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**Protection of Grain from Insect Damage Through
Storage in Semiarid and Arid Regions**

M. Calderon, S. Navarro, E. Donahaye, R. Davis

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Names of Investigators:

Principal Investigator: Moshe Calderon
Co-Principal Investigator: Shlomo Navarro
Co-Principal Investigator: Ezra Donahaye

Cooperating Investigator: Robert Davis

Name and Address of Affiliated Institutions:

Principal Institution: Agricultural Research Organization, Bet Dagan,
Israel.

Cooperating Institution: USDA-SEA-ARS, Stored-Product Insects Research and
Development Laboratory, Savannah, Georgia.

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Principal Investigator

Institution's Authorizing Official

M. Calderon

Yehud Eilat

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C. Abstract

From the laboratory studies data were obtained on the following subjects:

1) The relative susceptibility of four stored product insect species to a temperature of 40°C at two low relative humidities (RH) - 25% and 35%. Sitophilus oryzae was the most susceptible to this temperature - complete mortality was recorded after 24 h, while in the case of Rhyzopertha dominica this effect was obtained within 11 days. In view of the above results the feasibility of aeration with hot ambient air was discussed.

2) An acclimation effect to high (37°C) and low (22°C) temperatures was investigated using susceptible and resistant strains of Tribolium castaneum and T. confusum to malathion. The two strains of the latter species and the malathion resistant strain of T. castaneum were more tolerant to the high temperature if their parents had been reared at the low temperature. The malathion susceptible strain of T. castaneum on the other hand was significantly tolerant to low temperature when the parents had been reared at high temperature.

3) The thermal acclimation and the effect of alternating temperatures on the grain mite Acarus siro were also investigated. Mites reared at 21±1°C and 85% RH were acclimated as adults at 0°, 14°, 28°, and 33°C for one or four days. A treatment of one day was enough to acclimate A. siro and change the studied development parameters.

When subjected to alternating temperatures, both fecundity and longevity of this mite were affected. Higher fecundity and longer life spans were recorded at constant temperatures of 14°C and 21°C than at 28°C or at alternating temperature regimes. The lowest number of adults surviving was recorded when temperatures were changed every 12 h and the highest - at a constant temperature of 14°C.

Field studies provided results on the feasibility of safe storage of wheat in the arid region of Israel. A PVC silo containing 548 tonnes of wheat was equipped with an aeration system. The storage period lasted 30 months. The low ambient humidity and low night and winter temperatures were used for improving the grain storability. The grain bulk was cooled by aeration during winters and the storage structure was hermetically sealed

during summers. These environmental treatments suppressed insect infestations and prevented loss. The only chemical treatment (spot fumigation) was carried out for control of a localized infestation of Rhyzopertha dominica, which was the predominant insect species in the grain bulk. The overall loss of stored grain calculated from samples taken during inloading and outloading the grain was 0.60% or 0.24% on an annual basis.

It was concluded that safe storage of grain was feasible in arid regions using the PVC storage structure and the described storage regime.

D. Objectives of the Original Research Project

The main objective is to provide the necessary data in order to achieve a practical control program, which could be applied in grain storage sites located in desert climate regions.

Laboratory studies were carried out in order to investigate the effect of supraoptimal & threshold temperatures on the major stored product insects, encountered in both countries, namely: Rhyzopertha dominica, Sitophilus oryzae, Sitophilus granarius, Tribolium castaneum and Oryzaephilus surinamensis. The influence of air movement on the interrelated factors of temperature and humidity on insect survival was also studied. The data obtained could be useful in assessing the effects of the arid ambient conditions on the control of insect infestation, and on the monitoring the preservation of the stored grain.

To the list of the insect pests tested, a mite species - Acarus siro, a serious pest in grain imported from temperate climate countries, was added.

Field studies were carried out in order to evaluate the suitability of the storage structure - a mobile plastic (PVC) silo for the preservation of grain in desert climate conditions. The effect of the intensive solar radiation in this area on the PVC surface of the storage structure was also observed and evaluated. The mobile plastic silo was equipped with aeration system, which made possible the utilization of the desert ambient conditions (mainly low temperatures and low relative humidity) for controlling or preventing the development of stored product insects in the grain bulk ecosystem. The plastic grain container was also designed with the facility of airtight sealing which created an atmosphere of lower oxygen and higher carbon dioxide contents in the grain. These effects were also evaluated in terms of the level of insect infestations detected in the grain bulk.

Field studies made possible the follow up after the occurrence of the insect populations which were building up in the freshly harvested local wheat, the possible appearance of insect species, typical to storage sites in warm dry regions.

The original objectives included the erecting of permanent storage structure beside the temporary one. However, budget restrictions didn't

permit this expenditure. The aeration with hot ambient air for controlling the insects in the grain bulk was also noted in the original objectives, but this treatment didn't take place. The main reason was based on the results of the laboratory studies which showed that the lethal (for the insects occurring in the grain) temperatures were considerably higher than the ambient summer temperatures prevailing in the storage site. The use of solar heating of air system, with which probably higher air temperature could be introduced into the grain bulk, was considered. However, budget constraints again didn't allow us to investigate this possibility. On the other hand, aeration was used for introducing low temperature ambient air in the grain bulk, when available. This treatment was carried out in order to suppress insect activity in the grain mass.

Grain Quality Tests were conducted by examining grain samples taken before, during and after the storage period, according to the accepted parameters.

E. Body of the Report

1. Laboratory studies

1.1. Effect of supraoptimal temperature at low relative humidities on the survival of four stored product insects

Abstract

Adults, aged 7-14 days of Tribolium castaneum, Oryzaephilus surinamensis, Sitophilus oryzae and Rhyzopertha dominica in 1250 gr wheat samples were exposed to temperatures of 26°C and 40°C at RH of 25% and 35% for 4 days. The survival of the insects in the higher temperature was tested also in static and moving air of 15 l/h/kg wheat. The results show that the less resistant species to 40°C was Sitophilus oryzae on which 100% mortality was recorded after 24 hrs, and the most tolerant - Rhyzopertha dominica on which complete mortality was achieved only within 11 days. The effect of the two humidities, neither the air movement versus the static air, produced a statistically significant differences of this effect. The feasibility of aeration with hot ambient air for insect control was discussed.

1.1.1. Introduction

There is a considerable amount of data on the effect of temperature on stored product insects survival in the recent literature. Studies of this effect on Sitophilus oryzae and Rhyzopertha dominica were reported by Kirkpatrick and Tilton (1973). They found that at $39^{\circ}\pm 1^{\circ}\text{C}$ for 4 days very few insects survived while for Rhyzopertha dominica this effect was obtained at $43.3\pm 1^{\circ}\text{C}$. It should be noted that these experiments took place at 60% and 50% RH, respectively. Kirkpatrick (1978) investigated the high temperature effect on the immature stages of the two above mentioned species. He found that at $41\pm 1^{\circ}\text{C}$ the immature stage of R. dominica were completely controlled, while some immature S. oryzae were killed at $35\pm 1^{\circ}\text{C}$. Here again the RH's were $70\pm 3\%$ and $60\pm 3\%$ respectively. The sensitivity of R. dominica to higher temperature was experimented by Vardell and Tilton

(1980) also who found that in the first week of development the insect was most sensitive to high temperature (no emergence was observed at 40°C for 1-6 weeks) and the most tolerant stage was the fifth week of development. The same results were obtained at 44°C. The RH of the environment during these experiments were 40, 50 and 60%.

More studies on the effect of high temperatures on Ephestia cautella and Plodia interpunctella were reported by Arbogast (1981). He found that the median lethal time for exposure to 45°C was 7-8 fold longer for E. cautella (162-171 min) than for P. interpunctella (22 min).

The susceptibility of other stored product insects to high temperatures produced by infra red and microwave radiation (Tilton and Vardell, 1982; Tilton et al., 1983) was also investigated and reported by many authors, while the development of the technique of fluidized bed heating for insect control is reaching its practical application (Evans et al., 1983).

In the following study the effect of supraoptimal temperature, which may prevail in the ambient desert conditions, at low relative humidities (25%, 35% RH) were investigated. The survival of insects in small bulks of grain subjected to high temperature produced in static as well as in moving air conditions, (simulating the movement of air by forced aeration) was experimented in this study.

1.1.2. Experimental procedure

The test insects were adults of Tribolium castaneum, Oryzaephilus surinamensis, Rhyzopertha dominica and Sitophilus oryzae. These species were reared in controlled temperature (CT) and relative humidity (RH) room of 26°C and 70% RH, except for R. dominica which was reared at 30°C.

Adults of the above species aged from 7-14 days were exposed to 26°C and 40°C, at relative humidities of 25% and 35%.

The insects were exposed to the above treatments in wheat columns (composed by PVC sections) of 10 cm of diameter and 35 cm of height. Each column contained 1250 gr local wheat which filled the column up to height of 25 cm. The grain moisture content was equilibrated with the given air humidity in each treatment.

The test insects in the grain were put in a section of the column, from which they could be removed after the exposure period. To the aerated

columns, air with adjusted temperature and humidity levels was delivered through the base of the column at a flow rate of 15 l/h/kg wheat. For the above purpose an apparatus was devised as shown in Fig. 1. The air temperature were preadjusted by circulating air through spiral coils in the CT chamber, and monitored before entry and upon leaving the aerated columns. Similarly, air humidity was controlled by bubbling air through a glycerine solution, and monitored after the desired air temperature has been reached in the CT chamber (see Fig. 1).

A factorial analysis of variance was performed for mortality at each humidity level with aerated and unaerated wheat columns at two different temperatures and exposure times. Two replicates were performed for each test.

1.1.3. Results and Discussion

Data obtained from this study can be summarized in Tables 1,2,3,4 and on Fig. 2.

Effect of humidity. No significant difference was found as a result of exposure to the 2 RH levels although there seems to be a trend of higher mortality at 35% RH, than in 25% except for Sitophilus oryzae. This tendency is pronounced mainly at 40°C exposures and is expressed in higher mortality in shorter time on most of the insects tested. However, since no statistical significance could confirm these differences, these results cannot lead to conclusions. But, this aspect of higher resistance to high temperature at low humidity levels, deserves further investigation.

Effect of air movement. The movement of air through the grain samples which contained the test insect at the two temperatures tested did not result in a significant difference on the mortality of the exposed insects. The data obtained from the aerated grain samples were not significantly different from the unaerated ones. Exceptions are found only in the case of Oryzaephilus surinamensis, in which at 40°C higher mortality was obtained in the aerated samples. The study of this effect also needs more detailed investigation.

Effect of temperature. The effect of temperature was markedly significant for all tested insect species. The less resistant species to high temperature was found to be Sitophilus oryzae on which 40°C caused 100% mortality at 25%RH, after 24 hours. However, this temperature at 35% RH produced 100% mortality after 48 hrs exposure in all insect species except in Rhyzopertha dominica. The latter species was much more resistant to the higher temperature, and complete mortality was obtained only within 11 days. The relative susceptibility of the test insects to 40°C at 25% RH is summarized in Fig. 2.

This finding is of major practical importance since R. dominica is a serious stored grain pest in warm and dry climates. As mentioned above Kirkpatrick and Tilton (1973) also found that continuous exposures of $43.3 \pm 1^\circ\text{C}$ were required in order to obtain 99% control of Rhyzopertha dominica. The tolerance of this species to high temperatures was reported by others also. In an unpublished experiment we found that exposure to 45°C at 50% RH gave complete control of this species.

The marked tolerance of R. dominica to the higher temperature tested indicated to us that heating with hot ambient air during the hot summer days in the desert alone may not be sufficient to obtain grain temperature of more than 40°C. For the control of Rhyzopertha dominica by the above method an additional source of heating may be needed.

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Table 1 Mortality (%) of Tribolium castaneum adults exposed to 26° and to 40°C at two relative humidities in unaerated (U) and aerated (A) wheat bulks.

Air relative humidity (%)	Temperature (°C)		Exposure time (days)						
			1	2	3	4	5	6	*
25	26	U**	1.5	3.5	4.0	2.0	2.0	2.0	a
		A**	2.5	3.0	3.0	3.0	3.0	20.0	a
	40	U	1.5	74.5	84.5	100	100	100	a
		A	4.5	65.0	83.0	100	100	100	a
35	26	U	0.0	0.0	1.0	2.0			a
		A	0.0	2.0	1.0	2.0			a
	40	U	100	100	100	100			a
		A	100	100	100	100			a

Table 2 Mortality (%) of Oryzaephilus surinamensis adults exposed to 26° and to 40°C at two relative humidities in unaerated (U) and aerated (A) wheat bulks.

Air relative humidity (%)	Temperature (°C)		Exposure time (days)				
			1	2	3	4	*
25	26	U**	0.0	14.0	2.0	7.0	a
		A**	0.0	4.0	1.0	25.0	a
	40	U	7.0	97.0	100	100	a
		A	14.0	100	100	100	a
35	26	U	5.0	9.5	2.5	0.0	b
		A	6.5	14.0	7.0	15.5	a
	40	U	79.0	100	100	100	b
		A	92.5	100	100	100	a

*Analysis of variance was performed for each relative humidity separately. Duncan's multiple range test for mortality is summarized for the means of unaerated and aerated groups. Means with the same letter are not significantly different at p=0.05.

** U = unaerated; A = aerated.

Table 3 Mortality (%) of Rhyzopertha dominica adults exposed to 26° and to 40°C at two relative humidities in unaerated (U) and aerated (A) wheat bulks.

Air relative humidity (%)	Temperature (°C)		Exposure time (days)						
			1	2	3	4	10	11	*
25	26	U**	0.0	7.0	3.0	3.0	3.0		a
		A**	0.0	5.0	5.0	5.0	7.0		a
	40	U	3.0	22.0	28.0	54.0	80.0		a
		A	3.0	18.0	27.0	40.0	93.0		a
35	26	U	10.0	14.0	24.5	34.5		20.0	a
		A	2.0	11.5	21.5	40.0		17.0	a
	40	U	3.0	31.0	21.0	67.5		100	a
		A	11.5	19.0	11.0	69.0		100	a

Table 4 Mortality (%) of Sitophilus oryzae adults exposed to 26° and to 40°C at two relative humidities in unaerated (U) and aerated (A) wheat bulks.

Air relative humidity (%)	Temperature (°C)		Exposure time (days)				
			1	2	3	4	*
25	26	U**	6.0	32.0	12.0	15.0	b
		A**	5.0	31.5	11.0	27.0	a
	40	U	100	100	100	100	b
		A	100	100	100	100	a
35	26	U	1.0	4.0	18.5	17.5	a
		A	10.0	3.0	23.0	15.0	a
	40	U	100	100	100	100	a
		A	100	100	100	100	a

*Analysis of variance was performed for each relative humidity separately. Duncan's multiple range test for mortality is summarized for the means of unaerated and aerated groups. Means with the same letter are not significantly different at p=0.05.

** U = unaerated; A = aerated.

Fig. 1: Laboratory apparatus for exposure of S.P. insects to high temperatures.

Fig. 2: The effect of 40°C and 25% RH on the mortality of 4 stored product insects in wheat columns.

1.2. Effects of suboptimal temperature in Tribolium confusum Jacquelin du Val and T. castaneum (Herbst)

Abstract

An "acclimation effect" to high (37°C) and low (22°C) temperatures was investigated using a malathion susceptible strain of Tribolium confusum and a malathion susceptible and a malathion resistant strain of T. castaneum. Populations of these strains had been reared for many generations at 27°C and then treated by rearing for 1 generation at 37°C or 22°C. Following temperature treatment they were reared for the next generation at the same temperature and the other suboptimal temperature. Factors recorded to assess effects were number of progeny, length of developmental time and oven dry weight. T. confusum was found to be more tolerant of the high temperature if its parents had been reared at the low temperature. The same general pattern was observed for the malathion resistant strain of T. castaneum. The pattern changed with the malathion susceptible strain of T. castaneum where a significant tolerance to the low temperature was observed in the length of development time when the parents had been reared at the high temperature.

1.2.1. Introduction

In January 1983, a United States-Israel Binational Agricultural Research and Development (BARD) project was funded jointly to the Stored-Products Department, Agricultural Research Organization, Israel, and the Stored-Product Insects Research and Development Laboratory, Agricultural Research Service, United States Department of Agriculture for a study entitled "Protection of Grain from Insect Damage through Storage in Semiarid and Arid Regions." The Israeli investigators were Moshe Calderon, Principal; and Ezra Donahaye and Shlomo Navarro, Co-principals. In the United States, Robert Davis was the Cooperating Investigator. The project was divided into two parts with both a field (Figure 1) and a laboratory phase conducted in Israel and only a laboratory phase conducted in the United States. This paper will report on a portion of the research conducted in the United States.

The literature provides us with an abundance of information on the adverse effects of adding and removing thermal energy to grain as a potential insect control procedure. The use of low temperatures has been reviewed by Mullen and Arbogast (1984) and the use of high temperatures in food plants by Sheppard (1984) and in stored grain by Kirkpatrick and Tilton (1973). Howe (1965) provides us with information on the minimal and optimal temperature conditions for population increase and the fact that the maximum temperature for most stored-product insects is usually less than 5°C above the optimum. Therefore it was believed by the investigators that semiarid and arid regions of the temperate and tropical areas of the world might provide low enough temperatures during the winter nights and high enough temperatures during the summer days to suspend insect activity or to create a lethal habitat. Any acclimation effect in the pest species to high and/or low temperatures could affect such an attempt to control insects in stored grain.

The phenomenon of acclimation to temperature has been reviewed by Prosser (1973) for animals generally and by Mutchmor (1967) for insects. Baldwin (1954) and others have distinguished between two types of

acclimation, one of a physiological nature in which an increase in tolerance occurs in adults that have been exposed to a sublethal temperature for a relatively short time and another of a developmental nature in which a tolerance to sublethal temperatures occurs during the organism's development. Neither of the above definitions precisely fit the study undertaken, however we use the term "acclimation" as we feel it fits better than other available alternatives.

In this study we attempt to elucidate whether or not acclimation could be expected to play a role in long-term storage where high and low ambient temperatures were used as control interventions. The insect populations investigated were a malathion susceptible population of the confused flour beetle, Tribolium confusum Jacquelin du Val, and a resistant and a susceptible population of the red flour beetle, T. castaneum (Herbst).

Materials and Methods

The insects used in this study were from stock colonies maintained at $27 \pm 1^\circ\text{C}$, $60 \pm 5\%$ RH and 12-12 h light-dark cycle in the insectory at the Stored-Product Insects Research and Development Laboratory, Savannah, GA, USA. All colonies had been maintained at these conditions for several years. Temperatures selected for testing were $22 \pm 1^\circ\text{C}$ and $37 \pm 1^\circ\text{C}$. The light regime during the study was variable but the relative humidity level was maintained unchanged. The medium used throughout was the standard medium used in the Savannah Laboratory's insectory for Tribolium and was composed of a mixture of white wheat flour, white cornmeal and yeast in a ratio of 10:10:1.5 parts by volume (Bry and Davis, 1985).

In establishing the experimental conditions the P_1 adult population acquired from the insectory was divided into 3 groups. One group continued to be maintained at the "optimal temperature" of 27°C . Of the remaining two groups one each was placed into one of the two treatment temperatures (22 or 37°C). The F_1 progeny from each of the temperature treatment tests were divided into two groups. One group was returned to the same temperature and the other group transferred to the other treatment temperature. Each condition was replicated five times. Each replicate consisted of 200 unsexed 2-3 week old adults in a 0.95 liter glass jar filled one-third with the standard Tribolium rearing medium. The adults were allowed 3 days on the medium for egg laying and then were removed and dried in a vacuum oven at 15 psi for 24 hr at 90°C .

Data recorded were the number of adult progeny, time of development to the first adult and dry weight of the adults. Replicates were dismantled 14 days after the appearance of the first adult. All data was treated by ANOVA and Duncan's New Multiple Range test ($P = 0.01$).

Results and Discussion

Results of the attempts to acclimate T. confusum are presented in Table I. Each temperature regime produced significant differences in the factors recorded in the F₁ generation except in the dry weight comparison between 37°C and the control. Development of the parents (F₁) at the lower temperature resulted in a significant increase in the number of progeny. This increase was significantly higher than for those reared continuously at 37°C. However, the progeny of the insects moved to 37°C from 22°C were significantly smaller than their parents, but larger than those reared continuously at 37°C. There appears to be an acclimation in this strain when reared at the cooler temperature before exposure to the higher temperature. There is very little acclimation to the low temperature resulting from the rearing of the prior generation at the higher temperature.

Results of the attempts to effect an acclimation of the malathion resistant strain of T. castaneum are presented in Table II. Again we note that there are significant differences in the F₁ between the control and test temperatures except for the dry weight comparison between the control and 22°C. In these data we find an acclimation to 37°C in the progeny of the F₁ reared at 22°C. The data on length of development showed a significant shortening of the developmental time at 37°C when the adults were reared at the lower temperature. No significant difference was noted for weight.

Results of the attempts to effect an acclimation of the malathion susceptible strain of T. castaneum show that rearing of the previous generation at the low temperature did not provide any acclimation to the high temperature in the F₂ (Table III). The data showed the reverse to be true and that a significant reduction in the number of progeny occurred compared to that observed for those reared continuously at the higher temperature. Examining the data on the length of development, it is seen that there is quite a different situation. Here we find that rearing of the F₁ generation at the higher temperature gave an acclimation to the F₂ reared at the low temperature. This effect, a reduction in developmental time, was significant and reduced the time by one-half. Slight but significant differences in weight are seen for temperature changes in both directions.

When these data are viewed in the context of the storage plan of the BARD on arid and semiarid sites they take on added meaning. The BARD program called for rather rapid changes of the grain mass twice each year using forced ventilation to cool the grain during the winter nights and to heat it during the summer days. The data presented here suggest that if sublethal high temperatures or low temperatures which do not result in complete inactivity are achieved instead of lethal or inactivating temperatures, this could result in increased population numbers of these pest species and/or strains in the storage.

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Table I. Results of suboptimal temperature effects (acclimation attempt) on a malathion susceptible strain of Tribolium confusum to 37°C and 22°C. (Average of 5 replications, each initiated with 200 unsexed adults)

		TEMPERATURE		
		37°C	27°C	22°C
NUMBER OF ADULT PROGENY	P ₁		600	
	F ₁	1698 d	2572 f	1013 c
	F ₂	275 a		563 b
	F ₂	1991 e		59 a
LENGTH OF DEVELOPMENT (DAYS)	F ₁	38.2 c	36.6 b	74.2 f
	F ₂	26.2 a		58.6 d
	F ₂	38.0 c		63.4 e
DRY WEIGHT OF 200 ADULTS (g)	F ₁	0.23 c	0.23 c	0.24 d
	F ₂	0.21 a		0.22 b
	F ₂	0.22 b		0.22 b

Means in factor rows followed by the same letter are not significantly different (Duncan's MRT P = 0.01%)

Table II. Results of suboptimal temperature effects (acclimation attempt) on a malathion resistant strain of Tribolium castaneum to 37°C and 22°C. (Average of 5 replications, each initiated with 200 unsexed adults)

GENERATION		TEMPERATURE		
		37°C	27°C	22°C
NUMBER OF ADULT PROGENY	P ₁		600	
	F ₁	4180 f	2399 d	1034 b
	F ₂	1997 c		1305 b
	F ₂	3222 e		493 a
LENGTH OF DEVELOPMENT (DAYS)	F ₁	22.0 b	30.4 d	77.2 g
	F ₂	24.4 c		60.8 e
	F ₂	20.0 a		73.6 f
DRY WEIGHT OF 200 ADULTS (g)	F ₁	0.176 ab	0.167 a	0.183 b
	F ₂	0.174 ab		0.168 a
	F ₂	0.167 a		0.180 b

Means in factor rows followed by the same letter are not significantly different (Duncan's MRT $P = 0.01\%$)

Table III. Results of suboptimal temperature effects (acclimation attempt) on a malathion susceptible strain of Tribolium castaneum to 37°C and 22°C. (Average of 5 replications, each initiated with 200 unsexed adults)

GENERATION		TEMPERATURE		
		37°C	27°C	22°C
NUMBER OF ADULT PROGENY	P ₁		600	
	F ₁	4951 d	4134 c	398 a
	F ₂	3384 c		504 a
	F ₂	2060 b		594 a
LENGTH OF DEVELOPMENT (DAYS)	F ₁	31.6 d	26.8 b	78.4 f
	F ₂	20.6 a		57.6 e
	F ₂	20.0 a		28.8 c
DRY WEIGHT OF 200 ADULTS (g)	F ₁	0.244 b	0.243 b	0.247 b
	F ₂	0.225 a		0.244 b
	F ₂	0.245 b		0.221 a

Means in factor rows followed by the same letter are not significantly different (Duncan's MRT P = 0.01%)

Figure 1. 500 ton plastic mobile silo in Israeli desert at Ashalim.

2. Field Studies

2.1. Prolonged storage of wheat in the arid region of Israel

Abstract

A PVC silo equipped with an aeration system was erected in the arid region of southern Israel, near the moshav Ashalim. This was used to store 548 tonnes of locally grown wheat over a 30 month period. The grain was inspected periodically and temperatures, moisture content, atmospheric gases, and insect infestations were recorded, as well as temperature and the relative humidity of the ambient.

The grain was aerated for cooling during winters, taking advantage of the arid environment, and the silo was sealed hermetically during summers. The aeration regime cooled the grain to temperatures below 17°C while the highest CO₂ and the lowest O₂ concentrations during hermetic storage were 10.6% and 5.8%, respectively.

During the course of storage the relatively high initial infestation was suppressed, and the only outbreak after this, was caused by a localized infestation by Rhyzopertha dominica which was the predominant insect species in the storage site. The above infestation was the only one dealt with by chemical control means (spot fumigation).

The overall loss of stored grain calculated from samples taken during inloading and outloading the grain was 0.60%, or 0.24% on an annual basis. Observations regarding the role of water condensation, microflora, and rodents were also recorded. It was concluded that safe storage in the arid region using this type of storage structure was feasible.

2.1.1. Introduction

The dependence of long and safe storage of grain on the climate at the storage site is well known (Sinha, 1974; Sinha and Utida, 1967; Calderon, 1974). Accordingly, the arid, quasi desert areas seem to be very attractive for a safe storage of grain. The almost complete lack of rainfall together with the very low ambient humidity reflected in low moisture content of the stored grain, practically eliminates the hazards of microfloral damage.

Also, this low humidity restricts the presence of certain major insect pests in the stored grain.

The high daily temperatures prevailing in these regions accelerate the development of some insect species which may cause significant damage. On the other hand, due to the extreme diurnal and seasonal changes in temperature occurring in this climate, fairly low temperatures may frequently occur. The proper use of these low temperatures could suppress insect development and reduce storage losses.

It is also relevant to note the well known occurrence of grain storage in underground pits in the arid areas of the Middle East (Attia, 1948; Hyde and Daubney, 1960). This is an ancient method practiced for many centuries by the inhabitants of these regions. Using this storage method, our ancestors apparently succeeded in changing the atmospheric gas concentrations in these hermetic underground pits, resulting in higher carbon dioxide and low oxygen concentrations in the intergranular air. This method, again, was aimed to suppress insect development and to reduce stored grain losses.

In the following study, the authors aim was to take advantage of the 3 elements mentioned above in existing arid region storage sites:

1. To store dry grain, which will remain dry in the given ambient low relative humidity.
2. To use the low night (or winter) temperatures for introducing cold air into the grain bulk, by forced aeration.
3. To create low oxygen and high carbon dioxide concentration in the intergranular air by proper sealing of the storage structure.

To the best of the authors knowledge, studies of this nature have not been conducted yet, and the results obtained may serve as a basis for World Food Reserve Projects in order to combat famine and food shortage in developing countries.

2.1.2. Experimental

2.1.2.1. The storage site

A P.V.C. mobile silo was erected at the Agricultural Experimental Station in the southern Negev, about 40 km south of the town of Beer Sheva, near moshav Ashalim. This site, situated in the arid zone of the Negev

(mean annual rainfall of 100 mm, or about 4 inches), offered the following advantages:

- a) Proximity to the main road, permitting the traffic of lorries carrying the grain.
- b) Provision of basic services - such as telephone, mail, secretarial work, agricultural machinery etc. (Electricity was not available except for a 5 amp petrol generator).
- c) Local meteorological station recording the necessary climatic data.
- d) Qualified competent staff, university graduates, to assist the recording and transfer of data.

2.1.2.2. The storage structure

The P.V.C. mobile silo was obtained on loan from "Haogenplast Ltd. Plastic Industries". It was developed jointly by the Stored Products Department and "Haogenplast" as an improvement of the concept of the "Butyl Rubber" silos, imported for emergency storage in Israel in the early 70s (Navarro and Donahaye, 1976).

The prefabricated "Haogenplast" silo consists of a circular floor-wall unit of flexible PVC, 0.83 mm, UV protected, sheeting (Fig. 1). The floor is 16 m. in diameter, surrounded by a peripheral weld mesh fence, 2.2 m. high to which the wall is attached (Fig. 2).

2.1.2.3. Construction of the silo

The site was cleared of stones, lined with a 5 mm sand layer, forming circle on which the container was erected. After anchoring and assembling the fence units forming the wall, the PVC floor-wall unit was placed opposite the first fence unit, then unrolled and unfolded to the sides. The floor was secured to the base and the walls were lifted over the fence and attached to the fence, after inserting split plastic tubing around the top rim of the fence (Fig. 3,4). The installation of the aeration system took place next and afterwards the container was ready for loading. The construction was carried out by the staff of the Department of Stored Products.

2.1.2.4. Loading and sealing

The silo was inloaded with 548 tons of locally-grown wheat (varieties, 'Lachish' and 'Miriam'), harvested in the same year. The grain was loaded from trucks after an interim storage in the open for 1 month on asphalt aprons near kibbutz Maon in the western Negev.

The silo was filled by means of a "sucker-blower", the grain stream being directed to the center of the silo, thereby forming a cone, 5 m. high at the peak (Fig. 6).

After the filling was completed and the initial grain sampling undertaken, (see on) 33 thermocouple cables and 7 gas sampling points were installed in the grain bulk (Fig. 5). The capping and sealing of the silo was done by raising the roof cone unit over the edge of the wall, pulling it over the top and then unfolding it to the sides (Fig. 7). The sealing was carried out using a special zip attached to the rims of the wall and the roof cone unit (Fig. 8). The silo was filled in late July 1983.

2.1.2.5. Storage regime design

On the basis of past experience it was assumed that the wheat had been inloaded with an undetected initial infestation. It was therefore, decided to keep the silo hermetically sealed until autumn in order to create an unfavorable atmosphere for insect development. This was followed by aeration to maintain as low a grain temperature as permitted by the environmental climatic conditions.

A subsequent period of hermetic storage ensued until grain temperatures rose to within the range favorable for insect development. The hermetic storage was followed by autumn and winter cooling. This same storage procedure was repeated the following years.

The aeration system consisted of a centrifugal fan designed to supply an airflow rate of $8250 \text{ m}^3/\text{h}$ at an axle rotation speed of 1240 rpm. The fan axle was propelled from a belt run off a 5 hp petrol engine. Air was blown into the storage structure through a system of ducts as shown in Fig. 5. The aeration ducts made from weld mesh and covered by jute cloth sheeting were placed on the PVC floor, before loading (Fig. 9).

2.1.2.6. Initial and final grain sampling

Sampling

Upon completion of inloading, 330 g grain samples were removed from points 9, 13, and 20 -33 respectively, (see Fig. 5). These were used for initial examination of grain quality.

During break-down of the bin, 29 samples were taken at intervals from the entry point of grain into the sucker-blower. Each sample represented a truck load of grain.

Moisture Content

Initial and final moisture contents of all the wheat samples were recorded by the standard oven method of the AACC (135°C for 2h).

Germination

Initial germination was recorded by pooling 5g from each of the 16 samples. This was followed by thorough mixing and then random removal of 4 groups of 100 grains from the pooled sample (4 repetitions). Germination at the end of storage was recorded by random removal of 100 grains from each of the 29 samples taken during unloading. Germination was measured according to the ISTA method.

Thousand grain mass (TGM) recordings

To enable estimation of changes in grain quality during storage the following procedure was adopted:

For the initial 16 samples and the final 29 samples, each sample was reduced by Boerner divider to app. 100 g sub-samples and weighed. Then for each sub-sample the dockage and broken grains were separated out by hand.

- Entire grains were counted and weighed.
- Broken grains were weighed and percentages of brokens by weight were calculated.
- Dockage was weighed and percentage by weight was calculated.

The TGM was calculated using the following equation (Proctor & Rowley, 1983):

$$\text{TGM} = \frac{10m(100-H)}{N}$$

where: m = net wt of sample
 H = % moisture content (wet weight)
 N = number of grains

Insect infestation

Free living insects were recorded on the entire samples by sieving through a 18 mesh sieve.

Baking quality

Baking quality tests were carried out on the out-loaded grain by dividing the 29 samples with a Boerner divider to form 400g subsamples. Every 6 sets of subsamples were pooled to form 6 composite samples of app. 2.4 kg. These composite samples represented consecutive stages in the out-loading process. Baking quality of the outgoing grain was compared with that of Miriam and Lachish wheat of the 1980 harvest.

2.1.2.7. Periodic Monitoring Procedures

Fifteen grain samples were withdrawn at approximately monthly intervals from the silo via 5 sampling points (Fig. 5) at depths of 0.0, 0.5 and 1.0m and analyzed for insect infestation, moisture content and microflora. Temperature at the 33 sampling points were recorded at weekly or fortnightly intervals.

Ambient temperatures and humidities were recorded on the thermohygrograph of the meteorological station, adjacent to the storage site. The degree of hermetic seal was measured during the initial hermetic storage phase by the pressure decay method.

2.1.3. Results and Discussion

2.1.3.1. Ambient conditions during storage

Weekly average, maximum and minimum temperatures at the Ashalim experimental station are given in figure 10. From the figure it can be seen that maximum average winter temperatures for 3 months of each year were below 20°C indicating that there were many hours suitable for aeration to cool the grain. Table 5 gives the number of hours of ambient temperature below 15°C and below 10°C for the 1983/84 season. In contrast the average maximum summer temperatures did not rise above 34.5°C thus indicating that summer aeration to heat the grain to above 40°C for insect control would require a solar heating device to pre-heat the air entering the aeration system.

2.1.3.2. Temperature of the grain during storage

The grain temperature at point 22 (5 cm below the surface layer at the peak of the silo), at point 22 (at the center of the grain bulk, and average temperature of 33 sampling points (with a preponderance of sampling points in peripheral areas of the bulk), are given in figure 11. From the figure it can be seen that initial temperatures of the grain were extremely high (around 36°C) and typical of newly harvested grain entering storage in Israel. This grain remained above 37°C at the centre of the bulk and above 30°C for the average of the temperature recordings until November of 1983 when the first aeration procedure was initiated. Aeration reduced grain temperatures to below 17°C which is sufficient to arrest most insect development, and temperatures below 20°C were maintained within the bulk until the end of March when ambient temperatures started to raise the grain temperature. During the summer of 1984 grain temperatures of the major part of the bulk ranged in the upper 20s until the second aeration procedure was carried out in November. However grain at the center of the bulk again reached 36°C, reflecting the metabolic activity of the insects that developed over this period. The second aeration process brought grain temperatures down to as low as 10°C. This was sufficient to maintain

temperatures within the grain bulk at below 20°C until early June and at the center of the bulk for the whole of the summer season. The figure clearly shows how the aeration phases succeeded in cooling the grain in autumn, and how the concerted influence of summer ambient temperatures and metabolic activity within the bulk had only a limited and retarded effect in raising temperatures of the bulk over the summer seasons.

2.1.3.3. Atmospheric gas composition in the container during storage

The average oxygen and carbon dioxide concentrations recorded from 7 points within the storage liner during the periods of hermetic seal are given in Fig. 12.

Tests for gas-tightness (see section 2.1.3.7) indicated that although the liner was not completely gas-tight it was sufficient to enable the principle of insect control by hermetic storage to be effective.

From Fig. 12 it can be seen that the rapid increase in initial infestation (see infestation counts in Figs. 14 and 15) resulted in a rapid decrease in O_2 to a minimum of 5.8% and an increase in CO_2 to a maximum of 10.6% during the first period of hermetic storage until aeration in mid November 1983. The hermetic storage periods of the summers of 1984 and 1985 showed progressively slower and less pronounced changes in intergranular atmosphere, indicating that the biotic activity within the liner was less in 1984, and was even smaller in 1985 being insufficient to produce conditions lethal to insects. It is possible that hermetic conditions of the liner in 1985 were less complete than in 1983/4 due to rodent penetration of the floor around the aeration ducts (see section 2.1.3.7) and this may have contributed to the slow consumption of O_2 and build-up of CO_2 in that season. Particularly interesting is the period between July and November of 1984 where it would appear that the hermetic conditions resulted in an insect kill followed by subsequent increase of O_2 and decrease of CO_2 concentration as a result of gas diffusion across the liner.

2.1.3.4 Moisture content of the grain during storage

Average monthly moisture contents of the grain at 15 sampling points taken from three depths within the grain bulk are given in figure 13. From the figure it can be seen that there were extreme fluctuations in moisture content at the surface layer in accordance with seasonal temperature fluctuations. These moisture contents ranged from below 9% m.c. immediately after the overliner was placed in position in August 1983, to above 14% m.c. in November of that year. They typify the establishment of a steep temperature gradient just below the surface layer with accompanying migration of moisture to the surface layer. The initial peak in m.c. in the first autumn was due in part to the very high temperature of the grain upon entry, the rapid cooling of the surface layer in November, and the fact that aeration had to be delayed for technical reasons until mid November of that year. It was not repeated in the second and third autumns of storage when fluctuations were much more moderate. Seasonal fluctuations in moisture content were also present at 0.5 m level, but were hardly noticeable at a depth of 1 m. It should be noted from both these findings and moisture content recordings of grain made during out-loading that the storage regime succeeded in maintaining relatively uniform low moisture contents over the 30 month storage period.

2.1.3..5 Insect infestation during storage

Average infestation levels (number of insects per kg) of both dead and live R. dominica for the 15 grain samples removed during periodic sampling are given in figure 14. Figure 15 shows pooled average infestation levels for the other, secondary insects recorded, namely: Tribolium sp., Oryzaephilus sp. and Cryptolestes sp.. In addition a total of 8 dead adults of S. oryzae were recorded on two occasions in 1985. A spot infestation of R. dominica in the western segment of the container revealed during 1985 is reported on in para: 8.7. From fig. 14 it can be seen that initial infestation of R. dominica was first revealed in the container in the month following in-loading. Maximum live infestation was recorded in December of that year and clearly, population growth of this species was very rapid over the first few months of storage, as witnessed also by the changes in

atmospheric composition of the intergranular air between August and mid-November of 1983 (see fig: 12). The following storage regime of winter cooling followed by spring and summer hermetic storage maintained infestation by this species throughout the major part of the grain bulk at a very low level as witnessed by the fact that only dead specimens of R. dominica were recorded for the remainder of storage except for one outburst in August 1984. As shown in the pie charts in fig: 16 the main other insect pest was Cryptolestes spp. (identified in initial samples as C. ferrugineus). This insect was recorded mainly from the samples taken at the surface layer beneath the sampling ports indicating that a combination of slightly higher grain moisture content and oxygen ingress through the sampling ports may have facilitated their survival in these regions.

2.1.3.6. Isolation and identification of fungi from the stored grains

In order to determine the fungal population present on the grains throughout the storage period - samples of grains taken from the silo were analyzed as follows: 100 gr were surface-disinfected by submerging for 1 min in 2% NaClO, rinsed twice in sterile water and dried over a sterile filter paper in a sterile cabinet. Five g of grain were then blended in 45 ml of sterile agar solution (0.1%) and two additional dilutions were obtained by transferring 1 ml of the suspension to 9 ml of agar solution. Three aliquots (2x0,25ml+1x0,5ml) were taken from each dilution and seeded on the surface of either malt salt agar (4,5% malt agar 7,5% NaCl/liter) or PDA (with 0.25 mg/liter chloramphenicol) in petri dishes. Dishes were then held at 27⁰c and fungal colonies were counted after 4 and 7 days. Identification of colonies isolated from the grains was carried out. Table 3 shows the common fungi isolated from the grains. It can be seen that species belonging to Aspergillus and Penicilium were predominant while species of Fusarium were not isolated throughout the storage period. As A. flavus and A. ochraceus appeared on the grains taken from several points of the silo, it was of special interest to study the ability of these fungi to produce aflatoxin and ochratoxin respectively. The results indicate that both fungi are mycotoxigenic and capable of producing the toxins on both-synthetic media and wheat grains, (see Table 4). Some other toxigenic fungi were also isolated (A. versicolor-sterigmatocystin; P.

cyclopium-cyclopiazonic acid) and although their ability to produce toxins was not determined it seems likely that the risk of mycotoxin presence in local harvested wheat undoubtedly exists. However, no aflatoxins were found at the end of the trial in 10 samples taken from the sampling points before unloading thus indicating that conditions governing toxin production or even those permitting fungal growth, were below the optimum in the silo during the storage. Indeed, this is evident from the findings on grain moisture content as given in section 2.1.3.4.

2.1.3.7. The storage regime and its effect on the in-liner microclimate

Hermetic seal: Examination of the hermetic seal during hermetic storage was carried out by the pressure decay method (Banks and Annis 1984). By this method a positive pressure within the liner was obtained by forcing air into the sealed liner through the aeration fan. Then the rate of pressure decay was measured within the liner. Initial tests were carried out in October 1983, and subsequent tests in October 1984. Calculations indicated an area of leak (total area permitting free diffusion of gases across the liner) in the liner of 6.3 cm^2 in 1983, 6.56 cm^2 in 1984 before additional sealing, and 4.1 cm^2 after additional sealing. This additional sealing was carried out at points where monitoring cables and gas tubes passed into the liner using an acrylic sealer.

The level of hermetic seal recorded above is quite sufficient to permit the principle of hermetic storage to be effective.

Aeration System: The airflow rate of the aeration system was examined in November of 1983. Initial airflow rate as recorded by a velometer at the fan entry was $5,322 \text{ m}^3/\text{h}$, at an axle rotation of 1,050 rpm. Static pressure as measured by a Dwyer inclined manometer at app. 2 m within the main duct was 33 mm water, giving an airflow rate of $5,800 \text{ m}^3/\text{h}$ according to fan specification. A subsequent measurement of airflow rate in November 1984 gave $5,298 \text{ m}^3/\text{h}$. However it should be noted that airflow rate in this case is dependant on axle rotation as produced from the take-off of the petrol motor. This was very unreliable and required adjustment of the throttle position to give optimum results- a procedure that was not normally carried

out. Aeration hours could not be set automatically under these circumstances and consequently the fan aeration was turned on and off manually by the night watchman according to a schedule given to him before-hand. Other drawbacks to the system were faulty maintenance of the motor, and the need to refill the petrol tank at frequent intervals. Such conditions, albeit simulating those liable to be encountered in developing countries, were not conducive to the recording of reliable results under controlled conditions.

Distribution of air through the grain bulk was not measured directly. However, the production of a local hot-spot in the western area of the container (see section 2.1.3.8) and an aeration pass made specifically to lower temperatures in this area indicated that the ducting did not provide adequate aeration in some areas of the bin - especially at floor level. A further fault of the aeration system was discovered during unloading when it was revealed that rodent activity had occurred mainly in the aeration ducts. Rodents had gnawed the jute sacking used to cover the ducts and by so doing they caused cave-ins of grain into the ducts resulting in partial blockage. Further blockage was caused in the main duct by the accumulation of large quantities of loess sucked in by the aeration fan when operated under dusty conditions. If known beforehand this could have been precluded by construction of a simple filter. It is therefore assumed that distribution of the forced air became more uneven as storage progressed, though even in the 1985/86 aeration pass, grain temperatures in all of the monitored areas dropped to below 20°C.

Utilization of aeration hours: Utilization of the suitable aeration hours available as provided by the ambient temperature recordings are given in table 5. From this table it is clear that many more aeration hours were available for cooling than those utilized, and that optimum cooling would be by using available hours in September and October, to commence gradual cooling, instead of beginning in November, - a constraint forced upon us in 1983 because of delay in delivery of the fan from the manufacturers.

2.1.3.8. Miscellaneous observations

Moisture Condensation: A moisture condensation phenomenon was observed in the spring of 1984 and a similar one to a much smaller degree in 1985.

In the first case, creases in the roof-liner which overhung the weldmesh walls to form "pockets" had filled with water. By temporarily opening the zipper at three places, some 40 litres of water were drained from these pockets. This was preceded by an observation that areas of the surface had become hard underfoot in December 1983. In order to ascertain the reason for this, the liner was partially folded back to reveal mold development on the "hillocks" of the undulating surface layer. These areas of molded grain forming a total of some 60 kg were removed and the surface layer was evened out. A possible explanation for this phenomenon was that the late aeration in November pushed hot air (35°C) to the top where it came into contact with the cool inflated roof liner (at less than 20°C) before leaving via the aeration exit hoop. This caused condensation on the under side of the liner and water flowed down the liner to the point where it contacted the grain. This was in addition to the fact that moisture content of the surface layer in general had increased due to the temperature gradient established in the grain. In most areas the whole of the roof-liner lifted above the grain during aeration and condensed water flowed down to accumulate in the pockets formed by creases in the overlap as described above. This phenomenon would also explain the presence of at least two columns of caked dry grain attached to the walls of the liner and revealed during unloading. Their presence was remarked in the spring of 1985 by the odour of rotting grain and an attempt was made to remove them. Some 60 kg of rotting grain were removed at this stage as well as about 240 kg of sound grain which were returned to the Beersheva flour mill.

Insect infestation and heating: In early January 1984 a hot spot caused by a heavy infestation of R. dominica was observed in the western quadrant of the container. Temperatures at a depth of 2 metres (floor level) at the center of the hot spot reached 39°C . Temperature recordings made by pushing probes into the grain and infestation levels recorded from samples removed from the area enabled the dimensions of the hot spot to be delimited. The hot spot composed of grain above 30°C was approximately 1 m from the western perimeter with a diameter of about 2 m and a height of 1 m. Grain above this was relatively cool.

This hot spot was originally discovered by noting the high

temperatures at point 27 which reached 30.5°C on 21.12.83 and continued to rise to 35°C on 8.1.84, whereas at this period temperatures at all other points were decreasing due to aeration.

Aeration at this stage had cooled the upper grain layers but had left the lower layers hot. It was therefore decided to carry out a spot fumigation with phosphine. Immediately after fumigation, temperature at point 26 situated 1 m above point 27, continued to rise, and then temperatures at both points gradually decreased. In late March 1984 a further 9 temperature probes (Nos. 34-42) were inserted into the region and temperatures were monitored until the end of storage. This was the only hot spot recorded during the storage period. However, continuous observations carried out during unloading of the silo revealed grain very heavily infested by R. dominica at floor level at several points along the aeration ducting. Mostly dead, but some live insects were also observed. In several places beneath the ducts the liner was riddled with pin point holes caused by the insect, and clearly in these places hermetic storage was no longer feasible.

Rodent infestation: No holes in the liner attributable to rodents were observed during the entire storage period though rodents were visibly active in the area and clearly had attempted to burrow beneath the liner. During unloading, several (10-15) mice were found in the aeration ducts and several newly-born mice in nests were discovered. There were also numerous holes caused by mice beneath the aeration ducts and it was evident that the mice had benefited from aerobic conditions within the ducts for some time. Had this been realised beforehand, a simple fumigation with phosphine tablets in the main duct would have controlled these pests and probably also the R. dominica infestation described above.

2.1.3.9. Grain quality and estimations of losses

Grain quality

The evaluations of grain quality according to the criteria of moisture content, germination, dockage, broken grains and TGM, at the beginning and end of the 30 months of storage are given in table 1. From the table it can be seen that there was a slight increase in moisture content from 9.6 to

10%, though this was not significant ($p > 0.5$). Average germination decreased from 94% to 84% but again, due to the high SD of the outloaded grain this difference was not significant ($p > 0.5$).

Calculations of weight losses during storage were carried out according to the following equation:

$$\% \text{ weight loss} = \frac{M_1 - M_x}{M_1} \times 100$$

where M_1 is the TGM of the grain at the beginning of storage
 M_x is the TGM of the grain at the end of storage

According to this equation the % weight loss due to metabolic processes of the grain, insects and microflora was calculated as 0.60%, or a total of 3.28 tons of the initial 548 tons of grain in store. This represents a loss in weight of 0.24% on a yearly basis.

Calculated additional in-storage losses of grain spilled and removed during storage were as follows:

1) Grain samples removed for quality control at beginning and end of storage	13.5 Kg
2) Fifteen samples of 250 g each taken 31 times during storage	116.25 Kg
3) Estimated spilled grain during loading and covering	486 Kg
4) Spilled grain during storage caused by overfilling	288 Kg
5) Caked and mouldy grain removed during storage	120 Kg
6) Clean grain removed together with mouldy grain	200 Kg
7) Estimated spilled grain and damaged grain separated from the bulk during unloading	140 Kg
Estimated total loss due to spillage and removal of damaged grain	1363.75 Kg

This represents 0.25% of the total grain in store.

Therefore according to the above evaluation, the total loss during the storage period due to all factors was 4.643 tons or 0.84% of the total grain in store. On an annual basis this is 0.34% of the total grain in store.

It should be noted that this figure differs considerably from the loss recorded on the basis of truck weighings at the Beer-sheva flour mill where a difference of 10.02 tons was recorded between inloading weighings in 1983 and out-loading weighings in 1986. However a number of other factors would account for this discrepancy. These include possible pilfering during overnight parking of haulage trucks after weigh-in and inloading in 1983, and after out-loading and before weigh-in on the following morning in 1986; also suspected on-site pilfering as evidenced by a depression recorded beneath the overliner during the summer of 1985, and possible weighing discrepancies due to weighing on different weigh-bridges at in-loading (Maon) and out-loading (Beersheva).

Insect Infestation

No free living insects either dead or alive were recorded in the samples withdrawn immediately after in-loading.

Insect infestation in the 29 samples withdrawn during out-loading are given in table 2. From this table it can be seen that in 24 out of the 29 samples dead adults of Rhyzopertha dominica were recorded, in some cases in very large numbers. This conforms with the infestation counts throughout the storage period where R. dominica was always the dominant pest. However only in one case was a live R. dominica infestation recorded (sample 28); this was taken from the floor of the bin at the last stages of emptying, (see section 2.1.3.8.). The other two insects recorded during out-loading were Cryptolestes sp. and Psocid sp.. Both were recorded as live and dead insects; however these species are unable to penetrate the sound grain and are also considered as pests of minor importance in Israel. Both Tribolium and Oryzaephilus were only recorded in 3 samples and only as dead insects. These findings all indicate that considerable insect activity had occurred

during the 30 month storage period, but that the vast majority of the insects had been controlled by the storage regime. The activity of these populations would account for the metabolic weight loss of 0.6% recorded in above.

Baking quality

Measurements of loaf volume of bread made from flour prepared from the composite wheat samples averaged 2264 ml $\pm$ 20.3 SE as compared with 2263 ml $\pm$ 58 SE for Miriam wheat of the 1980 harvest stored in conventional silos and tested in 1982. The relative uniformity of loaf volume among the composite samples indicates that in none of the areas of the silo was there a clear decrease in baking quality at the end of the storage period.

2.1.4. Conclusions

The main conclusion from the above described investigation is: that long term safe storage of grain in arid conditions is feasible, and may be carried out with environmental treatments only, or, at the most with a minimal chemical treatment (spot fumigation). Consequently, it can be concluded that these positive results are due mainly to the following 2 factors:

2.1.4.1. The environmental condition in the arid region.

2.1.4.2. Thorough inspection and monitoring of conditions in the grain bulk.

2.1.4.1. The role of the environment can be analyzed as follows:

2.1.4.1.a. The ambient humidity is in general beneficial, in that the moisture content of the grain can be maintained at low levels is because comparatively low humidity air was used for aeration cooling of the grain mass during the winters.

2.1.4.1.b. The ambient temperature, especially during winter nights, can be successfully taken advantage of. Air with temperatures near 5°C could be blown into the grain mass, thereby lowering its temperature considerably. In this regard the role of the aeration system is crucial: its construction

should take into consideration the phenomenon of blocking the main ducts with dust (sucked in with the ambient air) and the stability of the ducts assembled on the silo floor before inloading.

2.1.4.1.c. The change of the atmospheric gas composition in the grain bulk, achieved by the airtight sealing of the storage structure was also beneficial. The high CO_2 and lower O_2 concentrations created in the grain bulk reduced considerably the initial insect population and kept it low during the whole period of storage.

2.1.4.1.d. The lack (or very negligible) rainfall was of course advantageous. However, the impressive water condensation during cold nights may pose a problem since this water runs down from the top of the silo to the ground around it. The accumulation of this condensed water in folds formed by the PVC roof section on the edge of the wall, can be dangerous, since it could penetrate into the grain during opening.

2.1.4.2. Thorough inspection and monitoring of storage conditions. It was concluded that inspection is a decisive factor for a long term safe storage of grain. The silo should be inspected periodically, and the grain moisture and temperature, the atmospheric gas composition (in case the hermetically sealed) and the presence of insects should be recorded, as well as miscellaneous observations.

2.1.4.2.a. Insect infestations, being the main cause of damage in stored grain must be monitored permanently. From this field experiment, it was concluded that the major insect pest was Rhyzopertha dominica. Its presence in the depth of the grain bulk, is best located by detecting rise in temperature or CO_2 concentrations. If the infested focus is found, a local spot fumigation can then be carried out.

2.1.4.2.b. Microflora damage, can be detected also by temperature or CO_2 measuring equipment. The cause of some mold damage encountered was, as mentioned above, the accumulation of condensation water and its penetration into the grain. The prevention of this phenomenon should be made certain.

The common mold damage caused by the increased moisture content of grain in the cooler parts of the bulk, was prevented due to equalizing the grain temperatures in the whole bulk by aeration.

2.1.4.2.c. Rodents - In spite of the preventive control measures taken prior to inloading the silo, some damage was recorded. This was done mainly by small rodents which penetrated either from under the silo through the folds of the PVC floor or through the main aeration duct.

Special care should be taken as to prevent any fold formation on the PVC floor before loading the grain. In addition to this more periodic rodenticide treatments should be carried out during the storage period.

2.1.4.2.d. Termites - No termite activity was observed throughout the storage period.

2.1.4.2.e. Storage structure - The structure proved to withstand adequately during the 30 months of storage in arid conditions. It should be noted that the UV resistant PVC liner remained undamaged and it preserved its elasticity under the intensive solar irradiation typical to the region.

The heating of the grain for insect control with ambient air by means of the aeration system could not be demonstrated as feasible. The maximum ambient temperatures recorded during the warmest summer months ranged from 34° to 38°C. These temperatures are below the lethal limits found for Rhyzopertha dominica. However, the heating of the grain bulk for insect control with heated air through solar collectors should be considered as an important aspect for increasing the grain bulk temperature for the control of storage insects.

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Table 1: Summary of grain quality criteria as monitored during inloading and outloading of wheat after 30 months of storage

	Germination %		% Dockage		T. G. M.		Moisture content		Broken %	
	In-load	Out-load	In-load	Out-load	In-load	Out-load	In-load	Out-load	In-load	Out-load
Average	94.25	84.7	0.89	1.0	33.2	33.0	9.64	10.0	4.03	3.3
Samples	8	29	16	29	16	29	16	29	16	29
S.D.	1.26	1.45	0.52	0.8	2.06	1.0	0.27	0.3	1.99	1.3
Max.	96	99	2.1	2.9	37.5	35.2	10.3	10.7	7.02	7.5
Min.	93	49	0.3	0.3	29.9	31.3	9.3	9.5	0.48	1.4

Table 2: Presence of free stage insects in 29 grain samples taken during out-loading of grain after 30 months of storage

Sample	<u>R. dominica</u>		<u>Cryptolestes sp.</u>		<u>Tribolium sp.</u>		<u>Oryzaephilus sp.</u>		<u>Psocid sp.</u>	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
1	-	86	4	2					8	-
2	-	26	2	9					13	4
3	-	17	3	1					2	4
4	-	2								
5	-	54	9	6	-	1	-	1	55	6
6	-	26	2	7	-	1			7	-
7	-	9	1	-						
8	-	89	-	6			-	2		
9	-	6			-	1				
10	-	148	11	21			-	2	21	4
11	-	48							1	-
12	-	11	1	-					1	-
13										
14	-	2								
15	-	1								
16										
17										
18										
19	-	1								
20	-	19	7	-					11	-
21	-	54	2	1					2	-
22	-	14	1	-					2	-
23	-	<100	<100	-					<100	-
24	-	16	2	-						
25	-	1							3	-
26	-	124	2	-					3	-
27	-	114	11	1						
28	7	32	5	2						
29	-	50								

Table 3 A list of fungi isolated from wheat grains stored in mobile silo.

<u>Aspergillus</u>	<u>Penicillium</u>	<u>Others</u>
A. amstelodami	P. brevicompactum	Alternaria alternata
A. candidus	P. chrysogenum	Cladosporium cladosporioides
A. flavus	P. citrinum	Epicoccum nigrum
A. nidulans	P. crustosum	
A. niger	P. cyclopium	
A. ochraceus	P. expansum	
A. repens	P. frequentans	
A. tamaraii	P. griseofulvum	
A. terreus	P. italicum	
A. versicolor	P. puberulum	
A. wenti	P. viridicatum	

Table 4 :Mycotoxin produced by A. flavus (aflatoxin B1)and A. ochraceus (ochratoxin A) isolated from local harvested wheat grains.

<u>Medium.</u>	<u>Amount of Toxin</u>	
	<u>Aflatoxin B1.</u>	<u>Ochratoxin A.</u>
PDA	15.0	5.5
Malt salt *	12.0	6.2
Wheat **	10.0	10.0

* micro g/ml media

** micro g/50 g grains

Table 5 : Available aeration hours for cooling in 1983/4 and
monthly aeration hours utilized

	<u>No. of hours with ambient temps</u>		<u>Aeration hours utilized</u>		
	<u>below 15°C</u>	<u>below 10°C</u>	<u>1983/4</u>	<u>1984/5</u>	<u>1985/6</u>
Sept	74	0	-	-	-
Oct.	172	11	-	-	14
Nov.	263	43	92	-	103
Dec.	509	259	65	92	-
Jan.	572	335	-	33	39
Feb.	410	148	-	29	-
March	347	117	30	41	-
April	267	58	-	-	-
May	79	7	-	-	-
June	38	1	-	-	-
July	0	0	-	-	-
August	0	0	-	-	-
			190	195	156

Fig. 1: Initial stage of silo erection with floor-wall unit positioned opposite the first fence unit

Fig. 2: Erection of first fence unit with temporary guy-ropes staked on inside and outside of perimeter

Fig. 3: Successive stages in unfolding of floor-wall unit

- a - Aeration sleeve positioned at aeration port
- b - Unrolled package forming a strip across the diameter
- c - Strip unfolded to the sides
- d - Floor secured to the base

Fig. 4: Attachment of wall section to weldmesh fence

- A - Insertion of plastic tubing around top rim of fence
- B - Overlap of wall secured to fence

Fig. 5: Map of silo showing sampling points and aeration ducting

Fig. 6: Correct loading procedure to form cone at center

Fig. 7: Method of covering grain with roof unit

- a - Roof cone package raised over edge of wall
- b - Section pulled to the top
- c - folded section rolled down to cover grain

Fig. 8: Method of securing roof cone to floor-wall unit and weldmesh walls

Fig. 9: Aeration duct covered with jute cloth sheeting

Fig. 10: Average monthly maximum and minimum ambient temperatures
during the 30 month storage period

Fig 11: Grain temperature at two points and average grain temperature in the bulk during 30 months storage

Fig 12: Changes in concentration of O₂ and CO₂ (average of 7 points) and aeration periods during 30 months of storage

% C I

Fig 13: Average monthly recordings of grain moisture content in the container during 30 months storage

Fig 14: Average infestation by *Rhyzopertha dominica*
(insects/kg) of 15 samples withdrawn over 30 month storage
period

Fig 15: Average infestation by secondary insects (insects/kg)
of 15 samples withdrawn over 30 month storage period

Fig 16: Relative population sizes of stored product insects at three stages of the storage period

1983

1984

1985

F. Description of cooperation

Cooperation between the Israeli investigators and Dr. Robert Davis from Savannah Georgia, took place at all stages of the project. Dr. Davis came to Israel twice, firstly at the planning stage, to help choose the most suitable location for the silo in the arid region of the Negev, and later during the work on the laboratory experiments, which were divided between the Bet-Dagan and Savannah Laboratories. The two Israeli partners visited Savannah to coordinate preparation of the First and the Second Reports.

Dr. Davis inspected the field trial, during the storage of wheat in the PVC silo near Ashelim, and at this time the maximum storage period was determined. It should be noted that the American partner, visited Israel again, during the 4th International Working Conference on Stored Product Protection, on September 1986, and at this time, the evaluation of the results, and the planning of the Final Report took place.

Plate 1 General view of the
PVC silo located
near Ashelim.

Plate 2 Covering the PVC
silo with the
roof unit.

G. Evaluation of the research, achievements with Respect of the aims of the original research project.

The aim of the original proposal was to investigate the feasibility of grain storage in arid quasi desert regions, with its benefits and limitations. This goal was tackled by conducting Laboratory and Field studies, which were planned to elucidate the problem.

The laboratory studies were directed toward determining the sensitivity of typical stored product insect species to supraoptimal or alternating temperatures. The results show that one of the major insect pest species, Rhyzopertha dominica proved to be very tolerant to relatively high temperatures, and exposures to higher than 40°C were needed, in order to control it. This finding was very decisive in planning and performing the field trial. Valuable data was obtained also by examining these effects on other stored product insects, as well as the possibility of thermal acclimation on two Tribolium species and on a grain mite.

The field trial was conducted in view of the findings mentioned above. Consequently, grain heating by blowing ambient air during the hot summer months for insect control, as originally planned, did not take place. This decision was taken, after taking into consideration the ambient air temperatures which did not exceed 38°C during the hottest days in summer, while the lethal temperatures for Rhyzopertha dominica, as mentioned above, are above 40°C. Two storage methods aimed at suppression of insect activity in the grain bulk were applied, alternatively:

- 1) Aerated grain storage and
- 2) Hermetic storage.

The combination of these 2 methods namely: aeration for cooling the grain during winters, with hermetically sealing of the silo during summer months, gave the expected results. Insect population was kept low, during the 30 months of storage, with the exception with a local outbreak of Rhyzopertha dominica which had to be dealt with by local fumigation. In general, the results showed that by taking advantage of the climatic conditions in this arid region, characterized by low humidity and low night and winter temperatures, and applying the above mentioned storage methods, the more than 500 tons were stored in a temporary plastic storage structure for two

and a half years practically without chemical treatments, and without substantial loss.

Benefits to agriculture.

The benefit to agriculture and especially to post harvest agriculture is obvious. The project showed clearly the feasibility of long term storage of grain in the arid regions of the world. It was shown that this result was obtained by environmental control methods only, and the grain was protected from insect infestations, practically without the use of chemicals. The decisive role of inspection and monitoring of storage conditions was emphasized. Also the advantages and the requirements for storing grain in the specially designed PVC silo were described.

The project paves also the way for establishing of large grain storage stocks, in arid regions for combatting the famine which prevails mainly in these regions.

H. List of publications

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