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7-YEAR RESULTS OF HERMETIC STORAGE OF BARLEY UNDER PVC LINERS: LOSSES AND JUSTIFICATION FOR FURTHER IMPLEMENTATION OF THIS METHOD FOR GRAIN STORAGE

A. VARNAVA AND C. MOUSKOS
Cyprus Grain Commission,
Stasandrou 26, P.O. Box 1777, Nicosia, Cyprus

ABSTRACT

From 1988 to 1995 barley of 8–11% moisture content (m.c.) was stored at 32–38°C for 1–3 years on two concrete platforms (2,500 and 4,000 t, respectively) under UV-protected PVC liners 0.8 mm thick. In some cases platform floors were covered with a polyethylene liner 0.2 mm thick. Grain moisture, temperature, insect infestation, germination and some other quality parameters were measured during storage. Concentrations of oxygen (O_2) and carbon dioxide (CO_2) were also recorded. At the end of each storage period mold and total losses were determined.

The effect on intergranular O_2 and CO_2 concentrations of covering the floor with a polyethylene liner was significant. With a polyethylene underliner, O_2 and CO_2 were 2–6% and 8–12%, respectively. Without it, concentrations were 6–10% and 2–4%, respectively. However, this did not have a significant influence on losses. Zearalenone (760 ppb) and ochratoxin A (1,990 ppb) were detected in samples of mold-damaged grain, and the total fungal count was 5.7×10^9/g. In sound grain, concentrations of zearalenone and ochratoxin A were zero, and the total fungal count was 1.6×10^6/g. The longer the storage, the higher both mold losses and total losses. After 1 year of storage, they were 0.16 ± 0.1% and 0.32 ± 0.06%, respectively. After 2 years of storage, losses were 0.22 and 0.52%, respectively, and after 3 years of storage mold losses and total losses reached 0.66 and 0.96%, respectively. After 1 year of storage, germination remained above 95%, and after 3 years it was above 88%. Hermetic storage under the PVC liner successfully protected the grain against insects, birds, rodents and rain.

The total expenditure for both fixed and running expenses (building a concrete platform 25 m wide and 75 m long and hermetically storing 4,000 t of barley under the PVC liner) was US$4/t/1 year or US$2.50/t/3 years.

INTRODUCTION

It is quite frequent for many countries to face serious problems in undertaking the safe and timely collection and storage of newly harvested crops. In Cyprus, due to limited

storage capacity, almost every year thousands of tons of harvested barley and wheat remain stored in the open for 4–5 months. In some years considerable amounts of grain are destroyed by rain. Deterioration and loss of grain stored in the open is also caused by attacks by birds, rodents and insects. In Australia this problem was addressed by the development of bunker storage (Banks and Sticka, 1981; McCabe and Champ, 1981), while in Israel emphasis was placed on the development of hermetically sealed bunkers (Navarro *et al.*, 1984).

The need to provide a rapid and effective solution to the problem of storing newly harvested grain in Cyprus prompted the Cyprus Grain Commission, in cooperation with the Volcani Center of Israel, to develop a modified platform hermetic-storage system. Aspects of the Cyprus platform storage have been published (Navarro *et al.*, 1993; Varnava *et al.*, 1994), while this paper reports on the quality of hermetically stored grain, with particular reference to the problem of mycoflora and mycotoxins (Bullerman, 1979), and on a cost–benefit analysis of the platform method.

MATERIALS AND METHODS

Two platforms have been used for hermetic storage since 1987. Each consists of a re-inforced concrete floor with a 1 m high peripheral retaining wall. Grain is loaded either directly on the concrete floor or onto a polyethylene underliner 0.25 mm thick. A UV-protected PVC liner 0.8 mm thick is used to cover the grain. Where the floor is covered by a polyethylene liner, the overliner and underliner are brought together over the walls, folded over at the outer base of the walls, and weighted with sandbags, thus forming a hermetic seal.

The first platform is 75 m by 25 m and has a capacity of about 4,000 t of barley. The second platform is 50 m by 25 m and has a capacity of about 2,500 t of barley. The height of grain at the peak is 6.5 m.

Both platforms are used for storing local barley with a maximum m.c. of 11%. Normally, incoming grain is already infested by insects when it arrives at the platforms. However, no chemicals are used during loading or during storage of the grain on the platforms.

Grain has been stored on these platforms for 8–10 months, and in some cases 2 or 3 years. During storage grain samples have been taken from different depths and locations to monitor moisture content (m.c.), insect infestation, germination and mycotoxin deterioration. Grain temperature and intergranular oxygen (O_2) and carbon dioxide (CO_2) concentrations have also been measured. In addition, both mould losses and total loss have been evaluated.

Estimates were also made, for comparison, of losses caused in 1992 and 1995 by heavy rain during storage of grain in the open.

Finally the cost of on-platform storage per ton for 1, 2 and 3 years was calculated.

RESULTS AND DISCUSSIONS

Covering the floor with polyethylene liner

The influence on intergranular gas composition, insect infestation and grain losses of covering the platform floor with a polyethylene liner is given in Table 1.

TABLE 1
Influence of covering the platform floor with a polyethylene liner (duration of storage 8–10 months)

Liner	Gas concentration (%) 3–4 months after covering		Infestation[1]	Losses due to mould (%)	Total grain losses (%)
	O_2	CO_2			
Yes*	2–6	8–12	Rare	0.16 ± 0.1	0.32 ± 0.06
No**	6–9	2–4	Yes	0.13 ± 0.06	0.28 ± 0.06

* = data for 4 years; ** = data for 5 years.
[1]Presence of adult insects in samples from the upper grain layers after covering with the PVC liner.

The data obtained over several years indicate that covering the floor with polyethylene significantly influences change in intergranular gas composition and also provides better control of insect infestations. It would not appear to have any serious influence on the amount of grain on the top of the platform damaged by mould or on total grain losses by the end of storage.

Duration of storage

The influence of the duration of storage on grain loss, infestation and grain germination is given in Table 2. This table shows that satisfactory insect control can be achieved for 1, 2 and 3 years of storage on a platform with a polyethylene covering over the floor. Grain germination remained very high (94–97%) even after 2 years of storage, and it was reduced to 88% only after 3 years of storage.

TABLE 2
Influence of duration of storage on grain losses and other parameters (platform floor covered with a polyethylene liner)

Duration of grain storage (months)	Platform capacity (t)	Infestation[1]	Germination (%)	Losses (%)	
				Mould	Total
8–10*	2,500–4,000	Rare	95–97	0.16 ± 0.1	0.32 ± 0.06
23	2,500	Rare	94–98**	0.22	0.52
34	4,000	Rare	88 ± 1.6	0.66	0.96

* = data for 4 years; ** = viability.
[1]Presence of adult insects in samples from the upper layers after opening the PVC liner.

TABLE 3

Microflora and mycotoxins in barley samples of different degrees of deterioration at the end of a 10-month platform storage under a PVC liner

Parameter	Threshold value for the occurrence of symptoms of mycotoxicosis to animals	Sample A Taken from center of mould spot Visible signs of mould deterioration Very spoilt grain	Sample B Taken 10–20 cm below mould spot Visible signs of mould deterioration Less spoilt grain	Sample C Taken from grain surface free from any mould spot High moisture grain (17% m.c.) Sound grain	Sample D Taken 0.5 m below grain surface Low moisture grain (12% m.c.) Sound grain
Mycotoxines (ppb)					
T-2	200	0	0	0	0
Zearalenone	200	760	260	0	0
Deoxynivalenol	400	0	0	60	0
Fusarenon X	400	0	0	0	0
Nivalenol	200	0	0	350	0
Diacetoxyscirpenol	400	0	0	0	0
Ochratoxin A	100	1990	1570	0	0
Aflatoxin B1	20	0	0	0	0
Microflora (fungi number per g)					
Total fungi		2.7×10^{10}	5.7×10^{9}	2.2×10^{6}	1.6×10^{6}
Fusarium		5.5×10^{4}	1.5×10^{4}	4.5×10^{5}	5.5×10^{5}
Alternaria		9.2×10^{7}	4.2×10^{7}	1.2×10^{4}	0.7×10^{4}
Penicillium		2.4×10^{10}	5.5×10^{9}	1.7×10^{6}	1.1×10^{6}
Aspergillus		3.2×10^{8}	9.7×10^{7}	9.7×10^{4}	4.7×10^{4}
F. graminearum		Few	Few	3.7×10^{5}	3.8×10^{5}
F. colmorum		Few	Few	0.7×10^{5}	1.7×10^{5}
F. moniliforme		Few	Few	9.5×10^{4}	2.5×10^{4}
P. ochraceus		2.4×10^{10}	4.4×10^{9}	1.4×10^{6}	0.8×10^{6}
P. urticea		3.1×10^{9}	7.2×10^{8}	0.2×10^{6}	0.2×10^{6}
Mucor		Many	Many	Few	Few

On the other hand, the duration of storage had a significant influence on both mould losses and total loss. At the end of 3 years of storage, mould losses were four times greater than average mould losses after 1 year of storage. Similarly, total loss after 3 years of storage was three times greater than average loss after 1 year of storage.

Microflora and mycotoxins

The initial temperature of grain stored on platforms was between 30–37°C, whereas the lowest ambient air temperature during the winter season was 2–6°C. This resulted in the establishment of strong temperature gradients within the bulk which in turn caused convection currents, leading to transfer of moisture to the peak area of the bulk and therefore to mould deterioration of the grain in some spots at the apex of the bulk. These spots were 5–50 cm deep.

Two samples of very spoilt barley and spoilt barley taken from these mould spots at a depth of 0–20 cm and two samples of sound barley at 17% m.c. and 12% m.c., respectively, were analysed for mycotoxins and microflora. The results are given in Table 3. These results demonstrate that spoilt grain from the mould spots could be seriously contaminated by zearalenone (260–760 ppb) and ochratoxin (1,600–2,000 ppb). Spoilt grain was contaminated primarily by *Alternaria, Penicillium, Aspergillus* and *Mucor* fungi. The quantity of spoilt grain at these spots was very small, but the importance of carefully removing all spoilt grain from the bulk surface must be emphasised.

Analyses of samples "C" and "D" show that the grain stored on platforms actually remains free from mycotoxins and is suitable for animal consumption.

Total costs of platform erection and hermetic storage of 4,000 t grain

The fixed cost of building a concrete platform (75 m by 25 m), together with the costs of PVC and polyethylene and the current cost for storing 4,000 t of barley for 1, 2 and 3 years are all shown in Table 4. The total per-year cost for storing 1 t of barley for a period of 3 years is C£1.23.

Table 5 shows the losses that occurred in 1992 and 1995 during storage of local barley in the open. Grain was affected by rain, and a part of it was completely destroyed. In the years 1992 and 1995, 65,500 t of barley stored in the open were affected by rain and, based on the weighted average loss of 5.23%, some 3,425 t were completely destroyed. The economic loss was about C£387,100.

Table 6 shows the estimated monetary saving in losses to the 65,500 t of barley, which in 1992 and 1995 remained in the open unprotected against the rain, had they been placed in hermetic storage. The total fixed and running costs for 1 year's hermetic storage of 65,500 t of local barley on a concrete platform under PVC is estimated to be about C£152,000. The economic loss due to the lack of appropriate protection was about C£387,100. In addition, hermetic storage of grain on platforms under PVC successfully protects the grain against insect, bird and rodent attacks and also prevents its contamination by mycotoxins.

TABLE 4
Costs of building a concrete platform and of hermetic storage of 4,000 t of barley under PVC liner

Costs	Total cost	Depreciation (years)	Costs per 1 year storage (C£)	Costs per 2 years storage (C£)	Costs per 3 years storage (C£)
Fixed costs					
Building platform	56,250	30	1,875	3,750	5,625
PVC sheet for covering grain	10,990	7	1,570	3,140	4,710
Polyethylene liner for covering floor	522	1	522	522	522
Total fixed costs			2,967	7,412	10,857
Current costs					
Electricity to inload 3000 t	75		75	75	75
Labour to inload 3000 t and level grain surface	1,711		1,711	1,711	1,711
Labour to cover grain and weld PVC sheet	1,100		1,100	1,100	1,100
Labour to cover floor with polyethylene liner	40		40	40	40
Labour to remove PVC sheet	155		155	155	155
Labour to inload grain into trucks using a tractor	800		800	800	800
Total current costs			3,881	3,881	3,881
Total of fixed + current costs					
Total costs per 4,000 t			7,848	11,293	14,738
Total costs per 4,000 t per year			7,848	5,647	4,913
Total costs per t per year			1.96	1.41	1.23

Platform 25 m wide, 75 m long, 7 m high; C£1 = US$2.1.

TABLE 5
Barley loss due to rain during open storage after harvest (1992 and 1995)

Year	Total quantity harvested (thousand t)	Quantity affected by rain (thousand t)	(%)	Quantity completely spoilt by rain (t)	Losses (completely spoilt grain), % of total quantity harvested	of quantity affected by rain	Losses (completely spoilt grain, C£113/t) (C£ × 1,000)
1992	161.4	48.3	30.0	2,463	1.5	5.1	278
1995	122.6	17.2	14.0	1,011	0.8	5.9	114
Average of 1992 and 1995	142	32.8	25.8*	1,737	1.2	5.23*	196

* = weighted average.

TABLE 6
Economic effectiveness of grain storage using the hermetic method on platforms under PVC liners

1-year hermetic storage of 65,500 t of barley under PVC	C£ × 1,000 (C£1 = US$2.1)
Total cost (fixed + current): 65,500 t × C£1.96/t/year	128
Total losses after 1-year hermetic storage: 65,500 t × 0.32% losses × C£113/t	24
Total (cost + losses)	152
Total losses due to deterioration by rain occurring in 1992 and 1995 during storage of 65,500 t of barley in the open 65,500 t × 5.23% losses × C£113/t	387

CONCLUSIONS

The results of trials over a period of 7 years clearly showed that using the hermetic method of storage on concrete platforms under PVC was suitable for prolonged storage of dry barley under the climatic conditions of Cyprus.

The hermetic method of storage on platforms under PVC successfully protected stored grain against rain and against insect, rodent and bird attack. Ecologically it is an advanced method for grain storage which also has a low structural cost.

The serious problems faced by Cyprus because of limited grain storage facilities, particularly during harvest time, could be addressed by widely implementing the hermetic method of storage on platforms.

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