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Long-term hermetic storage of barley in PVC-covered concrete platforms under Mediterranean conditions

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Abstract

A method for the bulk storage of barley in the open air under Mediterranean conditions was developed. A large (75 × 25 m) concrete platform with low walls was filled with barley and covered with a PVC overliner and a polyethylene underliner. The barley formed a pile of 4018 tonnes with a peak 7 m high and was stored for 34 months under hermetic seal. Periodic monitoring was carried out to determine temperature fluctuations, intergranular gas composition, insect infestation, and grain quality parameters. Ambient temperatures were shown to create temperature gradients in the upper layers, and moisture migration occurred towards the peak of the grain bulk. However, the resulting spoilage by moulds was limited to 0.22% weight loss on an annual basis. An additional 0.12% loss due to insect damage, and spillage resulted in an annual storage loss of 0.34%. Possible solutions to this problem were discussed. The platform successfully protected the grain against insect, bird, and rodent attack and provided safe storage during the rainy season. At the end of storage the PVC overliner, which had been used continuously since 1988, remained with low gas-permeability, retained its mechanical characteristics and was suitable for reuse.

Keywords: Barley; Storage; Hermetic; Plastics; Bunker

1. Introduction

The use of bunkers for storage of cereal grain surpluses has been developed recently both in Australia (McCabe and Champ, 1981) and Israel (Navarro et al., 1984). Whereas in Australia the bunkers receive an initial phosphine fumigation (Banks and Sticka, 1981), the Israeli concept is based on the use of a 0.83 mm thick, white, non-reinforced, UV-protected overliner, and a 0.25-mm polyethylene

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underliner to obtain a level of hermetic seal that precludes the need for chemical intervention against stored product insects. The requirement for storage of surpluses of locally harvested grain and the similar typical Mediterranean climatic conditions — characterized by long hot summers, mild winters with winter rainfall — both contributed to adaptation of the Israeli-type bunker to storage requirements in Cyprus.

Two previous trials of bunker storage with barley, for periods of 7.5 and 9 months, provided basic information on sealing requirements and quality conservation (Navarro et al., 1993). They showed that storage was feasible on locally constructed concrete platforms instead of the earthen bunkers used in Israel, and it was on the basis of these findings that the long-term storage of barley was carried out. The objectives of this report are to: (a) evaluate the influence of climate on the grain storage ecosystem over a 34-months storage period; (b) evaluate the influence of hermetic seal on the composition of the intergranular atmosphere during storage; and (c) summarize changes in grain quality during storage and relate them to the storage system.

2. Materials and methods

Storage platform

This was one of two, and consisted of a 20-cm reinforced concrete floor with a peripheral support wall 1 m high and 15 cm thick, and a surrounding apron 80 cm wide outside the wall. The platform was 75 m long and 25 m wide and set on an east–west axis with all four corners angled at 45° by wall sections 3.5 m long to form an octagon. The platform had two entrances on the southern side, each one 5 m wide to permit loading and unloading with trucks, and the platform was constructed with a gentle slope towards the entrances.

Loading, sampling and sealing

Before loading, strips of 0.25 mm thick polyethylene underliner were laid transversely over the floor and walls. To keep the plastic from being torn by the concrete walls, two layers of 2–3 cm thick strips of insulation material formed from synthetic fiber were glued along the top of the wall before the underliner was placed in position. Loading was started by truck at the far end of the platform and as it progressed, successive strips of underliner were placed in overlapping position and joined together with adhesive tape. After the floor had been covered, the two entrances were sealed with wooden planks and loading was continued with screw conveyors that raised the grain along a central peak to a height of ca. 7 m at which stage the peripheral grain level was about 25 cm below the upper lip of the wall. After loading was completed, the grain bulk surface was trimmed to fill depressions.

The platform was loaded with 4018 tonnes of locally harvested barley (a mixture of cvs. Cantara and Athinais) during September 1989.

The platform was sealed using a 0.83 mm thick PVC formulated overliner. Rolls of the liner 10 m wide and 34 m long were placed over the wall, and were pulled over the top of the grain bulk. They were then welded together to form a continuous liner. The gastight seal was obtained by folding the over- and underliners together at the base of the wall and securing with sand-bags. A series of 15 cm wide polyester-woven fabric strips were placed at 10-m intervals across the platform above the overliner and these were anchored to the concrete apron. These strips prevented flapping of the overliner in high winds that frequently occur in the area.

After sealing, eight screw-cap inspection ports were welded along the peak from east to west, within which thermocouple cables and gas-sampling tubing were inserted to depths of 0.3, 1.0 and 3.0 m, respectively. The platform was sealed on 21st–22nd September 1989, and uncovered after 34 months storage.

In-storage monitoring and sampling

Grain: Samples were withdrawn from the inspection ports at one- to two-months intervals, and at three depths (0–0.3, 1.0, and 3.0 m). Each sample (ca. 500–600 g) was examined for moisture content (MC) by oven-drying ground samples at 130°C for 2 h, and insect infestation (using a sieve with 1 × 10-mm slots). A Probe-A-Vac vacuum sampler was used to withdraw the samples from the different depths.

Viability: After 19 months storage, the samples from 1- and 3-m depths were mixed to form four composite samples that were tested for viability by the tetrazolium method (Moore, 1962).

Temperature: Measurements at all ports were carried out at the same intervals.

Intergranular atmospheric composition: Oxygen (O_2) and carbon dioxide (CO_2) concentrations in the grain bulk were measured monthly by withdrawing gas samples through the plastic tubing inserted into the grain, and analyzing using a Gow-Mac portable analyzer for CO_2 concentration, and a Herman-Moritz analyzer for O_2 concentration determination. Towards the end of storage, gas monitoring was reduced by taking only one reading from a depth of 1.5 m at each sampling port.

Ambient conditions: Ambient temperatures, and rainfall during the storage period were taken from available meteorological data at the nearest meteorological station (Nicosia) and are provided in Fig. 1.

Equilibrium relative humidity: An equilibrium relative humidity (ERH)/MC curve for local barley varieties was determined separately using barley samples of mixed cvs. (Cantara and Athinais) at different MCs taken from a previous hermetically sealed platform. The barley MC was determined using the oven-drying method. The equilibrium relative humidity of the interstitial air space of the same barley was determined using a Novasina electronic humidity sensor suspended in a gastight 350-ml plastic container that contained the sample. The ERH/MC curve is given in Fig. 2.

Unloading and sampling

Before unloading, the overliner was removed and additional grain samples were withdrawn as follows: (a) from three areas of visible mould at the apex (0–30 cm) for moisture and mycofloral analysis; and (b) surface samples (0–15 cm) from the four slopes (north, south, east, and west) for moisture and insect infestation analyses. From each slope surface samples were collected (approximately from every 1-m distance in each of the slopes) from two locations: at a distance of 1 m from the retaining wall, and mid-way between the wall and the platform apex. In addition,

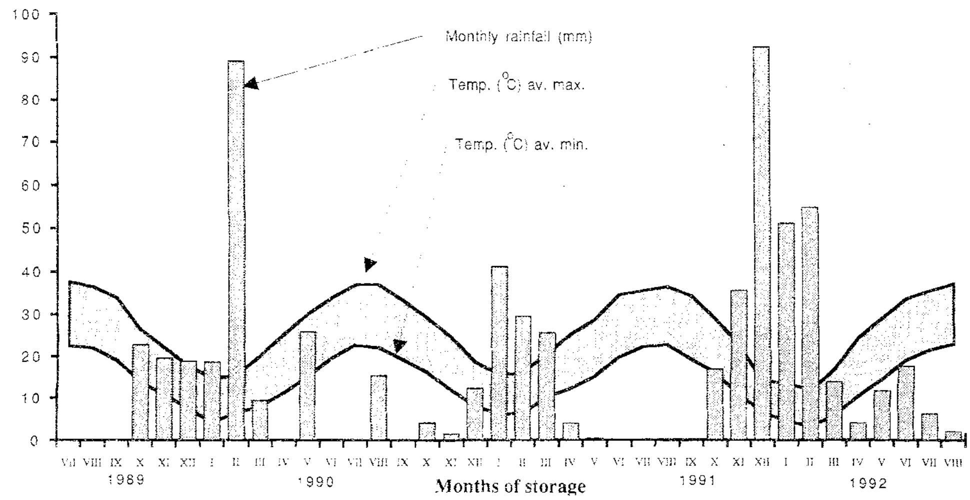

Fig. 1. Ambient temperatures and rainfall recorded at the Nicosia meteorological station between July 1989 and August 1992.

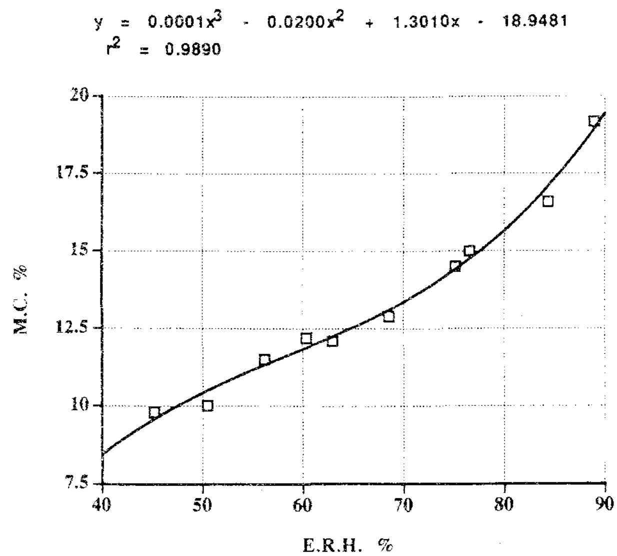

Fig. 2. ERH/MC curve for local barley at 25°C.

samples were taken from a depth of 1 m from a location mid-way between the wall and the apex over each slope using a hand sampler.

After removal of the overliner, mouldy barley that was located at the apex, was carefully separated manually from sound grain and removed from the platform. During unloading (with front-end loaders), 1–1.5 kg samples were taken from each truck. Samples from 20 consecutive trucks were pooled to form nine composite samples which were reduced to 5 kg each. The composite samples were used to determine germination (4 × 100 replicates in sand), chemical analysis (protein, fat, fiber, and MC), and physical analyses (test weight, purity, weed seeds, and broken kernels). One pooled composite sample was used for aflatoxin analyses by high-pressure thin-layer chromatography (HPTLC) fluorotensiometric method.

3. Results and discussion

Grain temperatures

The average temperatures of grain at three different depths beneath the apex of the platform over the storage period are given in Fig. 3. This shows the very marked influence of seasonal temperature fluctuations in the ambient on temperatures at 0.3 m within the grain bulk, whereas at 1.0 and 3.0 m fluctuations were progressively attenuated. This resulted in the establishment of strong temperature gradients within the bulk particularly between 64 and 200 days of storage (November 1989–March 1990), around 500 days (January–February 1991) and around 850 days (January–February 1992). These temperature gradients were considered responsible for convection currents that caused moisture transfer to the peak area of the bulk.

Moisture content

Fig. 4 shows the maximum and minimum MCs recorded at a depth of 0–0.3 m, and the average MCs from all sampling stations at depths of 1 and 3 m during storage. The average initial MC was 8.8% (range: 8.0–10.8%). In the 0–0.3 m layer, the MC rose more rapidly at some sampling stations than at others. The critical MC

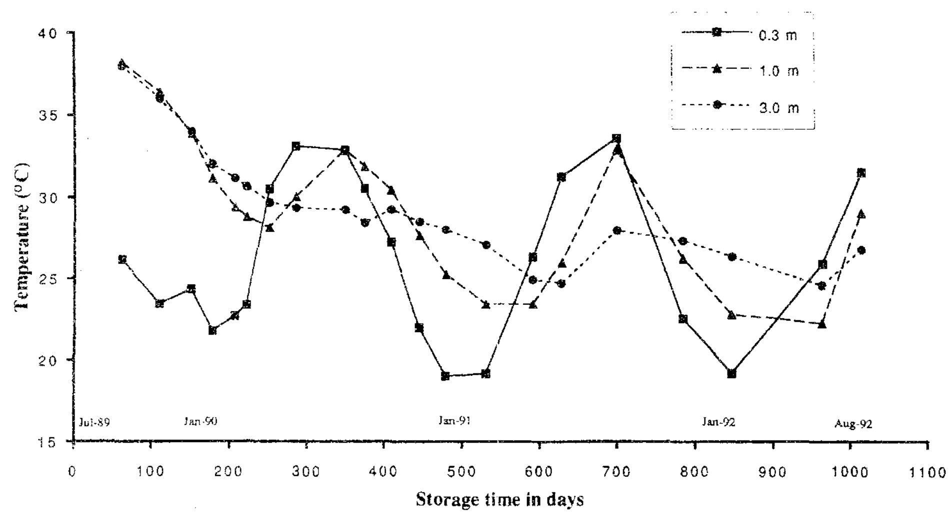

Fig. 3. Average temperatures at three depths of a pile containing 4018 tonnes of barley stored hermetically for 34 months in a PVC covered platform.

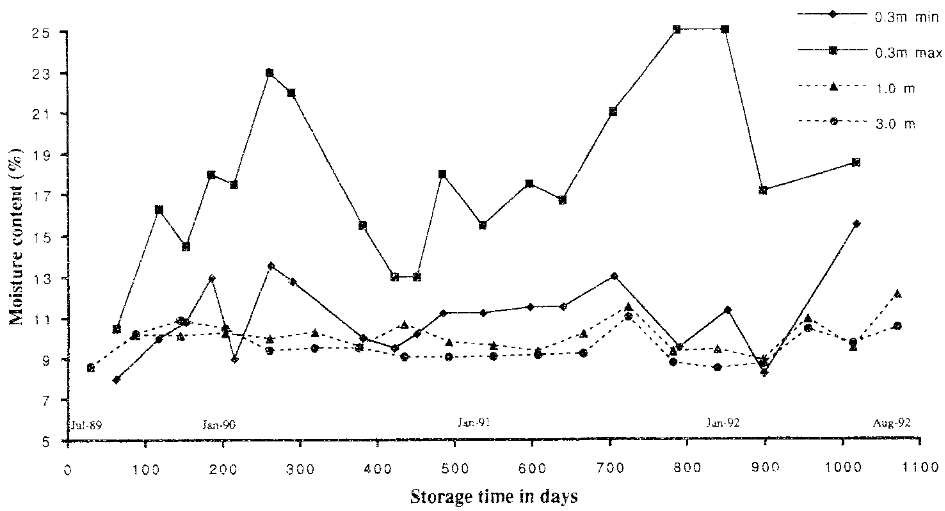

Fig. 4. Average moisture contents at three depths of a pile containing 4018 tonnes of barley stored hermetically for 34 months in a PVC covered platform.

of barley above which storage fungi are capable of rapidly developing is that above the ERH of 75%, namely 14.5% (Pixton and Warburton, 1971). After the MC had risen above this critical MC subsequent samples were found to be mouldy resulting in caking at the surface layer. Fig. 4 shows that there were cyclic moistening and drying effects caused by seasonal temperature fluctuations that resulted in a wide range of MCs recorded at the upper layer. By the end of storage, MCs above critical had been recorded at least once at all sampling stations, and mouldy grain was recorded from surface layer at seven of the eight stations. Samples from depths of 1 and 3 m were relatively uniform in MC throughout storage with no samples above critical MC. This and previous storage trials (Navarro et al., 1993) showed that the presence of mouldy grain was limited to the area at the peak of the grain bulk. This phenomenon was attributed to convection currents arising from temperature gradients, particularly occurring at pointed apices where condensation was marked. The daily cycles of warming and cooling of the surface layers determine whether there will be a net increment or decrement of moisture.

Gas composition

The CO_2 and O_2 concentrations of the intergranular air within the platform are given in Fig. 5. It can be seen that there was a rapid decrease in O_2 and increase in CO_2 concentration over the first 50 days followed by fairly stable levels for the rest of the storage period except for a sudden increase in O_2 and decrease in CO_2 after 540 and 900 days of storage. On these two occasions it was found that one or more of the plastic screw-caps were absent and the changes in gas composition were attributed to a temporary break in the hermetic seal of the platform. From experience on hermetic storage in Israel it has been found that in contrast to insect

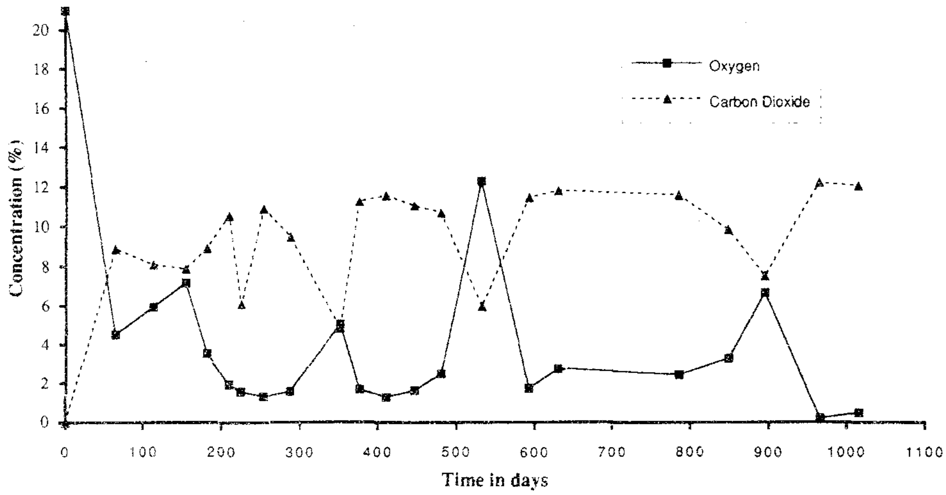

Fig. 5. Average gas concentrations in a pile containing 4018 tonnes of barley stored hermetically for 34 months in a PVC covered platform.

infestations, active microbial spoilage can raise CO_2 readings well above 12%. Since very few CO_2 recordings were made above this level during the storage period, this indicates that no extensive microbial respiration took place in the grain bulk.

Insect infestation

Of 450 samples examined for infestation (from three depths at the eight sampling stations) live insects were recorded from only 34 samples during the storage period. The distribution of infestation was: 26 infested samples from the surface layer; seven samples from a depth of 1 m; and one sample from 3 m. The species were: *Tribolium* sp. in 27 samples; *Oryzaephilus* sp. in five samples; and *Rhyzopertha dominica* in three samples. All were recorded during the first year of storage, mainly from the upper layer. Of these, only three infested samples were recorded during the second half of the first year.

No samples containing live insects were recorded at the end of storage except from samples taken from the grain bulk surface. To quantitate the intensity of this infestation, eight composite surface samples were taken after removal of the overliner before unloading the grain. Analysis of these eight samples taken from the surface revealed that three were infested with a total of 16 *Tribolium* sp. and three *R. dominica* live adults. This residual infestation may have survived due to the high MC prevailing at the surface of the bulk. No live insects were recorded from the 1-m depth samples.

Results from previous trials in Cyprus and those in Israel, all revealed initial infestations by stored product insects. The very rapid reduction in O_2 and rise in CO_2 concentrations after the platform was sealed, was attributed mainly to insect development especially at the surface layer of the bulk.

Germination

Samples taken after 19 months storage from 1 and 3 m depth served for analysis of viability. Sampling ports 1–4 formed one composite sample and samples from ports 5–8 formed another. Viability of the in-bulk composite grain samples after 19 months storage was 94–98%.

The germination tests of nine composite samples obtained during unloading after 34 months of storage, gave a germination level of 88.3 ± 1.6% (SD) with an additional 4.6 ± 1.0% (SD) abnormal seeds. The significance of these high levels of germination after prolonged storage lies in the possibility of utilizing the hermetically stored barley for seed grain, should this be needed.

Damage by moulds

Mouldy grain was only located along the apex of the grain bulk, and to a distance of 2–4 m from the peak along either slope. However, it did not form a continuous strip along the apex and the depth of affected grain ranged from 5 to 50 cm.

The following microflora were identified from three visible mould-damaged grain samples taken from the surface after the overliner had been removed: *Aspergillus ochraceus, A. flavus, A. fumigatus, Fusarium* sp., and *Penicillium* sp. All species were identified from both surface sterilized and non-sterilized seeds.

Although mould presence alone is not evidence of mycotoxin production, some of the above species are capable of producing mycotoxins under favorable conditions (Mirocha and Christensen, 1974; Bullerman, 1979). Therefore, it was most important to remove all mouldy grain from the sound grain of the bulk before unloading.

Aflatoxins were not found in the pooled sample formed from the composite samples of sound grain taken from the bulk after the platform had been uncovered.

Other grain quality parameters

Chemical analysis: No initial analysis of the barley was made. However, for comparative purposes chemical analyses of the barley after 34 months storage were made together with those of two local barley varieties from the 1993 harvest analyzed before storage. Results given on a dry weight basis showed that crude protein in the stored barley was 11.8%, while in fresh barley var. Cantara it was 11.9% and in fresh barley var. Athinais it was 13.0%. Fat in the hermetically stored barley was 2.0%, in fresh barley var. Cantara it was 1.5% and in fresh barley var. Athinais it was 1.9%. Crude fiber in the hermetically stored barley was 7.5%, in fresh barley var. Cantara it was 6.7% and in fresh barley var. Athinais it was 6.3%.

During uncovering of the platform, the sound grain had the characteristic odour of fresh, recently harvested barley.

Physical analysis: The average results of the nine composite samples after 34 months storage showed 96.7% pure seeds, 0.2% weed seeds, 2.5% broken seeds, 0.6% inert material, and test weight was 603.2 kg/m^3.

Durability of the PVC overliner

The durability and resistance of the overliner was shown to be suitable to protect the grain over the storage period from adverse climatic conditions of solar UV irradiation, high temperatures and high velocity winds. The same liner was used for a previous one-year storage period. Laboratory tests, carried out on samples of material cut from the liner at the end of storage, showed that its resistance to tear remained almost unchanged, elasticity changed by 10–20%, and gas permeability improved by 60% over that of the original liner. Improvement in gas permeability is due to the loss of plasticiser components.

High velocity winds in the Nicosia area occur particularly in November from the north. Since the liner forms an hermetic seal, air is unable to penetrate it, and the covering provides excellent resistance to stormy weather. Periodic examination of the liner over the 34 months of storage showed no weather damage to the liner, and the welded sections remained undamaged. Consequently, water penetration from the surface to the grain bulk was not possible.

The grain loading method and the overliner held under tension provides a slippery surface that makes it extremely difficult for rodents to make an incision in the material with their teeth. This has been confirmed by laboratory trials carried out with liners kept under tension and exposed to rodents (unpublished results). Although rodents may be able to climb over the walls, damage to the liner was not perceived.

Polyethylene underliner

The concrete platform was constructed at an elevated site to prevent water infiltration from underneath and also well protected from rainwater from above by the PVC liner. An adhesive tape was used for holding the polyethylene underliners together until the grain was loaded and held the liners against the floor. The underliner served as a gas barrier rather than protection from water.

Losses

The weight of mould-damaged grain removed from the peak of the platform was 26.72 tonnes, representing a 0.665% weight loss for 34 months or an annual loss of 0.222%. Additional losses (insect damage and spillage) based on inlet and outlet weigh-bridge data, amounted to 12.08 tonnes. Total storage losses for the 34 months were 38.8 tonnes or an annual loss of 0.34%. These losses were relatively high in comparison with trials conducted in Israel (Navarro et al., 1984, 1993). The major loss in the present trial was from mould-damaged grain due to moisture migration. This problem has been significantly alleviated in recent bunkers in Israel which have a flattened area at the peak. We believe this serves to broaden the area over which moisture is deposited during phases of convection currents and condensation beneath the liner, and in consequence mouldy grain is only rarely encountered.

4. Conclusions

The results of the above trial clearly show that this type of structure is suitable for the prolonged storage of dry barley. It should be noted that in addition to the low structural cost and ecological advantages of the bunker system, storage losses can be compared very favorably with weight losses in conventional structures.

The major problem encountered was the establishment of temperature gradients in the upper layers of the bulk that promoted moisture migration towards the peak. This resulted in small quantities of mould-damaged grain that had to be separated from the rest of the bulk before unloading. A possible solution to this problem could be by altering the structural configuration of the apex to a flattened area at the peak.

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