A sealed granary for use by small-scale farmers

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Abstract

A sealed granary was designed and tested for on-farm storage of harvested grain by small-scale farmers to provide food security for rural communities. It has the advantage of sealed storage that obviates the need of employing residual insecticides and fumigants. The granary, designed to hold 540 kg nominal capacity of grain, consisted of a gastight cylindrical flexible plastic bag It was equipped with an upper conical collapsible sleeve for loading and a flexible sleeve for unloading. It was inserted into a rigid white polypropylene board curved into a cylinder that forms a sheath surrounding the vertical sides of the flexible bag To prevent accumulation of rain-water on top of the bag, it was kept suspended beneath a horizontal strut During unloading, the bag collapsed progressively so that the volume of headspace remained minimal Artificially infested maize at a moisture content of 10.3% was tested Insect survival, gas composition and temperature of the maize was measured. Oxygen concentrations dropped to 5.5% within 40 days Maize temperatures were within the range of 36℃ to 26℃. In spite of favorable temperatures for development of insects, at the end of two months storage and during the 6 weeks unloading, the initial populations of *Tribolium castaneum* and *Rhyzopertha dominica* were successfully controlled without the use of pesticides.

Introduction

Throughout the developing world, the on-farm storage of harvested grain by small-scale farmers is critically important in providing food security for rural communities In the past, traditional storage structures provided some protection against storage losses, particularly by insects and rodents, though annual losses at the village level which are estimated to run at between 5 and 10% were usually considered as inevitable. Attempts to reduce these losses through the introduction of modern storage technologies have consistently failed being either socio-economically unacceptable, or inappropriate to local climatic conditions and agrotechnical practices (Donahaye and Messer 1992). A different approach has been the modification of existing structures or the construction of new structures in the conventional style but employing modified technologies to improve grain conservation without causing disturbing changes to village life This was termed by Guggenheim (1978) as the 'invisible' technology and the following study is based on this concept

The storage structure under evaluation in this trial has the following characteristics which are understood to be important pre-conditions to acceptance by farmers throughout the developing world:

a) Design basically similar to those of many traditional storage structures (cylindrical container, raised above ground on a platform, with an upper loading port and a lower spout to remove the grain)
b) Storage capacity appropriate to harvest volumes of small-scale and subsistence farmers.
c) Integration of local, freely obtainable elements in the structure (raised platform, straw roof-cap)
d) Suitable for frequent withdrawal of small quantities of grain.
e) Minimal and affordable price with an anticipated life-time of several years Fig. 1: Section of granary for sealed storage of 540 kg maize showing design features and sampling positions
f) Appearance that is not alien to the natural village architecture

The potential advantage of the structure under trial is that the grain is contained within a sealed plastic liner, and therefore the principles of hermetic storage for control of insect pests are utilized This obviates the need for employing residual insecticides and fumigants with the accompanying hazards they pose to the users and the environment. The objective of the trial described below was to examine under field conditions the performance of this granary in preventing damage, and maintaining the quality of grain during storage, by controlling initial insect infestations.

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Materials and Methods

Description

The granary reported on in this trial, (Fig. 1) and for which patent application has been submitted, was developed over a series of previous trials during which, progressive modifications were carried out. It consisted of a cylindrical bag made from a PVC formulation, 110 cm high and 90 cm diameter (volume: 700L), and was equipped with an upper conical collapsible sleeve for in-loading the grain. This sleeve was equipped with a welded strap and buckle so that when loading was completed the sleeve can be rolled over a horizontal wooden strut and firmly sealed using the pressure of the strap. The bottom of the bag was equipped with a cylindrical flexible sleeve, 50 mm in diameter for unloading that terminates in a rigid PVC screw-on cap. The bag was supported inside a rigid white polypropylene (PP) board 115 cm high, 560 cm long and 1 mm thick, that was curved into a cylinder to form a sheath surrounding the vertical sides of the flexible bag.

To provide stability to the granary and to close the cylindrical PP sheath, the overlapping edges of the sheath were screwed together on to a wooden strut 135 cm long, 40 mm wide and 30 mm thick. An identical strut was then screwed to the outside of the sheath diametrically opposite the first one.

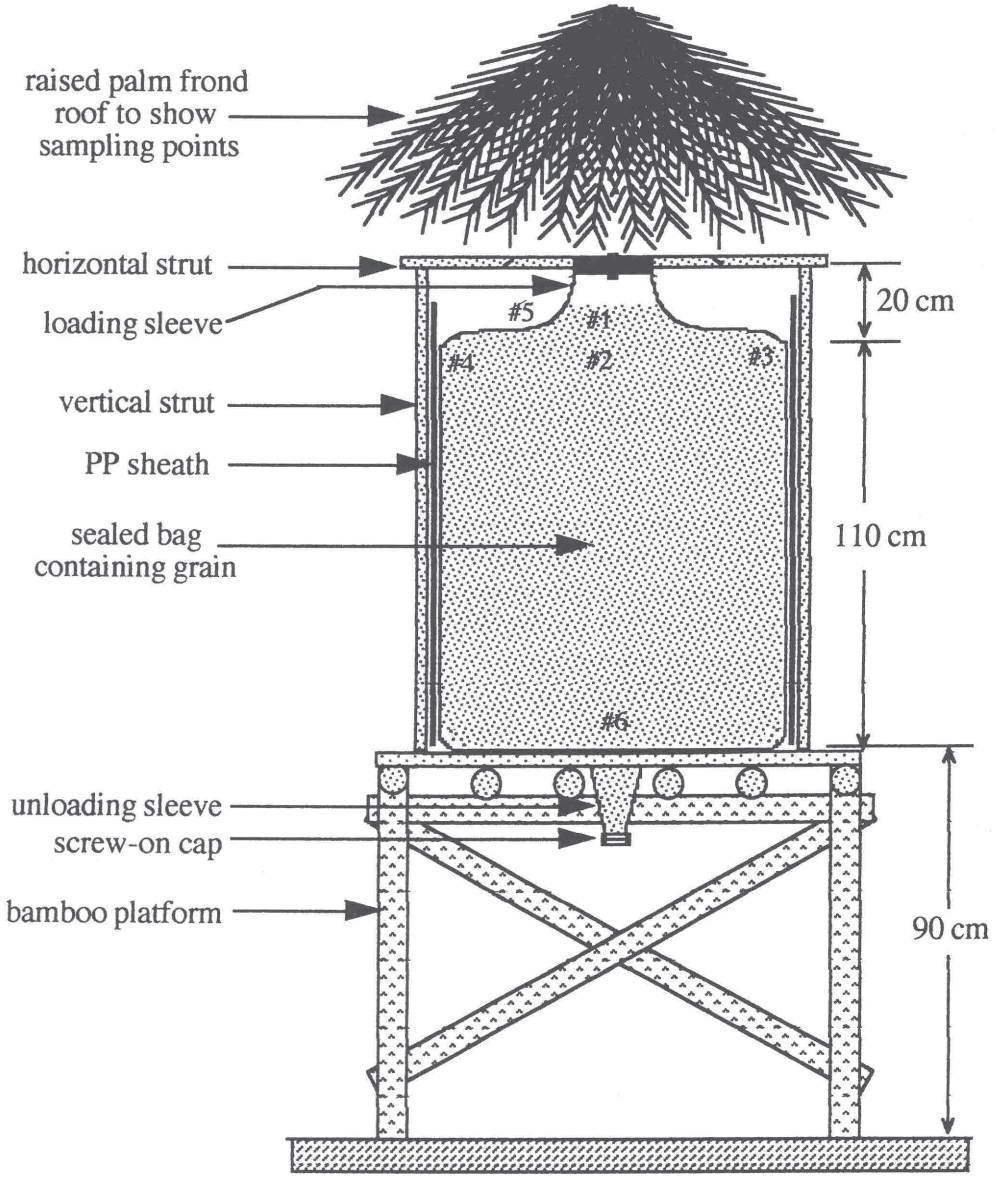

Fig. 1. Section of granary for sealed storage of 540 kg maize showing design features and sampling positions.

One necessary design aspect was the need to prevent accumulation of rain-water on top of the bag where an inverted cone forms at the upper surface when grain is removed from the bottom. This was achieved by lifting the horizontal strut that seals the loading sleeve, and positioning it across the top of the granary so that two holes at each end of the strut are fitted over pins screwed into the top of the vertical struts that serve to stabilize the PP sheath. Consequently as grain was removed from below, and the grain level dropped, the top of the bag remained suspended beneath the horizontal strut, but collapsed from the sides so that the volume of headspace remained minimal.

Granary construction and ancillary equipment

Before loading with grain, a platform 120 cm square and 100 cm above the ground was constructed to protect the structure from rodent attack, and to enable unloading to be undertaken subsequently from beneath it. The platform was made from bamboo poles approximately 6 cm diameter, and consisted of 4 vertical legs, attached to 4 horizontal poles in one direction and two in the other. Six additional poles were attached crosswise between the vertical poles to prevent sideways movement. To form the floor, planks 15mm thick were then cut to 120cm lengths and laid across the horizontal poles leaving a 15 cm square gap in the center to allow for insertion of the unloading sleeve from above. The bag was then placed on this floor and the unloading sleeve was threaded through the hole in the platform and the cap screwed on.

The grain

The grain to be stored was imported maize corn destined for animal feed and supplied locally at moisture contents (MC) ranging from 13.4 to 14.1%. Therefore this grain was spread-out and sun-dried for 4 days to reduce its MC to an average of 10.1%. A total of 540 kg was loaded into the granary.

Loading

In-loading of the grain was carried out by bucket through the conical loading sleeve until the bag was filled to a height of about 20 cm. The PP sheath was then placed in position, and loading resumed. Loading was continued until the bag was filled to about 10 cm below the upper margin of the PP sheath.

Introduction of monitoring equipment

To sample the intergranular atmospheric composition, PVC tubing (3 mm i. d) was inserted to the center of the bag and led out of the granary through the loading sleeve. The granary was also equipped with temperature loggers (Onset Co. USA, model: Hobo) placed at the top center # 1, bottom center #6, 10 cm below the top center #2, at the surface interface with the bag-walls in the south #3 and north #4, and above the bag liner at the center #5 (Fig. 1).

Sealing and solar protection

The upper surface of the grain was flattened out and the loading sleeve was rolled over the horizontal wooden strut and then securely tightened with the strap and buckle provided.

To reduce the effect of solar radiation, the top of the granary was covered with palm fronds in the form of a conical shaped roof held in place by attaching them at the top to the horizontal strut, and at the sides to a circumferentially placed rope threaded through holes drilled near the top of the vertical struts..

Initial monitoring procedure

The trial commenced on the 11th September 1997. For the first 10 days of storage, carbon dioxide (CO_2) was measured by an analyser equipped with a thermal conductivity detector, ('Gow-Mac' model 20 − 600, USA,), and oxygen (O_2), using ananalyser based on an electrochemical detector, ('Oxycheck' model 270, David Bishop, UK), to determine the levels of metabolic activity, namely the respiration rates of the grain and microflora within the granaries when no insect infestations were present.

Insect infestations

After this initial monitoring period had been completed, the loading sleeve was opened and insect infestations were established by introducing laboratory reared adult insects into the granaries. The insects used were the lesser grain borer *Rhyzopertha dominica* (F), and the red flour beetle *Tribolium castaneum* (Herbst). The infestation level was: 1,800 individuals of each species (6 insects/kg) The upper sleeve was then resealed and gas monitoring was continued on a daily basis.

Unloading procedure

Unloading commenced 64 days after introduction of the insects. To investigate the influence of frequent partial removal of grain on the gas composition of the granary, unloading was carried out at a rate of about 100 kg each week for six weeks. This was done by opening the lower screw cap and permitting the grain to flow into a sack held beneath the platform To arrest the flow of grain, the sleeve was constricted by hand pressure about 10 cm above the screw cap leaving the sleeve below the constriction empty so that the screw cap could be tightened into position. Samples from each unloaded batch were examined for moisture content and the presence of both dead and living infestations.

After the first unloading it was noticed that insects were accumulating above the screw-cap and also that the grain at the bottom of the unloading sleeve was damper than the rest. Therefore, for all following unloadings a small grain sample (about 100 g) was taken from the first grain removed and this was examined for moisture content and insect infestation

Furthermore, to investigate if insects were concentrating in the unloading sleeve as a result of an oxygen differential between the sleeve and the rest of the bag, gas concentrations were sampled in the sleeve and the bag on a daily basis for two weeks by withdrawing samples through the liner with a 100μl syringe and measuring the O_2 and CO_2 concentrations using a gas chromatograph

At the final stage of unloading, the granary roof cone, was dismantled and the rigid PP cylinder was removed so that the remaining grain at floor level could be removed by lifting the edges of the bag to enable the grain to flow towards the centre and exit via the unloading sleeve

Results and Discussion

Gas Composition during storage

Daily readings of CO_2 and O_2 concentrations in the granary are given in Fig. 2. From the figure it can be seen that for the 10 days prior to infestation, changes in atmospheric composition within the granary were small indicating that the combined respiration of the grain and storage molds was negligible. After insects had been introduced, there was a gradual drop in O_2 concentration to 5.5% within 40 days, coupled with an increase in CO_2 concentration to 11% For the following 20 days both O_2 and CO_2 concentrations remained stable

Our calculations show that the total volume of the granary (700 L) filled to the top with 540 kg of maize would result in approximately 280 L of intergranular space (calculation based on a porosity factor of 40% of the total volume). A population of 1,800 adults of the two insect species was introduced at the start of the storage period, and Fig 3 shows that the initial grain temperatures were in the range of 30 – 36℃ and then dropped gradually to 23 – 25℃.

The equilibrium relative humidity of the 10.3% MC maize was calculated as being 50% at 27℃ (Pixton and Warburton, 1971) and this would result in an intergranular wet bulb temperature of 19.5℃ On the basis of an intrinsic rate of multiplication of 1.213 per week at 19.5℃ the R dominica population would increase by 2.478, and at a rate of multiplication of 1.495 per week the *T. castaneum* population would increase by 6.619 during the first 33 days of storage (4.7 weeks) (Wilson and Desmarchelier, 1994). Based on these weekly multiplication rates it would appear that *R. dominica* would increase from 1,800 to 4,460 insects and the T. castaneum population from 1,800 to 11,914 insects Since this is a progressive increase, for the sake of this discussion average insect populations were considered as 3,130 for *R dominica* and as 6,857 for *T. castaneum*.

The respiration rate of *Rhyzopertha dominica* adults was calculated as 3.2μl/insect/h (Birch, 1947), and for *Tribolium castaneum* adults as 3.1μl /insect/h (Chaudry and Kapoor, 1967) at 25℃. However, these rates do not reflect the average respiration rate of a mixed population containing all developmental stages, namely eggs, larvae, pupae and adults. For this purpose we referred to unpublished data of Emekci et al (1997a; 1997b; 1997c) in which they recorded the respiration rate of *R dominica* and *T castaneum* of t larvae, pupae and adults was measured. . Based on their work the average respiration rate of mixed populations of all developmental stages at 27℃ was estimated as about 4.5μl /insect/h Accordingly, the estimated O_2 consumption would be $(3,130 + 6,857) \times 24 \times 33 \times 10^{-6} \times 4.5\mu l$ /insect/h = 35.6 L O_2. This consumed volume of O_2 is equivalent to a reduction of 12.7 % of O_2 resulting in a residual O_2 concentration of 8.3 % Fig 3 also shows that the O_2 concentration after 4.7 weeks of storage was 11% The difference of 2.7 % O_2 may have been due to air permeation through the PVC plastic sheeting from which the flexible bag was made.

The PVC formulation used in this structure has a permeability rate of 87 ml O_2/day/m^2 at an O_2 concentration of 0% against the normal atmospheric concentration of 21% O_2 (Navarro et al., 1996) This would account for a diffusion rate of about 25 ml O_2/day/m^2 at an average concentration of 15% O_2. Assuming the entire sheeting of the structure as being 4.382 m^2, then the estimated O_2 penetration through the membrane could reach $25 \times 33 \times 4.382$ = 3.6 L or about 1.3 % O_2 It was estimated that at each gas sampling a volume of about 0.6 L was withdrawn from the granary Then for the entire period, in which 26 measurements were taken about 15.6 L of air, or an equivalent of 3.3 L of O_2 was removed.

Consequently, the difference between the estimated total O_2 consumed and the volume that penetrated the structure should result in the actual measured concentration in the granary. Accordingly the total O_2 consumed by insects during the first 33 days was 39.6 L, the estimated volume that penetrated through the sheeting was 3.6 L, the estimated volume that infiltrated as a result of gas sampling was 3 3 L. If the above calculations are correct then the expected O_2 reduction would result as $(35.6 - 3.6 - 3.3)$ = 28.7 L or $(21 - 10.3)$ = 10.7%. The difference of 0.3 % O_2 between the calculated (10 7 %) and the measured (11%) concentrations could be attributed to air infiltration into the granary through small and undetectable leaks

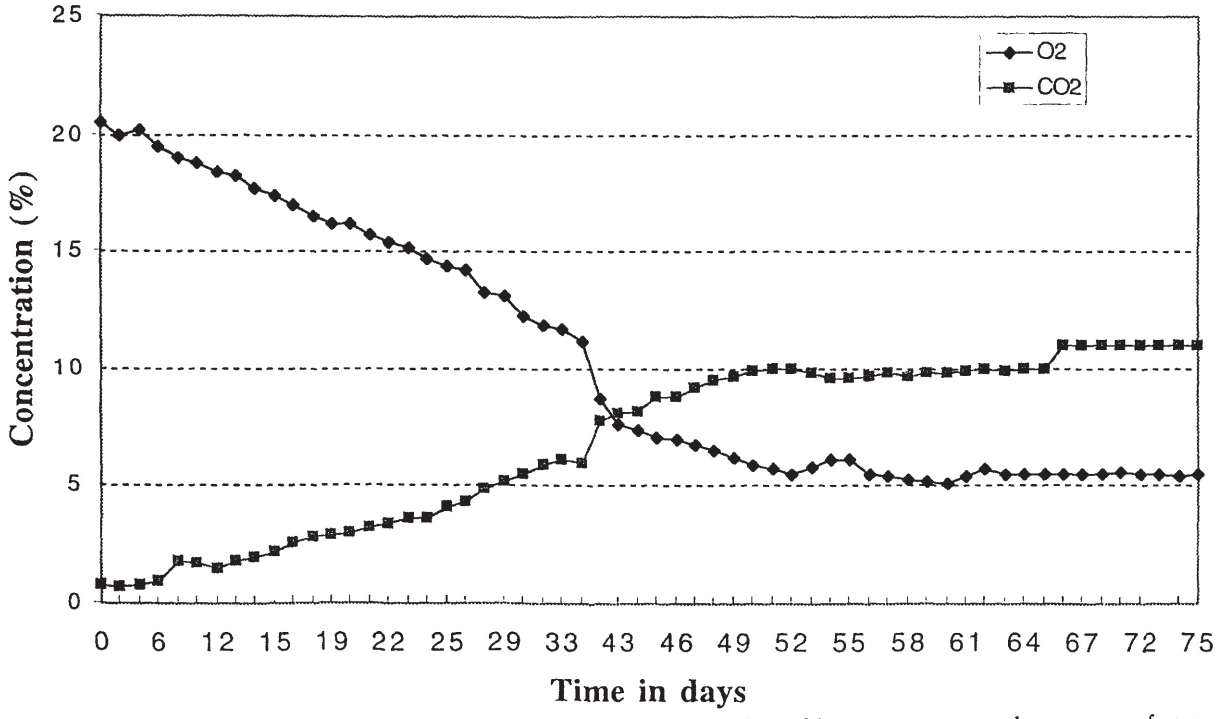

Fig. 2. Oxygen and carbon dioxide concentrations in the granary during 10 days of hermetic storage without insect infestation, and 64 days storage following introduction of adult *Rhyzopertha dominica* and *Tribolium castaneum* at a population level of 6 adult insects/kg

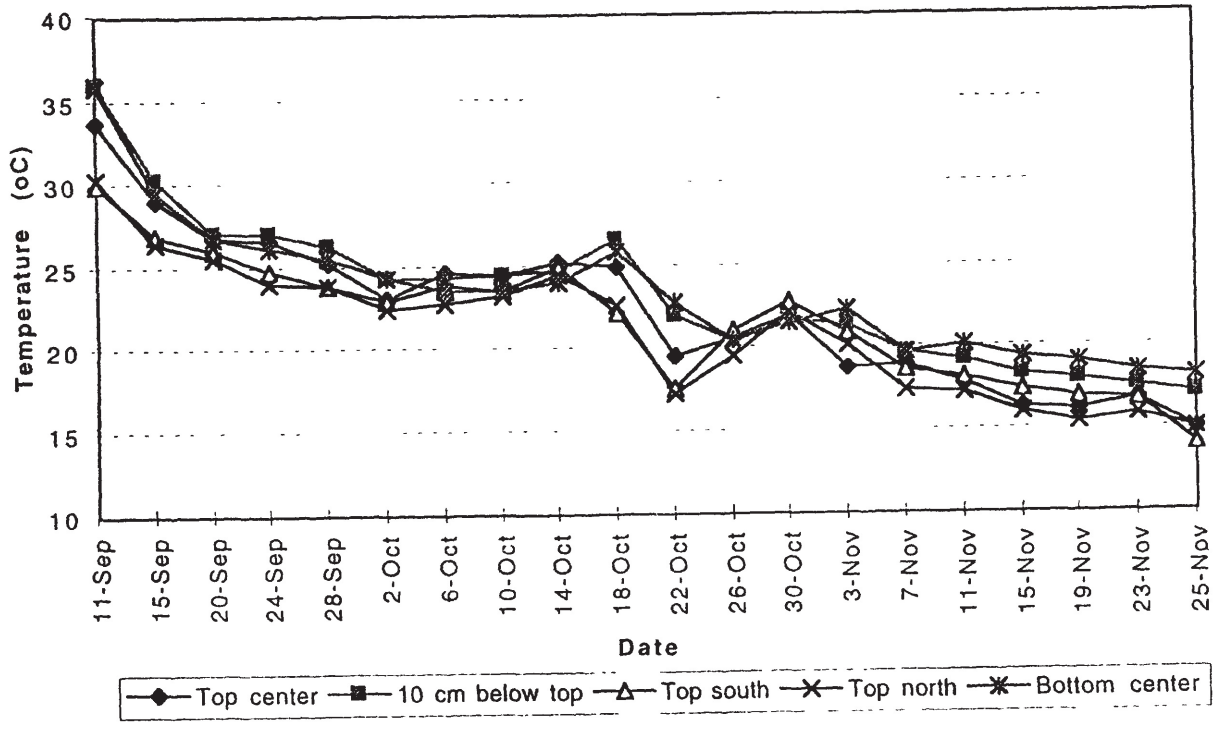

Fig. 3. Average daily temperatures at 5 points within the granary over the 74 day sealed storage period

According to Fig. 3, the O_2 concentration dropped from 21% to 11% within the first 33 days, and from 11% to 5% within the next 30 days of storage. During the first month of storage it was assumed that insect reproduction was still under conditions close to that of normal atmospheric air. However, during the second month, the further reduction in

O_2 concentration seems to be a result of a complex of effects. On the one hand insect respiration could be significantly reduced (Emekci et al., 1997), while on the other, because of the reduced rate of insect metabolism it is very possible that insect reproduction was arrested. Data regarding these effects are lacking in the literature; the only published information related to these influences of gastight storage being given in a model that would predict O_2 concentrations as a result of initial insect populations (Navarro et al., 1996).

Temperature fluctuations during storage

Data logger #5 situated above the liner was damaged by rain and consequently ambient temperatures could not be downloaded. Daily average temperatures within the granary over the two month storage period are given in Fig. 3. From the figure it can be seen that from mid September until mid October, grain temperatures within the bulk (10 cm below top and bottom center) dropped from 36℃ to 26℃. This was followed by a rapid drop to around 20℃ over the next week and a subsequent gradual temperature decrease to 17℃ at the end of the sealed storage period These findings indicate that for the first month, grain temperatures were favorable for development of both the insect species used to infest the grain, whereas during the second month temperatures were sub-optimal though they were still within the range that permitted insect development. Temperature recordings were not continued after the 74 day storage period (14 days acclimation plus two months infestation) because the loggers' memory were limited to 1800 hourly recordings. However, the evident cooling trend towards winter indicates that during the unloading period grain temperatures dropped to below 15℃, and at these temperatures insect activity is limited.

Average daily temperature gradients from the outer surface at the north, south and top center, to a depth of 10 cm are given in Fig. 4. From the figure it can be seen that the greatest temperature gradients occurred over the first 10 days due to the high temperature of the grain loaded into the granaries while the peripheral grain cooled as autumn nights became cooler. A second increase in temperature gradients occurred over the period of 14th to 26th October again due to a cold spell of weather. Average temperatures at the center (point 1) were higher than in the south (point 3), while those on the northern side (point 4), were lowest. Since the temperatures within the bulk (point 2), were usually higher than the average peripheral temperatures, the daily temperature gradients were greatest in the north. This can be seen in Fig. 5 where a typical 24 h temperature cycle is shown. For most of the storage period, average temperature gradients were no greater than 2.5℃, thereby indicating that there was no significant moisture migration to the upper surface. This was corroborated by MC recordings of grain taken during unloading.

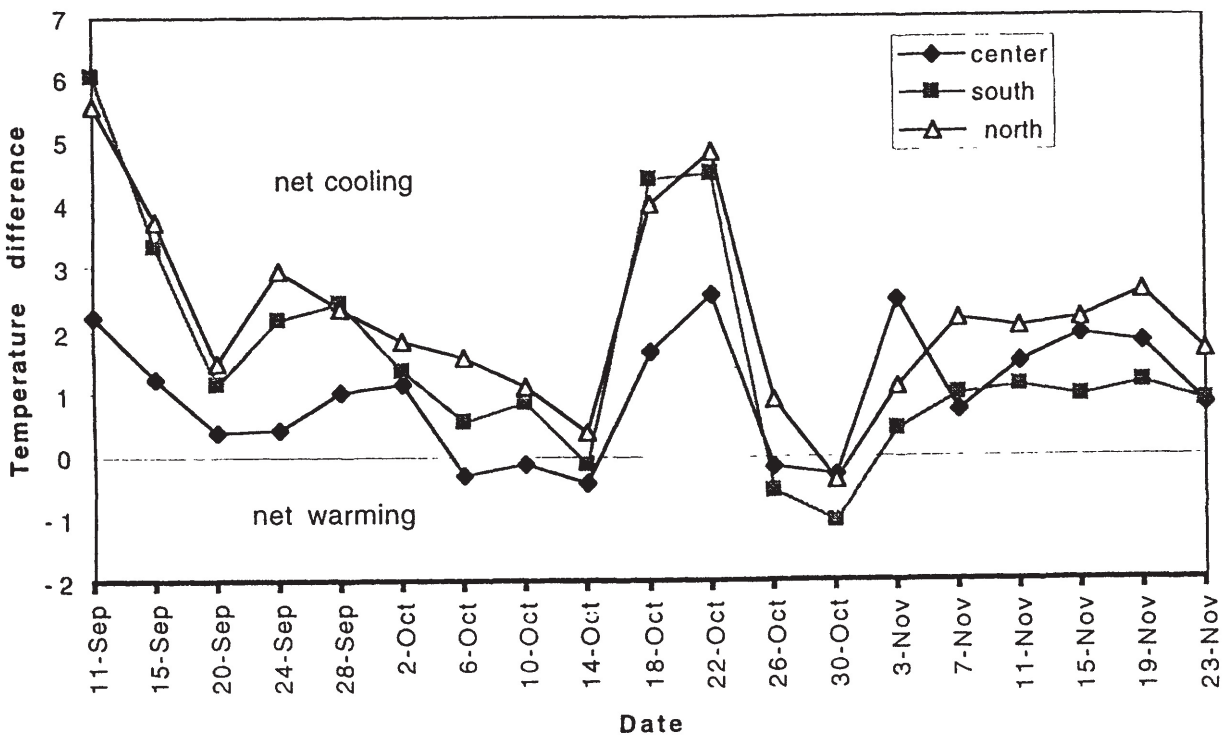

Fig. 4. Average daily temperature gradients in the granary from the outer surface at the north, south and center-upper layer, to a depth of 10 cm

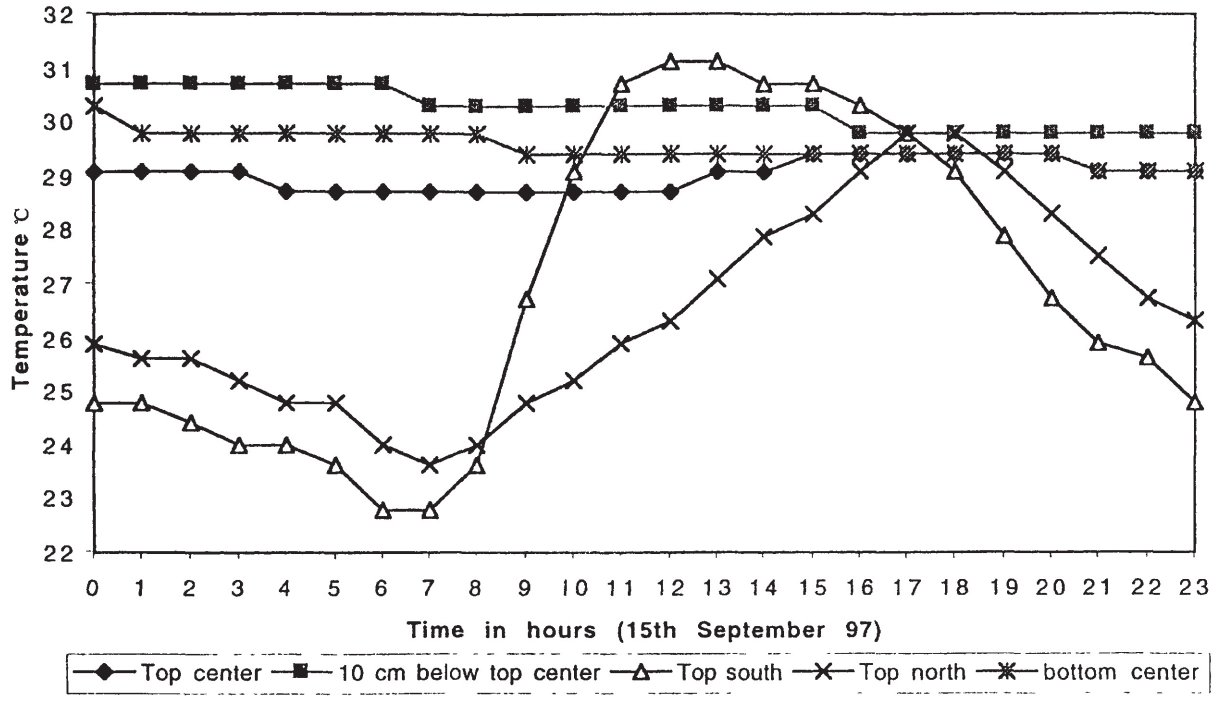

Fig. 5. Temperature cycles at five points within the granary for the 24 hours of 15th September 1997

Gas composition during unloading period

The atmospheric compositions in the granary over the 6 weeks unloading period are given in Fig. 6 The figure shows that the increases in O_2 concentration after each grain removal were relatively small, amounting to a maximum of 1.8%, with a similar decrease in CO_2 concentration of up to 1.4%. These changes were most pronounced at the first grain removal and decreased after each removal as the gas concentrations slowly returned towards the atmospheric composition. This may be explained by the fact that ambient temperatures were decreasing thereby reducing insect metabolism and as shown by infestation counts (Tables 1 and 2) very few live insects were recorded from each lot of grain removed.

Insect infestations in unloaded grain

The insect infestations found in app 1 kg samples withdrawn from each 100 kg of grain unloaded at weekly intervals from the granary, and in 100 g samples taken from the unloading sleeve are given in Table 1.

From these findings it is clear that at the end of the two month hermetic storage period and during the 6 weeks unloading period, the insect infestation in the grain bulk was extremely low. Apart from the isolated cases of live *T castaneum* larvae, the only living insects found in the grain bulk were individuals of *Sitophilus oryzae*, *Oryzaephilus surinamensis* and *Cryptolestes* sp. adults which were not species added to the grain at the time of loading and must have been present as hidden infestation or larvae which was not detected at the beginning of storage. In contrast the *R dominica* infestation seems to have died out completely.

In the unloading sleeve however, live infestations were more evident. This is a known phenomenon of accumulation of live insects in peripheral regions of hermetically sealed structures (Navarro et al., 1984), and may be explained by movement of the freely moving insect stages up an oxygen gradient to areas or pockets where O_2 remain higher, or movement to areas of higher humidity. In addition to the possibility of O_2 ingress into the sleeve during unloading, it is likely also that the large surface area of the sleeve in relation to volume inside the sleeve would enable the limited ingress of O_2 through the liner to have a greater influence on the O_2 concentration of the intergranular air of the immediate vicinity and thereby allow the survival of insects in this region. Evidence of this can be seen in Fig. 7. Furthermore, because of the very limited amount of grain in the sleeve, the diurnal temperature fluctuations of the ambient would have a greater influence on grain temperature fluctuations, with a consequent high probability of condensation on the inner surface of the liner as the plastic cools down at night. This would explain the higher MCs particularly in the first weeks of unloading.

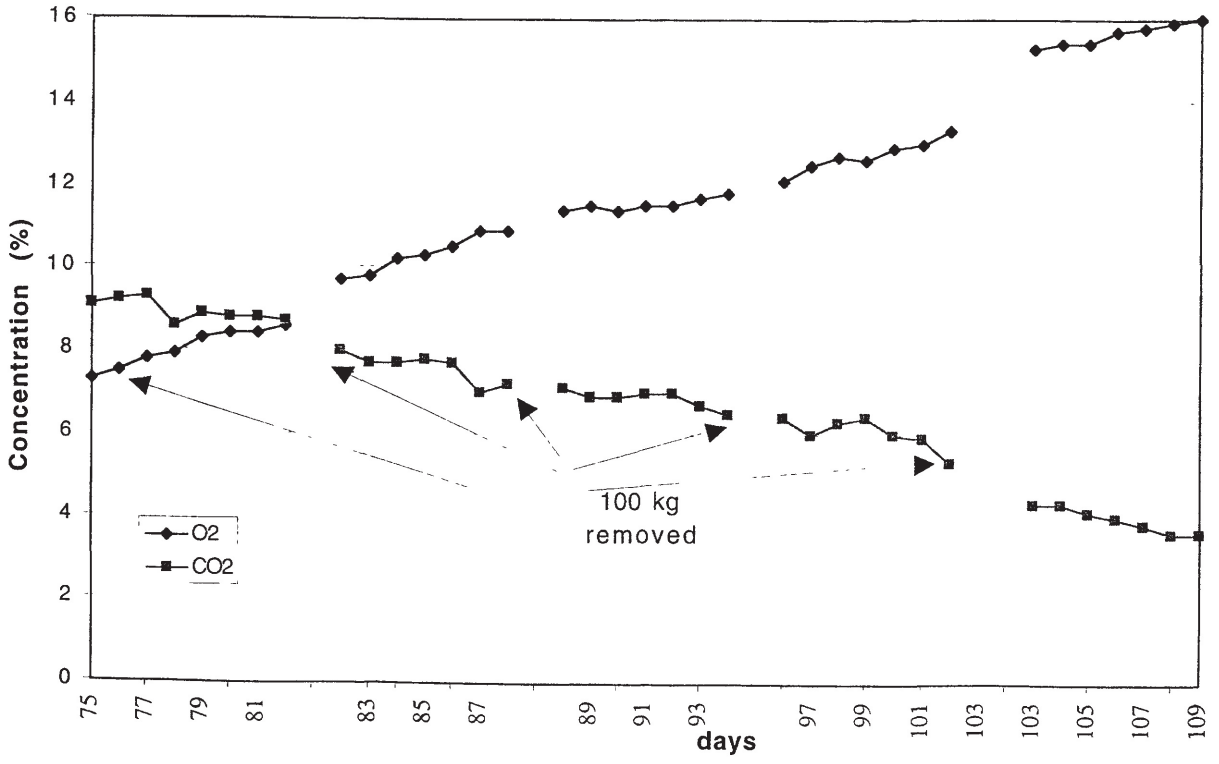

Fig. 6. Oxygen and carbon dioxide concentrations in the granary over the 6 weeks unloading period

Table 1. Adult insects found in 1 kg samples taken from 100 kg grain lots withdrawn from the granary, and in 100 g samples taken from bottom of the unloading sleeve, at weekly intervals after 64 days of hermetic storage.

Position	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Center of granary bag	0	Rd A (1) Tc L 1	0	Cr A 1	0	Tc A 3 Cr A 1
Sleeve	Tc A 5	Tc A 12	Tc A 2 + (2) So A (1)	So A 1 Tc A 5 + (1)	Tc A 3 Os A 1 Cr A 1	Tc A 17 + (1) Tc L 1 So A 1 Cr A 5

* Where Rd = Rhyzopertha dominica, Tc = Tribolium castaneum, So = Sitophilus oryzae, Os = Oryzaephilus surinamensis , Cr = Cryptolestes sp Cp = Carpophilus sp , A = adult, L = larva, P = pupa, numbers in brackets represent dead insects

Moisture content of unloaded grain

The results of analysis of moisture contents of grain samples taken during unloading are given in Table 2 The uniformity of the MCs indicates that there was no detectable migration of moisture in the grain bulk during storage. This is in contrast to the MCs of the samples taken from the unloading sleeve where water condensation was observed. It was assumed that the condensation was caused by the significant temperature gradient established in the exposed sleeve as the grain cooled during the nights. About 150 g of grain was subject to increased moisture content and this amount was discarded at the first week before the rest of the grain was withdrawn. This water condensation phenomenon was later prevented by tying a temporary ligature at the top of the sleeve, and thereby preventing grain from entering the sleeve during sealed storage

On the basis of previous findings in other storage structures it may be hypothesized that this is a phenomenon accentuated during the transient autumn season when the day-night temperature range in Israel is at its greatest. In fact, after the first three weeks of unloading, MCs in the sleeve were not significantly higher than those in the grain bulk.

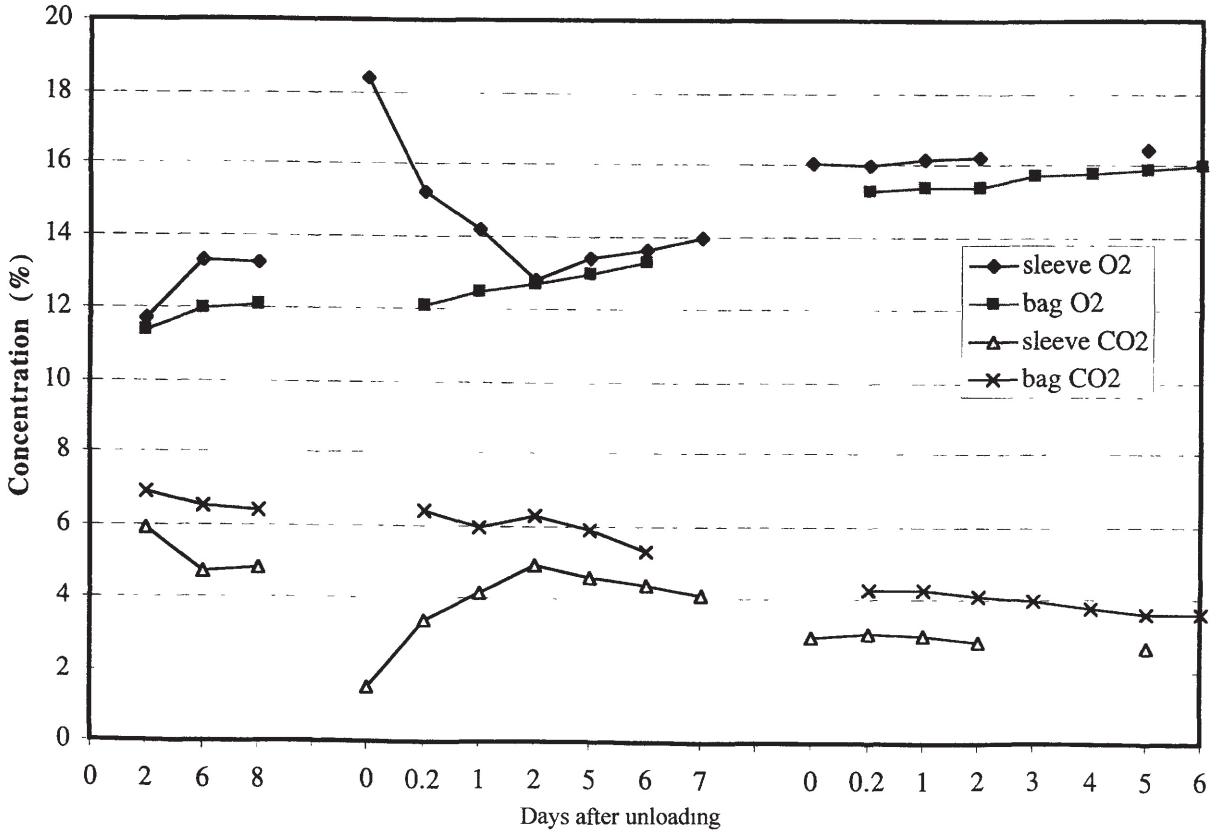

Fig. 7. Oxygen and carbon dioxide concentrations recorded in the unloading sleeve and bag of the granary during the last three weeks of unloading.

Table 2. Average moisture contents of two samples of maize taken during withdrawal of 100 kg grain lots from the center of the granary at weekly intervals after 64 days of hermetic storage.

Initial	Week 1	Week 2	Week 3	Week 4	Week 5
10.1	10.2	10.2	10.4	10.3	10.2

Conclutions

1. The findings in this trial clearly show that under Israeli conditions dry maize could be safely stored for 5 months in the sealed granary, without need for chemical control, even though it was periodically opened to permit partial removal of its contents.
2. The level of gas tightness and the construction design contributed to a minimal change in gas composition within the granary during each unloading.
3. A residual insect population survived, but could not develop to a level causing economic damage.
4. Gas concentrations indicate adequate sealing to a level that prevented grain damage.
5. Gas losses throughout the emptying process of 100kg per week, caused an increase in O_2 concentration at an average rate of 1.8% per discharge. However, this unloading rate did not adversely influence the storage potential of the maize.
6. The granary was shaded with a roof-cone of plant material, resulting in minimum temperature fluctuations, while condensation was not detectable at the top surface of the granary.
7. The initial 10.1% MC of the maize did not significantly change throughout the storage period.
8. The granary still has to be field tested in target countries, both to examine it under local conditions and to evaluate its acceptability from the socio-economic view-point.

Acknowledgments

The authors wish to thank Mr. Tom deBruin, export manager, and Eng Igor Koltunov of Haogenplast, Israel for their close cooperation in the development and construction of the granary. We also acknowledge the valuable suggestions and encouragement provided by GrainPro Inc. USA.

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