FIELD EXPERIENCE WITH HERMETIC STORAGE OF GRAIN IN EASTERN AFRICA WITH EMPHASIS ON STRUCTURES INTENDED FOR FAMINE RESERVES

De Lima, C.P.F.
National Agricultural Laboratories,
P.O. Box 14733,
Nairobi,
KENYA.

1. INTRODUCTION

Tropical countries are expanding agricultural production to meet the increasing food requirements of their people. More food is becoming available and requires storage for longer periods. With the uncertainties of climate, and the need for self-reliance, consideration must be given to storage systems that enable safe storage for long periods at low cost and with minimum use of pesticides.

Low cost storage can be achieved on a large scale with the use of semi-underground hermetic structures. Traditional underground semi-hermetic storage pits have been in use in Eastern Africa and elsewhere for several centuries. In recent years, large hermetic structures have been successfully used in Kenya for storage of famine reserves.

2. TRADITIONAL AND EXPERIMENTAL UNDERGROUND SEMI-HERMETIC STORAGE PITS IN EASTERN AFRICA

Underground pits have been traditionally used in Ethiopia and Somalia for semi-hermetic storage of grain (Gillman and Boxall, 1974). In Ethiopia the pits are generally conical but cylindrical pits are found in the South near the Somalia border and in Somalia. The pits hold 5 tonnes or less on average, although larger pits of 25-50 tonnes are constructed by traders. The main crops stored are sorghum, millet and maize and in some areas of Ethiopia wheat and barley. Occasionally beans are stored for temporary periods during the dry season.

A limited amount of experimental work was done in the mid-1950's on underground concrete pits lined with bitumen. These pits of approximately 120 tonnes capacity (35 x 18 ft at the top and 10 ft deep) were constructed in Tanzania and Malawi (Hall et al. 1956).

Underground pit storage is attractive because of the relative ease of construction, safety from theft, better thermal insulation, protection from rodent attack, less insect activity and protection from insect re-infestation. Disadvantages are that pits are difficult to empty and are subject to moisture damage if there is a rise in the water table. There is often more severe mould infestation of the grain due to moisture migration from the soil on the sides and condensation on the top. The grain is not very suitable for seed as the viability is reduced. Gilman and Boxall (1974) indicate that traditional underground pit storage is on the decline in parts of Southern Africa because of improvements in the marketing system and change in social habits creating a demand for better quality grain.

3. SEMI-UNDERGROUND HERMETIC STORAGE ON A LARGE SCALE

Some of the benefits of traditional underground pits have been made use of in planning for large scale storage of grain in Argentina, Cyprus and Kenya (Hyde et al. 1973). Advantage has been taken of modern methods of construction and suitable waterproof membranes have been used to prevent ingress of ground water. When good quality grain has been put into these structures it has been stored without loss of quality for several years and with the minimum of attention.

4. THE NEED FOR LARGE SCALE HERMETIC STORAGE IN KENYA

Although Kenya has been largely self-sufficient in producing her staple food maize, there have been occasions when poor rainfall has resulted in near famine especially in the marginal areas. As a long-term remedy it was decided to have a large scale reserve of grain suitably preserved in good condition for minimum periods of 3 years.

Following the successful development of hermetic bins in Cyprus (Oxley et al. 1960) similar structures were considered for Kenya. Construction was begun in 1966 and completed in 1967 and 1968 at two sites. 40 Bins were built at Kitale (approx. 250 miles from Nairobi) and 30 Bins at Nakuru (approx. 100 miles from Nairobi) giving a total capacity of 100,000 tons of maize.

5. THE DESIGN AND CONSTRUCTION OF THE "CYPRUS" BINS

The design and constructional details have been fully given by Hyde et al. (1973). Each bin is a concrete lined cone 20 ft in the ground, covered by a concrete shell dome 20 ft high. The underground cone gives rise to a reinforced concrete ring beam at ground level (diameter 64 feet) on which the dome rests.

5.1 The underground cone

The sites at which the bins are built have a water table 30 ft below ground level giving a 10 ft margin of safety. After excavation and formation of the correct slope, the slope was blinded with 3 inches of weak mix concrete and then treated with 4-5 coats of bituminous emulsion embedded (for binding) with a scrim of nylon mesh or hessian. Care was taken to ensure that the membrane was completely continuous. The membrane was then blinded with sand and, when dry, covered with a half inch coat of cement mortar. Reinforcing rods were fitted in position, and a 4 inch thick layer of structural concrete was placed in the slope of the cone. The ring beam was then formed at ground level.

5.2 The dome roof

The dome is required to support its own weight and withstand other forces such as the weight of operatives on the surface and internal grain pressures and for this reason it was necessary to form a corrugated shell (Fig. 1), the construction of which required considerable care and skill. A temporary formwork of 12 arch ribs was prepared and covered with a hessian envelope. After an initial ½ inch coat of sand/cement mortar was placed on the hessian, reinforcing rods were placed in the valleys and the crest. Two further coats of mortar 1¼ and ¾ inches thick were then applied. When the dome was thoroughly dry, the

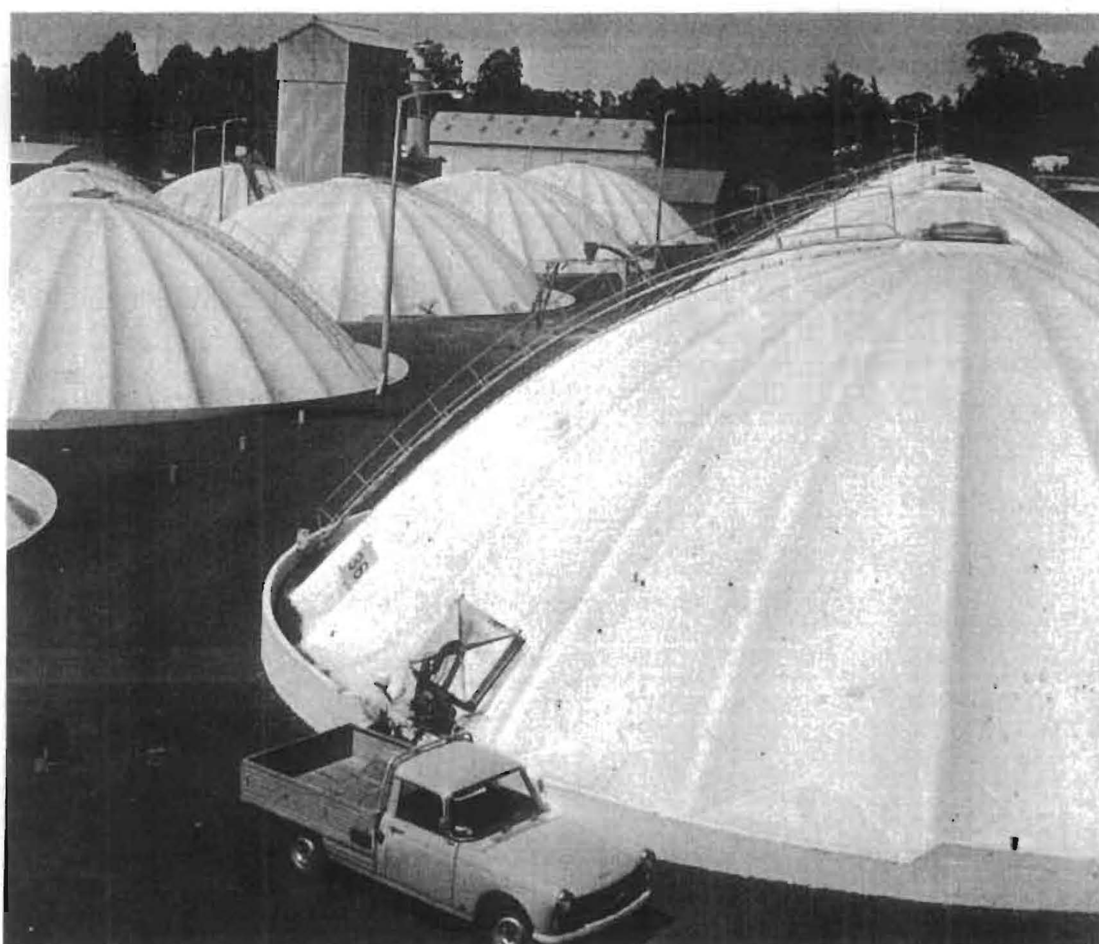

Fig. 1. View of the "Cyprus" bins at Kitale. In the foreground, a bin is being pressure tested for leaks.

bitumen membrane was applied using at least 4 coats of bitumen emulsion and nylon mesh scrim or lightweight hessian for binding. The membrane was continued through the gutters and over the kerb of the ring beam to join with that placed under the base cone. Two final reflective coats of white paint were applied.

Each bin has two man-holes: one at the apex of the dome for filling and one at ground-level for emptying. Air-tight hatch covers are provided for each man-hole.

6. CORRECTION OF STRUCTURAL FAULTS AFTER CONSTRUCTION

6.1 The ring beam

In 1971, approximately 3 years after the bins were constructed, a small amount of damage was observed to grain adjacent to the ring beam due to seepage of water through the external membrane of the bin and the structural joint at the point of connection of the dome to the ring beam.

Initial repairs consisted of renovation of the external bituminous membrane. This later proved ineffective mainly because the dome pivots about the point where it is connected to the ring beam. This movement is caused by the expansion and contraction of the thin shell due to solar radiation.

An alternative repair procedure developed in 1973, has since proved effective and is still in use on a routine basis. This consists of removing the bitumen membrane around the gutter area on the ring beam. The structural joint is then located, by chiselling away some of the concrete if necessary. The joint is then sealed using a suitable mastic sealant (Reebdeck mastic). This is done by placing the bin under negative pressure (6 in. wg) with a test fan and applying the paint over and about 3 inches on either side of the joint. The paint is drawn in until the crack is filled. A second coat is given to the joint (under negative pressure) and to the whole gutter area. The joint at the kerb of the ring beam is similarly treated. The effectiveness of the seal is tested by applying positive pressure (6 in. wg) and leaks detected by splashing water over the joints. Any leaks discovered are repaired and a final coat of white PVA emulsion is applied to protect the Reebdeck mastic from solar radiation. The bins are routinely tested for leaks after each emptying (Figure 1).

6.2 Hatch covers

The original steel hatch covers did not provide sufficient insulation against diurnal temperature variations. This resulted in a considerable amount of condensation on the underside of the steel cover. In addition, the cover could not be adequately sealed to prevent the entry of a small quantity of air into the bin. New hatch covers manufactured of fibre glass were installed and used with a sealant to provide an air-tight seal. The inspection cap was made air-tight with a rubber gasket.

7. OPERATION AND MONITORING OF GRAIN CONDITION

7.1 Operation

Only fresh good quality grain is accepted for storage in the Bins. This grain (which may arrive in bags) is passed through a cleaning and drying plant (where dust is removed and grain dried to below 12.5% moisture) before being conveyed in bulk carriers to the bin site. Before filling, each bin is thoroughly cleaned and disinfested.

The bins are rapidly filled to capacity (within 3 weeks) and before sealing, tablets releasing 30 gm of hydrogen phosphide gas or a strip releasing 17.7 gm dichlorvos are placed on the surface of the grain at the top and side hatches. This treatment is for the control of superficial infestation by Sitotroga cerealella and Ephestia cautella.

The bins remain sealed for a period of 6 months before the first sampling is done through the inspection cap (diameter 10 cm).

7.2 Monitoring of grain condition

Each bin is fitted with thermistors for monitoring temperatures and gas extraction tubes for recording oxygen levels. These measurements are taken remotely using the Telemax and Servomax instruments respectively. Grain is also sampled through the inspection cap of the top hatch using a sampling probe. Details of monitoring positions are shown in Figure 2.

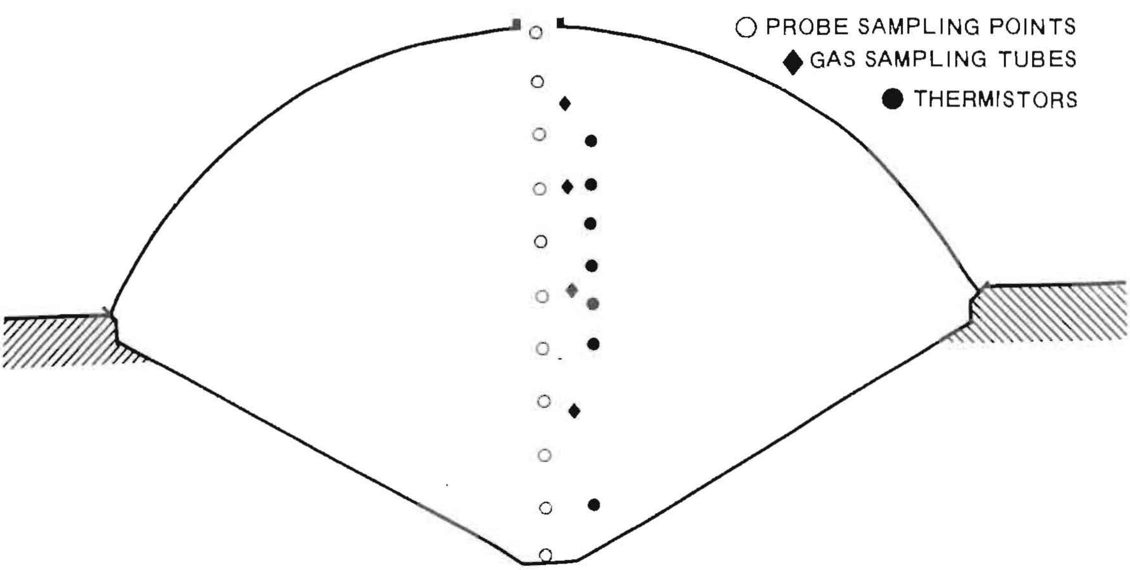

Fig. 2. Monitoring positions for grain samples temperature and oxygen levels in a "Cyprus" Bin.

7.3 Temperature

The grain temperature during loading is generally in the region of 20-25°C. Seven thermistors are located in each bin along the central axis, one each at the following depths; 9'9", 12'9", 15'9", 18'9", 21'9", 24'9", 36'9".

Temperatures are recorded daily after filling until the readings are fairly constant around 25°C. Thereafter records are taken at weekly intervals unless a sudden change is observed. In the event of a temperature rise to 35°C or 10°C above normally recorded values, daily measurements are taken and the bin sampled using a suction probe.

7.4 Oxygen

The oxygen concentration is measured using a Servomex Oxygen Analyser. Gas sampling tubes are installed at 6', 12', 20' and 30'. Records are taken as soon as the bin is sealed and thereafter at weekly intervals until the oxygen level is less than 6% or until a constant value is reached. When this happens further records are taken at intervals of 4 weeks.

7.5 Grain samples

Grain samples are taken by passing a Probe-A-Vac suction sampler through the inspection cap (diameter 10 cm) of the top hatch cover. Sampling is done immediately after the bin is filled and subsequently at 6 month intervals. More frequent sampling may be done in the event of a rapid increase in grain temperature.

Samples of at least 1 kg each are taken from the surface and at 4 ft. intervals through the central axis to the bottom of the bin. Sampling depths are 0', 4', 8', 12', 16', 20', 24', 28', 32', 36' and 40'.

Each sample is examined separately. A mercury glass thermometer is used to record the temperature of each sample as soon as it is removed from the probe. In the laboratory, each sample is weighed and then sieved.

The thrash passing through the sieve (including insects) is weighed and recorded. The moisture content of the sample is then taken using a meter (Supermatic or Burroughs). The insects present in the thrash are identified and the number of live and dead individuals recorded as numbers per kg. Each sample is then divided into approximately 4 sub-samples of 250 gm each using a box divider. One sub-sample is incubated at room temperature (approx. 20-22°C at both sites) for 8 weeks and the numbers of adult insects emerging recorded.

A second sub-sample is examined for damage. This is done in two operations. First, the grains are separated into four classes: broken, holed, tunnelled and whole. The weight of each class is recorded. The sub-sample is then re-constituted and the grains separated once again into discoloured and normal and a record made of the weight of the discoloured fraction.

8. OBSERVATIONS AND RESULTS

8.1 Routine monitoring

Some observations from the routine monitoring of Bin No. 13 in Kitale are shown in Figure 3. The results are fairly typical of the bins loaded with good quality maize using the chain conveyor. Oxygen levels remained between 17.5% and 19% over the first 18 months of storage then dropped gradually to 5-6% in the following 18 months before emptying.

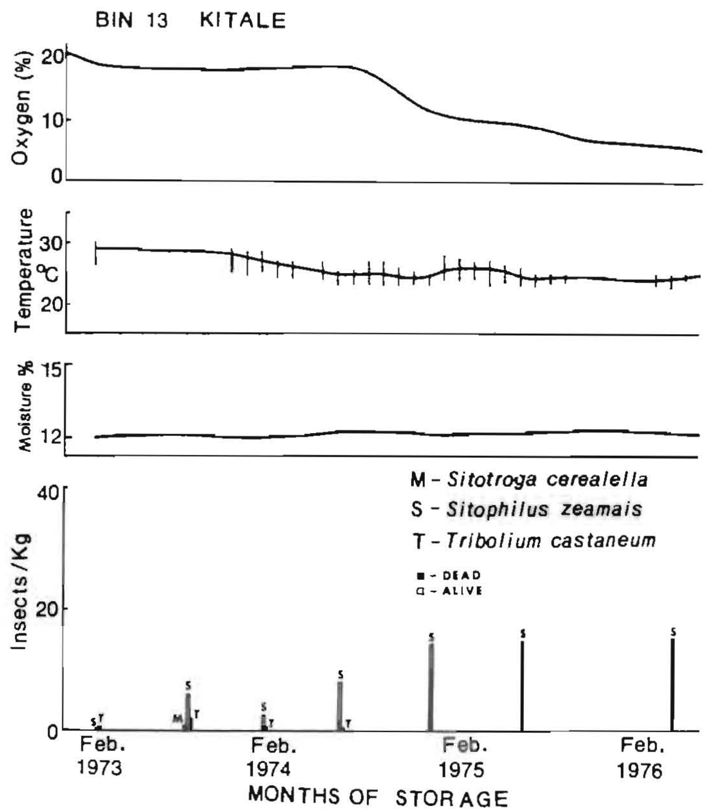

Fig. 3. Summary of routine monitoring data for oxygen, temperature, moisture and insect population levels in grain in Bin 13 at Kitale over 42 months storage.

Temperatures varied between 25°C and 30°C over the 3 years. The average grain moisture was below 12.5% for the entire storage period. Probe samples showed that infestations by Sitophilus zeamais, Sitotroga cerealella and Tribolium castaneum were kept in check by the hermetic conditions. The insects are mainly in the centre where sampling is done and so the infestation given as numbers/kg. is unrepresentative of the distribution of insect population through the grain bulk. However, for monitoring purposes, the central axis of the bin is an ideal place to sample.

8.2 Oxygen

Since the bins are loaded with grain that comes directly from the farm, there is a small amount of initial infestation by insects and fungi. The cleaning and drying process causes some mortality to the insects; and development of fungi and insects is further reduced by drying the grain to below 12.5%. Oxygen levels therefore remain high for a fairly long period of time and often for more than 12 months. When the concentration of oxygen begins to fall, this is associated with the increase in fungal growth. Daily fluctuations in temperature cause a small amount of condensation on the top of the dome. This moisture drops on the top layer of grain and enhances fungal development. Fungal development causes discolouration of the grain and is reflected as "discoloured" grain in samples. The association between the decrease in oxygen concentration with increased fungal growth on the surface layer of grain is shown in Figure 4.

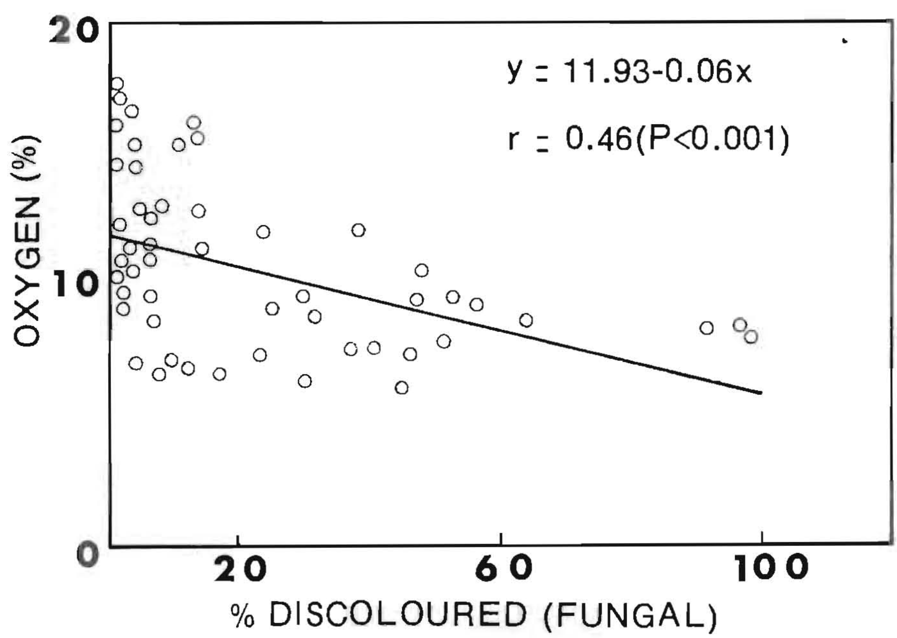

Fig. 4. Relationship between oxygen concentration and fungal growth.

Each point on the graphs represents the relevant observations made on individual bins at the Kitale site over the 1972-1980 period.

8.3 Moisture and Microflora

The increase in the amount of fungus infested grain was directly related to the amount of grain moisture (Figure 5). The average moisture content of the top 4 feet was above 14% and had fairly high fungal damage. The greatest fungal damage was in the top 2 ft. of grain and generally this had to be discarded as

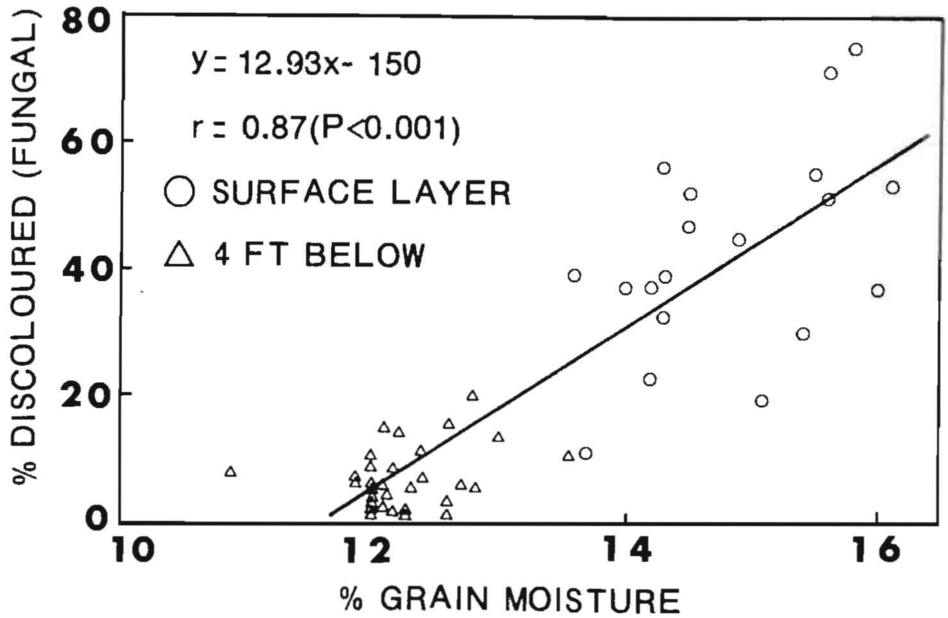

Fig. 5. Fungal growth and grain moisture at the top and 4 ft below.

rotten grain. As is explained later (Section 9.2) this represents a very insignificant amount of loss. The grain below this for another 2-3 ft. often required aeration and drying and was generally graded as animal feed. The average moisture content of grain in the 4-8 ft. layer was between 12 and 13 percent and showed little or no fungal discolouration. Grain below this level was entirely free of fungal discolouration except for small amounts at the ring beam where cracks had occurred and sometimes at the very bottom (40 ft. deep). The main fungi were species of Aspergillus, Pencillium and Rhizopus.

8.4 Temperature

Average daily temperatures over the year rarely exceed 25°C at both, the Kitale and Nakuru, bin sites. However, there is often a large difference between day and night temperatures. This difference, which usually exceeds 10°C, is transferred through the thin shell of the dome. The night temperatures on the inner surface of the bin dome are generally below the dew point temperature of the internal atmosphere. Condensation therefore takes place and the resulting moisture drops on the surface layer of the grain.

Average temperatures through the grain bulk are approximately 25°C. They are usually about 22°C through most of the grain bulk and slightly higher than average in the top 4 feet. The amount of dust in the grain has a very significant effect on temperatures. The original conveying machinery installed on the site in 1968 and used up to 1972 was pneumatic in design and caused breakage of grain and accumulation of dust especially along the central core of the bin. This resulted in severe heating and grain had to be transferred to other bins to arrest the problem (Figure 6.). For example, the grain in Bin 19 was transferred to Bin 35 when temperatures approached 40°C in the first 8 months after filling and within 6 months had reached 47°C in Bin 35. It was then re-cleaned and transferred to Bin 38 where it remained for a further 18 months without severe problems.

In the second filling of Bin 38 the chain and flight conveying equipment was used and no serious heating problems arose. The grain remained in a satisfactory condition for nearly 40 months.

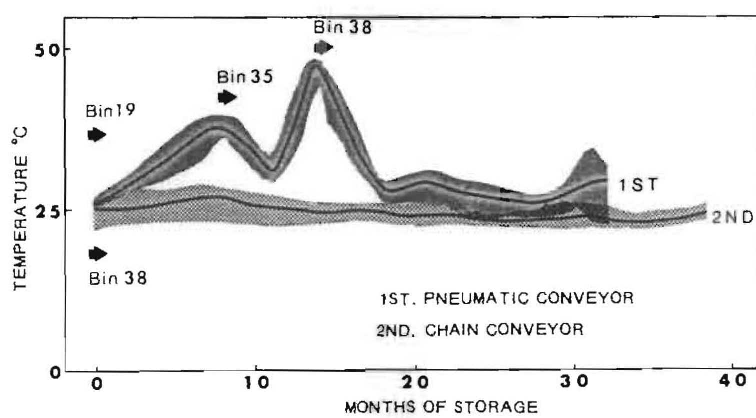

Fig. 6. Pneumatic conveyor causes grain breakage and heating results from dust accumulation. No breakage and heating with chain conveyor.

8.5 Insect infestation

The main insect species infesting the produce in the bins were Sitophilus zeamais (Motschulsky), Sitotroga cerealella (Olivier), Ephestia cautella (Walker) and Tribolium castaneum (Herbst). Sitophilus and Sitotroga usually accompany the grain from the farm. Ephestia and Tribolium are present in conventional stores and mills near the bins and infest the produce when the bins are open especially during extended filling operations.

The insect infestation is often fairly low in fresh grain but has the potential of building up to alarming levels within 2-3 months if not kept in check. When a bin is filled, a limited amount of disinfestation at the top and side hatches is carried out as explained earlier (Section 7.1). The amount of hydrogen-phosphide used (30 gm) is 1/300th of what would normally be required for complete disinfestation in a conventional non-hermetic store.

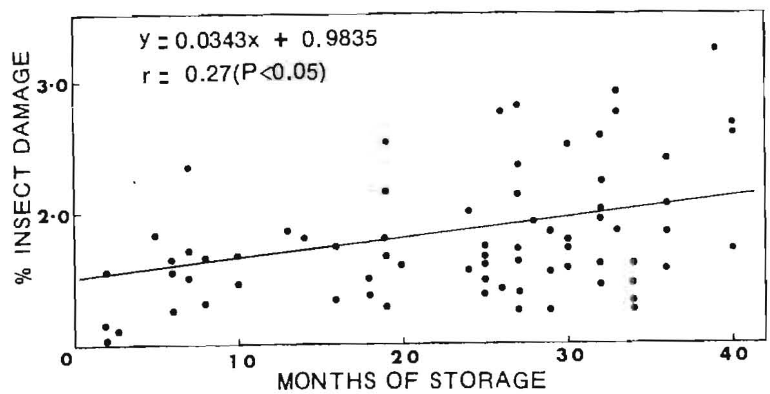

Fig. 7. Percentage of insect damaged grain in final samples before emptying the bins.

The hermetic conditions and the low grain moisture kept the damage caused by the insects in check. This is illustrated in Figure 7 which is a plot of insect damage found in final sampling before emptying each bin. Insect numbers rarely exceeded 10/Kg along the central axis, where the probability of finding insects is highest, and this was reflected in the very limited amount of insect damage to grain samples collected at intervals along the central axis. Insect damage represented by the percentage of grains showing exit holes and internal tunnelling is on average below 3% after 3 years of storage.

9. EMPTYING OPERATIONS AND DETERMINATION OF LOSSES

9.1 Emptying

Each bin is normally emptied after 3 years of continuous storage. Both (top and side) hatches are opened and the produce well ventilated before unloading begins. Usually a small quantity of wet and rotten grain is found below the top hatch on the underside of the dome, and sometimes around the ring beam and in the bottom of the bin. This is removed separately, weighed and destroyed. Damp and mouldy grain adjacent to the wet and rotten maize is also removed separately, dried and aerated in the cleaning plant, weighed and stored separately for inspection and grading by the National Cereals Marketing Board. This produce may be sold as undergrade stock for animal feed. All the good maize emptied from the bin is weighed and graded. If the maize is passed through the cleaner, the weight of the dust obtained is also recorded.

9.2 Determination of losses

In the early (1972) filling operations, records of the quantity of maize loaded into individual bins were not maintained. An average capacity was determined for the total number of bins filled. This was calculated as 15,474 (90 kg) bags per bin. Since there are variations in individual bin capacities, some bins registered fewer than 15,474 bags on unloading. Other bins registered more. This information provided some (unforseen) confusion in the determination of losses. It was therefore decided that separate records would be maintained of the weight of grain being loaded into each bin.

Losses were therefore determined on the actual quantities of grain unloaded. The contents of each bin when unloaded were separated into rotten grain, grain for animal feed, dust and good grain and then weighed. An analysis of these losses for the bins at the Kitale site are summarised in Table 1. In all the data presented in this paper, the results for Bin No. 16 (for the 1972 filling only) at Kitale are omitted because of an unaccountable discrepancy. The data in Table 1 shows the results from using the 40 bins at Kitale 78 times. The average period of storage (after sealing) was 26.5 months and a total quantity of 108,777 tonnes of maize (equivalent to 1,208,637 x 90 kg bags) was stored from January 1972 to March 1980. As a consequence of a current shortage of maize all the grain has been removed for consumption. The average period of storage (over this 9 year period) was also shortened because security problems at the border necessitated removal of the food reserve to safety in 1976.

TABLE 1

Analysis of losses at Kitale site (1972-1980)

Period of storage (months after sealing)	Number of bins	Rotten grain (%)	Animal feed (%)	Dust (%)	Good grain (%)
< 12	16	0.027	0.027	0.015	99.932
13-24	13	0.154	0.110	0.107	99.628
25-36	28	0.224	0.294	0.204	99.288
> 37	21	0.280	0.335	0.347	99.038

The loss in weight obtained as described above is the "gross" value and for the entire 9 years that the bins have been used the maximum loss of 2.17% occurred in Bin 19 after 42 months of storage (Figure 8). In general, average annual weight losses were below 0.3%. It should be pointed out that these weight losses do not imply monetary loss as part of the "losses" include animal feed.

The losses due to breakage caused by the pneumatic conveyor, classified as "dust", were successfully reduced by installation of the chain and flight conveyor.

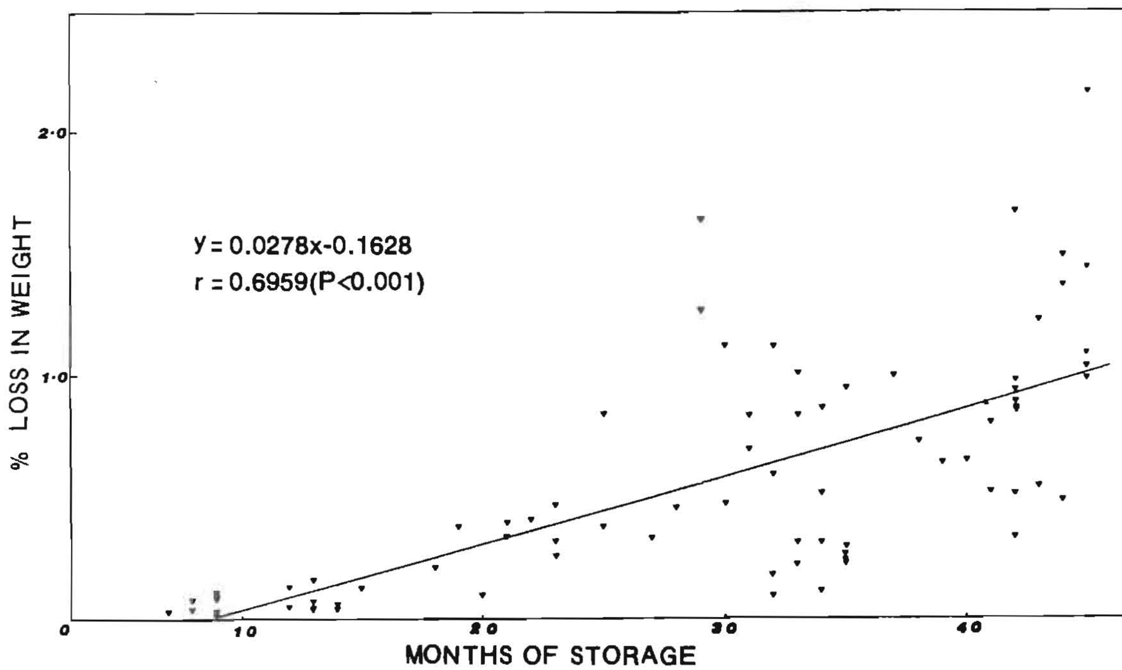

Fig. 8. Loss in weight (gross value) after hermetic storage.

The amount of "dust" in the gross value of losses dropped from 39% with the pneumatic conveyor to barely 5% with the chain conveyor (Figure 9). It is interesting to note that animal feed and rotten grain are approximately in the 1:1 ratio and with the present almost negligible amount of loss due to dust and breakage, true losses mainly due to rotten grain are in the region of 0.15% annually. In contrast annual losses in conventional storage are often in excess of 2% by weight despite regular insecticide and fumigation treatments.

10. DISCUSSION

Semi-underground hermetic storage has considerable potential for future use in the tropics especially for the preservation of national famine reserves of grain. The "Cyprus" bin may not be the most appropriate structure especially in countries with a shortage of trained personnel.

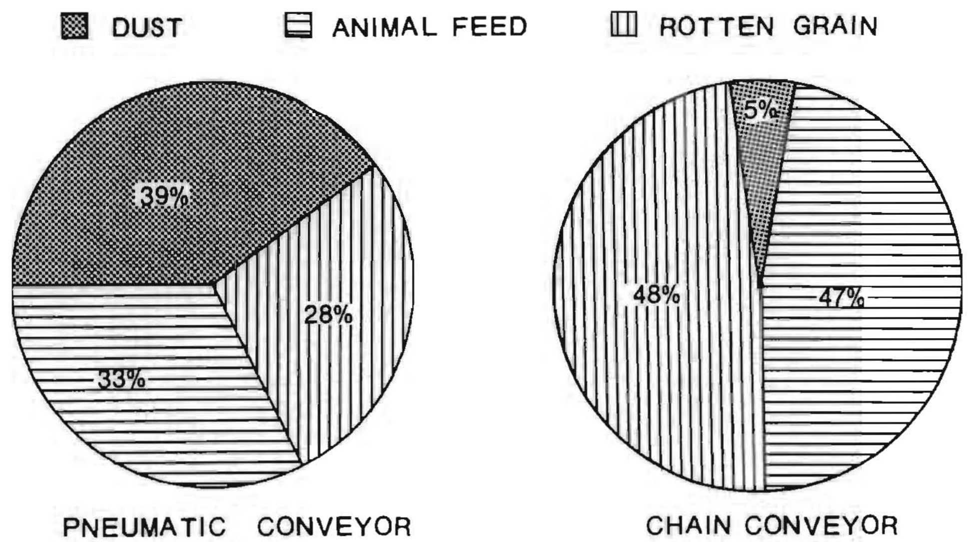

Fig. 9. Losses resulting from use of pneumatic and chain conveyors.

The experience reported here shows that a fixed roof for a semi-underground hermetic structure is not ideal and confirms previous experience in Argentina (Hyde et al., 1974). It would appear that temperature variations in the tropics is the most important aspect to be taken into consideration in the design of a suitable roof for a semi-underground hermetic silo. Presently a new set of hair-line cracks are appearing on the ring beam leading from the ridges of the dome. Although these are satisfactorily repaired following the procedures mentioned earlier, they are nevertheless a source of concern and an indication that future designs will have to be more carefully evaluated.

Moisture condensation on the inner surface of a semi-underground structure is inevitable in the tropics but can be reduced to fairly insignificant levels. The resulting fungal infestation is generally negligible and in a properly air-tight structure may be used to advantage in that a more rapid reduction of the oxygen concentration is achieved to limit insect development. Structural modi-fications to reduce condensation problems in the "Cyprus" bins are not econom-ically justifiable.

At the national level, planning for the storage of food grain should take an "integrated" approach (De Lima, 1979). A certain proportion of the national harvest should be reserved for hermetic storage and retained for periods of not less than 12 months and preferably for 36 months. As mentioned earlier, minimal use of pesticides is required in hermetic storage and with proper planning, national grain marketing organisations can make satisfactory use of modern hermetic storage technology.

11. REFERENCES

De Lima, C.P.F., 1979. Ecology and the integrated-control approach under tropical conditions. Proceedings of the 2nd International Working Conference on Stored-Product Entomology, Ibadan, Nigeria, 1978, 44-48.

Gillman, G.A. and Boxall, R.A., 1974. The storage of food grain in traditional underground bins. Tropical Stored Products Information, 28, 19-38.

Hall, D.W., Haswell, G.A. and Oxley, T.A., 1956. Underground Storage of Grain. Colonial Res. Studies No. 21, 28pp.

Hyde, M.B., Baker, A.A., Ross, A.C. and Lopez, C.O., 1973. Airtight Grain Storage, Agricultural Services Bulletin No. 17, FAO, Rome. 71pp.

Oxley, T.A., Hyde, M.B., Ransom, W.H., Hall, D.W., and Wright, F.N., 1960. The new grain bins in Cyprus. Colonial Office Report, 14pp.