation: To obtain an artificial infestation 1,000 adults of the rice weevil *Sitophilus oryzae*, 1,000 adults of the lesser grain borer *Rhyzopertha dominica* and 1,000 adults of the flour beetle *Tribolium castaneum* were taken from laboratory cultures and added to the grain from the top, thereby introducing an initial infestation of 2 insects per kg for each species.

Monitoring procedure: A temperature and humidity logger (ACR Smart Reader 2) was inserted into the grain to enable hourly readings of temperature and r.h. to be recorded at the bottom of the bulk and at the top above the grain surface layer. A polyethylene tube (0.4 mm o.d.) was inserted through the upper sleeve opening into the grain to enable daily readings of gas composition to be taken. Ambient conditions during the trial were recorded using a Davis weather monitor. The trial was set up on 29th May 1997 and terminated on 14th August 1997.

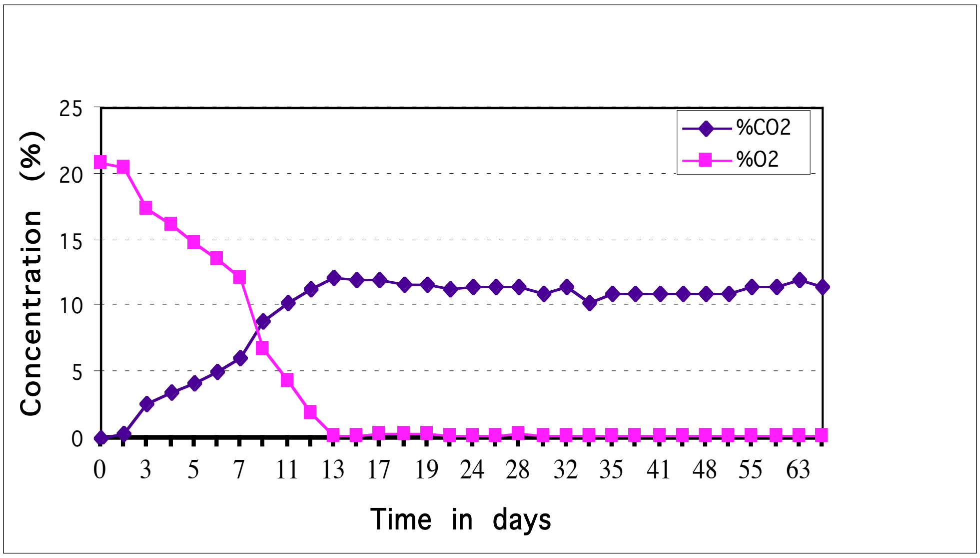

Fig. 1: Carbon dioxide and oxygen concentrations in the bag infested with 3 stored product insect species at a rate of 6 adults/kg.

Results and Discussion

Gas composition within the bag: The daily readings of CO_2 and O_2 concentrations are given in Fig.1. From the figure it can be seen that there was a rapid drop in O_2 concentration down to 0.2% within 13 days coupled with an increase in CO_2 concentration to 12%. For the following 50 days both O_2 and CO_2 concentrations remained stable at these levels. The findings seemed at first to indicate that at the relatively high level of insect infestation, the liner was sufficiently gas-tight to produce and maintain a combination of very low O_2 and high CO_2 concentration that rapidly killed the insects. However, after the insects had died, a gradual increase in O_2 and decrease in CO_2 concentrations would have been expected, due to gradual gas diffusion across the liner which has a limited permeability to both gases. This did not happen. Therefore a more likely explanation for the above rapid gas exchange was sought. Two other possibilities were, either the presence of an original undetected focus of moist grain in the bag, or the possibility that moisture had migrated to the walls or upper surface due to the establishment of temperature gradients in the grain bulk caused by ambient temperature fluctuations.

On 4th August the bag was opened, the m.c. of the grain at the top of the bulk was measured and found to be 14.6% which is above the critical m.c. for maize. This indicated that there had been moisture migration towards the surface and that the low O_2 contents maintained over the past two months had been due largely to respiration of microorganisms rather than insect respiration. From previous studies on hermetic storage we have found that mycofloral development usually causes CO_2 concentrations to rise above 12%, (Navarro *et al.* 1984). The fact that this did not occur in this case may indicate that micro-floral development was limited to the surface layer.

In view of the clear indication that gas exchange within the bag was being produced by respiration of microorganisms, the bag was probed through the upper loading sleeve on 14th August and three samples from the top center, middle center, and bottom center, were withdrawn and m.c. were checked. Recordings were: 12.9% m.c., 12.6% m.c., and 12.6% m.c. for the top middle and bottom samples respectively, indicating that if moisture migration had occurred it was not in the central region of the bag.

Temperature and humidity changes in the bag: Data-logger readings showed that temperatures within the bulk were close to average ambient temperatures and ranged from 23 to 34ºC. Recordings of inter-granular air relative humidities showed that at the top of the bag they rose to about 85% towards the end of the trial which is in equilibrium with about 17% MC. However, although these trends were probably correct, a later calibration test of the data logger showed that the r.h. sensors were unstable and were not reliable.

Grain removal and termination of the trial: Grain removed at the end of the trial had an average m.c. of 12.6%. However a number of small clumps of mouldy grain were recovered at the beginning of the unloading process and these were separated from the rest of the bulk. It was concluded that these clumps originated from the surface layers, probably at the junction with the walls and they were responsible for the maintenance of very low O_2 concentrations during the storage period.

TRIAL 2

This trial was carried out to examine changes made to the structure of the granary resulting from evaluations of trial 1. The objective was to reduce the price of the storage package while maintaining or improving the structural characteristics.

Changes made

The following changes were made: The method of supporting the granary sheath, namely four struts connected by three circumferential cables, was abandoned. Instead, the PP cylinder was closed by attaching one wooden strut (4 cm x 2.2 cm x 115 cm) to the PP cylinder at the overlap, using screws and washers, to form a gasket type seal. Diametrically opposed to this was attached another strut. A 'V' section was made at the top of each strut. This served to cradle a third horizontal strut (3 cm x 2.2 cm x 115 cm) that was threaded through a length of PVC pipe that served to seal the loading sleeve (by wrapping the sleeve round the pipe) and hold up the sack during the emptying stage. A white PP sheath was used to minimize sorption of heat from direct sun-rays into the grain-bulk.

The method of emptying was checked to examine whether the cylinder retained its shape when the bag was only partially filled and to examine how grain is best removed from the bottom of the bag.

Observations/Evaluation: During loading, over the two-week storage period, and during unloading, the cylinder maintained its shape much better than in the previous trial. There was no indication of inward bending of the sheath-cylinder because the horizontal strut took the weight of the bag during the unloading procedure. To remove the last 30 to 60 kg, the PP cylinder was removed and the grain was removed from the floor of the bag by lifting the outer edge of the floor and working the grain towards the center. In this way all the grain could be easily removed. By suspending the inner bag from the top of the cylindrical sheath, the bag volume decreased progressively during unloading as the sides collapsed towards the centre, and this obviated any pressure difference caused by removal of grain. Consequently ingress of air through the unloading sleeve was minimal.

TRIAL 3

In addition to the changes made in trial 2 a change in proportions of the sack and cylinder were made. This was done to improve the ease of loading and unloading by decreasing the diameter and increasing the height to 120 cm. The PVC piping used previously to seal the loading sleeve was dispensed with and the loading sleeve was wrapped around the horizontal strut, which because of its smaller dimensions and rectangular section, gave a better seal than the pipe.

It was found during loading that the vertical struts were not high enough to enable the horizontal strut to take the weight of the loading sleeve when the granary is full. It was calculated that an additional height of 20 cm is required above the level of the PP cylinder. Dimensions of the vertical struts were increased to 135 cm leaving 20 cm to

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rise above the height of the cylinder, thus allowing for attachment of the horizontal strut so that the loading sleeve is kept under tension from the beginning of storage. The loading sleeve was increased in length to 40-50 cm, and the unloading sleeve was fitted with a screw-on gasket type cap.

The findings in these trials served as a basis for the structural configuration of the GrainSafe that was fabricated for the fourth trial, the results of which have been published elsewhere (Navarro *et al.,* (1999).

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