AIRTIGHT STORAGE OF WHEAT IN A P.V.C. COVERED BUNKER

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ABSTRACT

Wheat of 11.4% moisture content was stored in an airtight structure formed by a polyethylene liner at its base and with a UV-resistant P.V.C. sheet over the surface. The wheat bulk of 15,566.5 t was supported by 2 m high earth banks. The oxygen concentration fell to 6% and the carbon dioxide concentration increased to 9% within 3 months. Insects were present only in the part of the upper layer where the wheat moisture content and high germination and baking quality was preserved. Wheat damage attributed to insects was estimated at 0.15%, and that to moulds at 0.06%. The P.V.C. liner remained in good condition and retained its elasticity, and no rodent damage was detected.

INTRODUCTION

Emergency or temporary storage facilities are frequently needed when very large crops are harvested following unusually favourable growing seasons, or in areas where buffer stocks are required yet permanent storage structures are lacking. This need has arisen after several recent large harvests in Israel so a trial was conducted to examine the suitability of bunkers for emergency storage.

The above ground bunker is an Australian adaptation of the previous underground pit type of bunker (Woolcock and Amos, 1976: Holley, 1979) which used the principle of hermetic storage to preserve the grain. It was lined with plastic sheeting, and wheat was loaded on to this and was then covered first by a top liner and then by a layer of soil. This final layer provided mechanical protection and also served as insulation. However, it added to the labour costs and considerable skill was required to avoid damage to the top sheet. The storage conditions maintained during the Australian trials and the final grain quality justified futher trials in Israel with appropriate modifications to suit local conditions.

This trial was conducted in southern Israel, in an area bordering on the Negev desert, which has long hot summers, mild winters and a low winter rainfall of 200 to 300 mm. The aims were to evaluate: (a) the airtightness achieved with the plastic liners, (b) the climatic and biotic conditions in the bunker and, (c) the grain quality and insect damage at the end of storage.

MATERIALS AND METHODS

The bunker site measured 50 x 150 m and was bordered on three sides by ramps of earth taken from both inside and outside the site with the fourth end left free for loading wheat. The ramps were 2 m high and 8 m wide at their base, with angles of slope permitting drainage of rainwater away from the outer sides. Before loading, the floor and ramps were lined using 250-μ polyethelyene sheeting with an overlap and fold-over at the edges to obtain a continuous underliner.

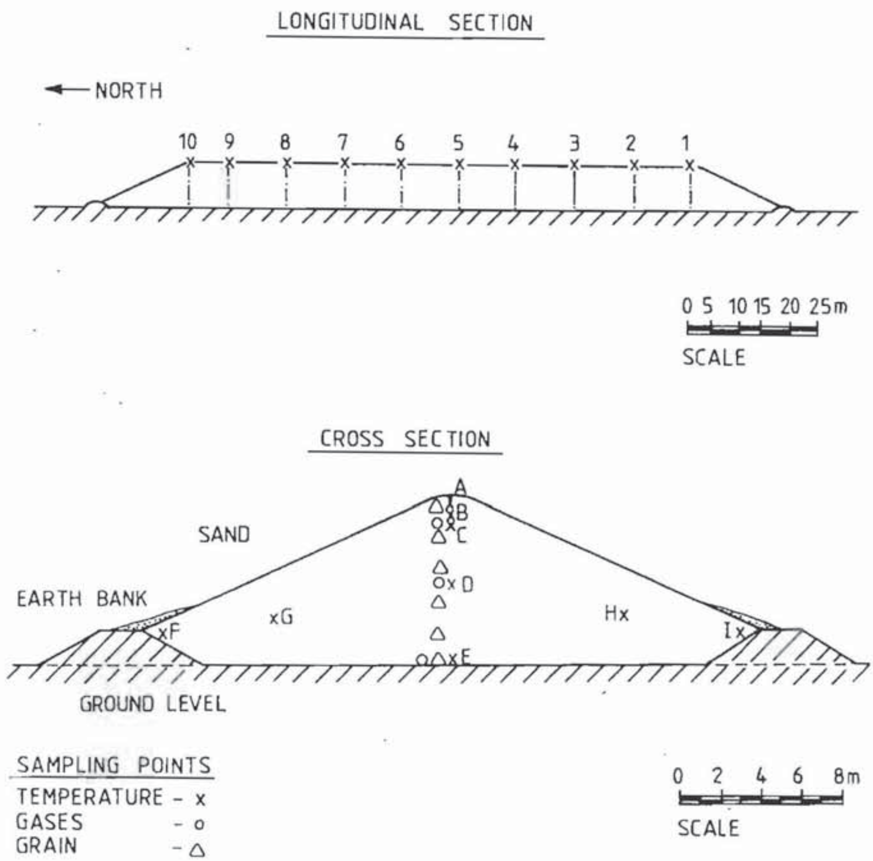

FIGURE 1

POSITION OF TEMPERATURE AND GAS MEASUREMENT, AND GRAIN SAMPLING POINTS IN THE EXPERIMENTAL SILO CONTAINING 15,566.5 TONNES OF WHEAT.

The overliner was 830-μ white polyvinyl chloride (P.V.C.) with an UV inhibitor (Haogenplast 5.196). The two liners came into contact on the outer bank of the ramps where they were folded over and covered with earth to provide a hermetic seal.

The bunker was loaded with wheat (var. Miriam) from the 1980 harvest and was transported to the site directly from the fields or after being cleaned on the farm. A total of 15,566.45 tonnes was loaded into the bunker in 28 days, and during this period 209 wheat samples were taken. The grain bulk was approximately 8.5 m high at the apex, and was contained between the earth ramps (Fig. 1).

Thermocouple cables for temperature measurements (90 points) and tubing for gas measurements (30 points) were placed in the bunker during loading at the points shown in Fig. 1. The cables and tubing were bundled together and directed out of the bunker at the junction between the over and underliner, so that ten measurement stations were set up along one of the ramps. Temperature and gas measurements were made approximately every 2 weeks.

To determine airtightness, a series of lowered pressures were applied by sucking air from the bunker at different flow rates and recording the pressure differential from ambient (Sharp et al., 1976; Navarro et al., 1978).

Sixty grain samples (1-kg each) were withdrawn from the bunker using a suction-sampler from ten equidistant sampling areas along the axis at 6 depths as noted in Fig. 1 on 10 occasions during the storage period. Moisture content of the grain was determined using a capacitance moisture meter, (Motomco Model 919). Insects were removed from samples by sieving the grain through a 10-mesh sieve with 2x2 mm holes. Germination was determined by the ISTA method (Annon., 1969). Baking tests were performed by a standard method that resembles closely the commercial method of bread making in Israel (Calderon et al., 1970).

Unloading was carried out after 15 months of storage. A 1-kg sample was taken from each truck (total, 585 samples) during the 3-week unloading period. Each sample was examined for insect infestation and moisture content. From every ten consecutive samples, two 1-kg composite samples were formed, using a Boerner divider. One of the composite samples was used to evaluate weight loss by the count and weigh method (Adams and Schulten, 1978) and for germination studies. These samples were also incubated in the laboratory at 26°C and re-examined after one month for insect development. The other composite samples were used to make up 13 samples destined for baking quality analysis.

RESULTS

Ambient conditions

Daily temperature fluctuation were especially large during the summer when the average maximum in both years of storage reached 37°C. Ambient temperatures fell progressively from October until January, when the average maximum temperature was 17°C. Relative humidities were high at night exceeding 90%, and between 30% and 40% during the day. Short periods of very low minimum relative humidity of around 20% were recorded in spring and early summer.

Grain temperature

The average temperatures at different depths in the grain bulk over the whole storage period from all 10 sampling stations are given in Fig. 2. Initially grain temperatures were uniform at ca 30°C. At the surface of the bulk the temperatures were obviously influenced by ambient conditions and a considerable drop was observed from ca 25°C in mid October down to 16°C in January. Deeper in the bulk, from 1 m to the base of the bunker there was a progressive lag in temperature when compared to ambient. Temperatures were also more uniform in the middle of the bulk over the 15 months of storage. During the final 3 months of storage the lowest temperature was recorded at the base of the bunker. The steady fall of temperature at the base even in the second summer reflected the insulating influence of the grain mass as well as the low ground temperature.

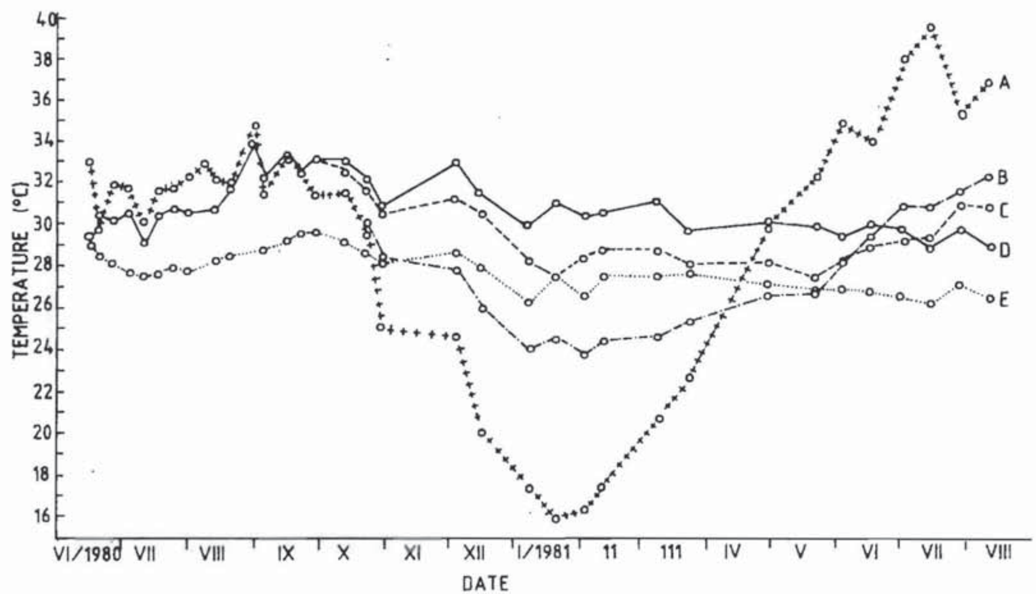

FIGURE 2

TEMPERATURES AT 5 DEPTHS IN THE WHEAT BULK PRESENTED AS THE AVERAGES FOR EACH DEPTH FROM TEN STATIONS ON EACH OCCASION OVER THE WHOLE STORAGE PERIOD. REFER TO FIGURE 1 FOR DEPTHS OF SAMPLES.

Wheat moisture content

The average m.c. of 209 wheat samples taken during inloading of the bunker was 11.4% $\pm$ 1.0% S.D. (range 8.7 to 14.3%). The highest m.c. averaging 12.6 $\pm$ 0.9 S.D. was found during the last 2 days of loading. This wheat was placed in the upper layers of the northern part of the bulk at stations 9 and 10 (Fig 1).

A low m.c. was maintained in the deeper layers of the bulk, but there was significant and progressive increase in parts of the surface, at stations 5, 6, 9 and 10 along the apex ridge of the stored wheat. The average m.c. of samples taken during unloading of the bunker was 11.4 $\pm$ 0.6% S.D.

Changes in atmospheric gas composition

The concentrations of oxygen (O_2) and carbon dioxide (CO_2) in the bunker expressed as averages of the 30 values taken on each occasion are shown in Fig. 3. The changes in gas composition reflect the total of all respiratory process in the grain bulk during storage. The grain was dry and no insecticidal treatment was applied before loading although insects were present. The rapid fall of O_2 concentration to 6% in 3 months of storage can be attributed to the insects, as can the rise of CO_2 concentration to 9%. A minimum O_2 concentration of 5% was reached in December, and this was followed by a gradual increase to 8% by the end of March when the CO_2 concentration had fallen to 8%. During the balance of the storage period the O_2 concentration decreased and the CO_2 concentration increased.

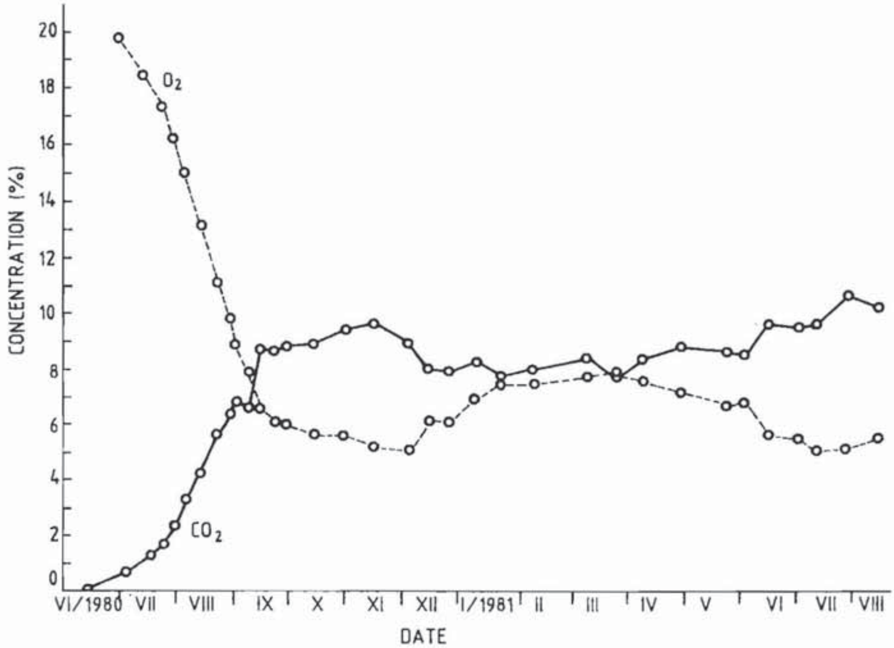

FIGURE 3

OXYGEN AND CARBON DIOXIDE CONCENTRATIONS IN THE WHEAT BULK PRESENTED AS THE AVERAGES OF ALL SAMPLING STATIONS ON EACH OCCASION OVER THE WHOLE STORAGE PERIOD.

Insect presence

Insects were not sieved from any of the 209 wheat samples collected during inloading. However, after incubation for 4 weeks at 26°C, *Oryzaephilus surinamensis* (L.) and *Sitophilus oryzae* (L.) were found in 7 of the 209 wheat samples examined.

Insects were found in the bulk during storage only in samples taken from the upper layers at stations 8, 9 and 10. The most abundant species, were *Tribolium castaneum* (Herbst), *Rhyzopertha dominica* (F.) and *Oryzaephilus surinamensis.*

The infestation which accumulated at the surface layer was controlled with a spot fumigation using 600 tablets of phosphine each containing 1 g PH_3. This fumigation was carried out in April, 1981 and was judged to be efficient since no live insects were found in samples taken at the end of storage.

Germination tests

Analysis of the wheat samples taken during loading indicated an average of 97% germination. The only samples in which a loss of germination was detected during the storage period were those from the upper layers of stations 9 and 10. In tests carried out on 65 composite samples taken during unloading the average germination was 91%.

Loaf volume

Measurements of the loaf volume of bread made from flour prepared from wheat samples taken during the storage period were based on pooled samples which represented groups of stations and different regions of the bulk. The loaves baked from wheat from the upper layers of stations 9 and 10 were adversely affected. This effect on baking quality was found to a depth of 3.2 m at these stations, where as at the other locations in the bulk the baking quality was preserved at an acceptable level for the local Miriam variety of wheat. The average loaf volume from composite samples taken during unloading was 2252 ml $\pm$ 18 SE as compared with 2263 ml $\pm$ 58 SE for the same variety of 1980 harvested wheat stored in conventional silos.

DISCUSSION

Insect presence

The storage method examined in this trial utilised the principle of airtight or hermetic storage (Hyde *et al.*, 1973) which was provided by the P.V.C. and polyethylene liners. Under these conditions the depletion of the O_2 and increase of the CO_2 in the container atmosphere proceeded to a level that controlled insects before they caused economically significant damage to the grain.

Calculations made on the data given in Fig. 3 show that over the period from the start of the observations until mid-September, the daily O_2 reduction rate was 0.185%. From the analysis performed to determine the degree of airtightness (Navarro *et al.*, 1978), it was calculated that the storage structure allowed the entry of O_2 at a rate of 0.494%/day. Taking these together, the estimated average O_2 consumption was 0.679%/day. This is equivalent to a total consumption of 51.6 m^3 O_2/day. Assuming the average daily O_2 consumption by insects to be about 103 μl O_2/ insect (Birch, 1947, Chaudhry and Kapoor, 1967), 51.6 m^3 O_2/day represents the consumption of 500×10^6 insects. The estimated population calculated from samples taken during September 1980 was about 352×10^6 insects. The discrepancy between these two figures is sufficient to require an additional source such as respiration of slightly damp grain for additional O_2 consumption. However, most of the insect infestation was found at the surface of the bulk. The average number of live and dead insects found in the deeper layers of the bulk was 4.6/kg wheat, and the average number of live insects was 1.3/kg wheat. On the basis of the number of insects found in the bulk, the dry matter consumed by insect activity was calculated to be 0.0133%/month. Live insects were found until the O_2 fell to its lowest level, after which more dead insects were found in samples taken below the surface layer. Therefore, for the period ending in late September 1980, or the first 4 months of storage, the estimated dry matter consumed by insects was 0.0532%. Fig. 3 shows that during the remaining storage period, equilbrium was reached between O_2 entry and the O_2 consumed by the insects. Then, for this period, the dry matter consumed by the insects would be ca 0.00967% per month or, for the 11 month period, ca 0.1064%. Dry matter loss that could be attributed to insect activity was estimated to be ca 0.1596% for the entire storage period.

Weight loss caused by insect activity was estimated to be 0.1472% from wheat samples taken during unloading (Table 1). This value may be compared with the calculated figure of 0.1596% based on dry matter loss derived from metabolic activity of the insects in the bulk.

Insect mortality recorded during the observation period was in accordance with the O_2 depletion recorded in Fig. 3. In work with *T. castaneum* and 30°C Calderon and Navarro (1979) found that a combination of 3% O_2 and 10% CO_2 caused high mortality of adult beetles at 57% relative humidity after a 5 day exposure. The lowest O_2 concentration obtained in our tests was 5.1% (Fig. 3), but, the effect of the adverse atmospheric composition obtained is dependent on length of exposure. It was evident from the dead insects found in the samples that the atmospheric composition obtained resulted in adequate control of insects in the deeper layers of the bulk. However, at the surface layer of the bulk where the wheat moisture content was considerably higher some insects survived. The effect of interdependence of atmospheric gas compositions and humidity on insect mortality has been demonstrated by Navarro, (1978). The composition of gas samples taken from the surface layer did not differ from that of samples taken at depth within the bulk. Therefore, insect survival at the surface layer could be attributed to the influence of high humidity in this region.

Wheat moisture content

Wheat at 11.4% m.c. (average of the bulk) is in equilibrium with 60% relative humidity (Pixton and Warburton, 1971). At station No. 10 the wheat m.c. was high from the start of the storage period (12.6%) and by September, 1980 had increased to 14%, which would be in equilibrium with 74% relative humidity. A drop in temperature to 28°C would be sufficient to cause this increase in relative humidity, (Navarro and Calderon, 1982), while a temperature drop to 23°C was necessary to cause water condensation on the surface layer of station No. 10. Temperatures lower than 23°C were recorded in December, and the most marked m.c. increase coincides with these low temperature measurements of this same period. From this discussion and the analysis of the possible contribution of insects to increasing grain moisture, it seems very probable that the major cause of moisture deposit on the surface layer of the bulk was steep temperature gradient in the surface layer. This was responsible for moisture migration to the cooler surface layer of the bulk.

Analysis of the samples taken during the unloading process revealed that the final average m.c. of the grain was 11.4% (Table 1). The fact that the average grain m.c. remained unchanged so well may serve as evidence that all the above mentioned moisture increase at the surface took place endogenously in the airtight structure.

Table 1 - Assessment of damage caused to wheat during the 15-month storage period.

		Initial	Final
Weight of wheat (tonnes)		15,566.450	15,537.155
Average moisture content (%)		11.41	11.41
Measured total loss	tonnes	0	29.295
	%	0	0.1882
Estimate of mould-damaged grain unfit for human consumption*	tonnes	0	9.0
	%	0	0.0578
Calculated average weight loss due to insect activity**	tonnes	0	22.914
	%	0	0.1472
Calculated total damage	tonnes	0	31.914
	%	0	0.205

* Weighing the damaged grain was not possible; 300 bags, each containing about 30 kg mould-damaged grain, were removed.

** Based on count and weigh method.

Preservation of wheat quality

Germination, baking quality as determined by loaf volume, and insect-damaged grains were used as criteria for quality determination. High germination and baking quality were preserved for most of the bulk. The damaged portions of the bulk were found at the surface layer, at stations 9 and 10, and down into the bulk to a depth of 3.2 m at stations 10. The major cause of reduced quality in this portion of the bulk was the high m.c. of the wheat. The estimated amount of wheat with reduced quality was approximately 30 tonnes. However, from tests carried out during unloading the amount of grain unfit for human consumption was determined. The amount of grain discarded was ca 9 t (Table 1). Samples taken from this portion of grain were analyzed for mycotoxin production. Analysis for the presence of aflatoxins and ochratoxin using thin layer chromatography method (AOAC, 1980) gave negative results.

Resistance of the P.V.C. liner

Analysis of the P.V.C. liner taken from the top of the bunker silo after 15 months of exposure to weather conditions showed that its original elasticity and resistance to tear were preserved. Although rodent activity around the bunker was recorded, and some poisoned field rodents were found around the bunker, neither gnawing of the liner nor penetration into the bunker was observed. The inability of rodents to damage the liner during 15 months of storage may be attributed to the smooth texture of the liner surface. In previous experiments, rodent damage was recorded mainly at the folds of the liner (Navarro and Donahaye, 1976). A possible explanation for this phenomenon could be the fact that rodents need to have a projecting end of the plastic material (such as the edge of the fold) to start gnawing However, the absence of rodent damage requires further investigation.

Assessment of total damage

A summary of different measurements and calculations is given (Table 1) to assess the total damage caused to the wheat stored for a period of 15 months. Although all the trucks during the loading and unloading process were weighed on the same scale near the storage site, the accuracy of the scale was not determined.

The average m.c. remained unchanged (Table 1), and therefore the measured total loss was attributed to biological and physical damage. Thus, the measured total loss was 0.1882%. The mould-damaged grain unfit for human consumption was estimated at ca 9 t. This, together with the calculated weight loss due to insect activity, was considered as the calculated total loss, which amounted to 0.205% of the initial weight of the bulk. There was a difference of 0.0168% (ca 2.6 t) between the measured (0.1882%) and the calculated (0.205%) loss. During the unloading process great care was taken to avoid mixing sand with grain at the edges of the uncovered base of the bunker. However, this procedure was not always successful, and some earth or sand was mixed with the grain. The difference between the measured and calculated amount of grain could be attributed in part to grain mixed with sand, which increased the actual weight of the unloaded grain.

CONCLUSIONS

At a degree of airtightness obtained with the above described bunker storage method, insect activity caused a reduction in O_2 to 5.1%, and an increase in CO_2 of 9.8%. The atmospheric composition obtained as a result of the airtightness of the structure provided an adequate control of insects and prevented damage due to insects.

An increase in moisture content, caused mainly by temperature gradients, was observed in the surface layer of the bulk. Wheat in the surface layer that entered storage with an initial moisture content of 11.4% was preserved adequately, while wheat with $\geq$ 13.5% moisture was considerably damaged. Visible mould was noted on high-moisture wheat and damage was accompanied by a reduction in germination power and in baking quality of the wheat.

Loss derived from insect activity was estimated at 0.1472%, where as mould-damaged grain unfit for human consumption was estimated at 0.0578%. Thus, the calculated total damage for the 15 month storage period was 0.205%.

The P.V.C. liner remained well preserved throughout the storage period and rodent damage was not detected.

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