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PRESERVATION OF GRAIN IN HERMETICALLY SEALED PLASTIC LINERS WITH PARTICULAR REFERENCE TO STORAGE OF BARLEY IN CYPRUS

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ABSTRACT

In Cyprus, barley of 10% moisture content (m.c.) was stored on two concrete platforms covered with PVC liners. The floor of one platform was lined with polyethylene on which about 4,000 tonnes of barley were stored for 9 months. On the second platform, 2,500 tonnes of barley were loaded directly on the concrete and stored for 7 months. Insect activity was controlled in the first platform within four months, but in the second platform was only partially suppressed. Moisture content remained stable except for the peak layer, where moisture migration caused a marked increase. Mold damaged barley unfit for consumption was 0.0088% and 0.1874% of the total quantity in the first and second platforms, respectively. Germination remained above 95% throughout the storage periods.

In Israel 15,567 tonnes of wheat of approximately 11% m.c. were stored for 15 months in a bunker bordered by earthen ramps using a PVC overliner and polyethylene underliner. Insect activity was suppressed and total damage from insects and molds were estimated at 0.15 and 0.06%, respectively. Moisture migration to the peak layer, particularly in the region of higher initial m.c., necessitated removal of damaged grain and affected germination and baking quality in that area. Elsewhere, germination averaged 95% and loaf volume was not lower than that of wheat under usual storage conditions.

INTRODUCTION

The intrinsic advantage of the hermetic storage of dry cereal grains lies in the generation - by the aerobic metabolism of insect pests and microorganisms - of an oxygen-depleted and carbon dioxide-enriched intergranular atmosphere of the storage ecosystem. By so doing, their development is arrested and storage damage minimized. This principle has been used since prehistoric times, perhaps unwittingly, in traditional underground storage structures that are still used, particularly in semi-arid regions of the Mediterranean basin and Sahel (Curride and Navon, 1986; Gilman and Boxall, 1974).

Above ground silos (concrete and metal) have also been constructed with specifications to provide a seal for hermetic storage. Earlier designs did not provide a sufficiently effective seal (Ctesiphon silos in Cyprus and Kenya) though sealing techniques have been developed that enable gas permeability to be reduced to a minimum (De Lima, 1980).

The concept of bunker storage was conceived to provide a low cost system for storing large quantities of grain for prolonged periods. It takes advantage of the low O_2 and high CO_2 concentrations below ground to reduce the rates of gas exchange beneath the grain bulk, in conjunction with the use of low retaining walls (earthen or concrete ramps). The floor of the bunker must provide an effective moisture barrier, while the walls and roof must provide an impermeable barrier to rain. The first documented bunkers were those used to store grain surpluses in Argentina and Uruguay during the second world war. The initial bunkers were deep pits lined with bricks or straw and wood, or a soil cement mix, and roofed with bitumen-treated sheeting and sometimes covered with soil. (Anon. 1949). Although grain was stored successfully for prolonged periods, these pits suffered from shortcomings both in the quality of hermetic seal and in grain handling procedures. However, the more recent development of durable plastic sheeting has facilitated the design of above ground bunkers. In this case, the grain is loaded into the bunker to form an elongated peak according to the angle of repose of the grain. The Australian initiative has been towards the use of reinforced PVC on nylon overliners sewn together to provide a continuous covering that is not sufficiently gas tight for hermetic storage, but can provide a seal for an initial fumigation plus an effective insect barrier to prevent re-infestation (McCabe and Champ, 1981; Banks and Sticka, 1981).

The Israeli design is based on heavy-duty PVC liners welded together to provide a continuous cover. The border of this cover is overlapped and folded with the border of a polyethylene underliner that is laid over the earthen floor and retaining ramps. The folded overlap is then buried in a trough along the top of the ramps, thereby forming a hermetic seal. This type of bunker has been progressively modified for use over the years by laying an asphalt floor that facilitates unloading by reducing the admixture of grain with soil when using front-end loaders.

The need to provide a rapid solution for storage of buffer stock in Cyprus prompted the Cyprus Grain Commission (C.G.C.) to develop a modified bunker storage system. It differs from the Israeli version primarily in the construction of platforms consisting of a reinforced concrete floor with 1 m high peripheral retaining wall. Loading has been either directly onto the floor or onto a polyethylene underliner. The overliner is made of the same material as used in the Israeli version.

The objective of this presentation is to provide data on quality preservation of barley and wheat under prolonged hermetic bunker storage in Cyprus and Israel, respectively.

MATERIALS AND METHODS

1. The Cyprus platforms

Both platforms are located in Nicosia, Cyprus.

Platform 1: Dimensions - 75m long (east-west axis) and 25m wide. Before loading, the floors and walls were covered by overlapping strips of 0.240 mm thick polyethylene sheeting that were taped along the edges to form a continuous underliner.

Platform 2: Dimensions - 50m long (east-west axis) and 25m wide. In this platform, grain was loaded directly onto the concrete.

1.1 *Loading, sampling and sealing:*

Both platforms were loaded with newly-harvested local barley (varieties Cantara and Athinais) after 1-2 months of field storage. Before loading, trucks arriving at the site were sampled, and those with grain at above 11% m.c. were rejected. Composite samples from the trucks were used to determine average specific weights of barley in the platforms. The height along the apex of both platforms was about 7 m and the slopes were smoothed to form a sharp peak. After loading, the grain bulks were covered by strips of white, 0.83 mm thick PVC formulated sheeting, that were then welded together to form a continuous overliner covering the grain bulk and over the retaining walls.

Platform 1: To seal this platform, the over- and underliners were folded over at the outer base of the wall and weighted with sandbags to form a hermetic seal. The overliner was equipped with 7 screw-cap inspection ports along the apex, within which thermocouple cables were inserted to depths of 0.3, 1.0 and 3.0 m respectively. The platform was loaded with 4,083 tons of barley. Loading was completed in late July 1989, the platform was sealed in mid-August, and the grain was stored for 9 months until May 1990.

Platform 2: Loading was completed in late August 1988, and grain was stored for 7 months until April 1989. Four inspection ports equipped with thermocouple cables were located along the apex of the overliner. The platform was sealed by weighted sand bags at the base of the wall.

1.2 *In-storage monitoring and sampling*

Grain: Monthly samples were withdrawn from the inspection ports at three depths (0-0.3 m, 1.0 m, and 3.0 m). Each sample (approximately 300 g) was examined for moisture content and insect infestation.

Temperature: Measurements at all ports were carried out at monthly intervals.

Intergranular atmospheric composition: In both platforms oxygen (O_2) and carbon dioxide (CO_2) concentrations were measured only once in December 1988.

Ambient conditions: Data on ambient temperatures, humidities, and rainfall during the storage periods were taken from available meteorological sources.

1.3 *Unloading and sampling:*

Before unloading, the overliners were removed and additional grain samples were withdrawn from Platform 2. Samples having different m.c. levels were used to determine the m.c./equilibrium relative humidity (ERH) curve for barley, while samples with visible mold deterioration were collected for aflatoxin analysis.

During unloading, 1 kg samples were taken from each truck. All samples were analyzed for insect infestation. For Platforms 1 and 2, 16 and 13 composite samples, respectively, were created, and grain viability and germination were determined by standard methods.

2. The Israeli bunkers

The following methodology is merely provided for a description of the conditions under which the results were obtained. Detailed results of this storage trial have been published elsewhere (Navarro *et al.*, 1984). Dimensions of the first Israeli bunker were 150 m long (north - south axis) and 50 m wide. The earthen floor was bordered on three sides by earth ramps upturned from the floor during leveling and grading, and the fourth end was left open for grain loading. The ramps were 2 m high, 8 m wide at the base and beveled to permit drainage of rain water away from the outer sides. Before loading, the floor and ramps were lined with overlapping strips of 0.25 mm polyethylene sheeting laid transversely to form a continuous underliner. Since the completion of the first bunker, this method of storing grain reserves has become routine practice in Israel.

2.1. *Loading, sampling and sealing:*

Wheat (var. Miriam) from the 1980 local harvest was trucked directly from the fields and a total of 15,567 tonnes were loaded into the bunker. The bulk was loaded using a belt that projected the grain to form a peak approximately 8.5 m high along the bunker axis. During loading, 209 1-kg samples were taken from trucks. The overliner was the same as that used in the Cyprus platforms. The two liners contacted at the top of the ramps where they were overlapped and folded, and buried in a 60 cm trench to form a hermetic seal. The grain was stored for 15 months from June 1980 until September 1981.

2.2. *In-storage monitoring and sampling*

Thermocouple cables for temperature measurement were inserted at 90 points into the bulk during loading, with tubes for monitoring gas composition placed at 30 points. Monitoring was carried out on a bi-weekly basis throughout storage. Grain sampling was carried out 10 times during storage. Each time, 60 1-kg samples were withdrawn from 10 sampling ports situated along the bunker axis. These samples were used to determine moisture content, insect infestation, germination, and baking quality.

2.3. *Unloading and sampling:*

Unloading was carried out by front-end loaders. Samples from each truck (total of 585 samples) were examined for insect infestation and moisture content. Two composite samples were created from every 10 consecutive samples; one was used to evaluate weight loss by the count and weigh method and to determine germination, while the other was used to make 13 sub-samples for baking quality analyses.

RESULTS AND DISCUSSION

1. The Cyprus platforms

1.1. *Moisture content*

The average initial m.c. of Platform 1 was 9.9% (range: 9.0-11%) and that of Platform 2 was 10.2% (range: 9.0-11.0%). Measurements during storage indicated a progressive rise in m.c. of samples taken at a depth of 0-0.3 m at the apices of the platforms, averaging 12.0% and 15.1% respectively, at the end of the storage periods. By contrast the 0-0.3 m samples taken from northern and southern slopes failed to reveal any significant increase in m.c. Examination of the grain surface after removal of the PVC liner prior to unloading revealed that the major area of moisture accumulation occurred at the surface layers along the apices of the platforms.

1.2 *Insect infestation*

Insects recorded from samples during loading were mainly *Tribolium* spp. and *Rhyzopertha dominica*. During storage, insect populations were very low and confined mainly to the upper 0.3 m of the bulk. During unloading, live samples of the above two species and *Oryzaephilus surinamensis* were recorded in 4% of the samples taken from Platform 1 and 10% of the samples from Platform 2. Mean live insect population densities were 0.089 and 0.333%, respectively.

1.3 *Grain viability and germination*

Grain viability remained above 95% in both platforms throughout the storage period. Similarly, germination remained above 96%.

1.4 *Damage by molds*

After the overliner had been removed, mold damage was visible at various sites along the peaks of both platforms. At these locations moldy grain reached depths of 20-50 cm. In Platform 1, the quantity of moldy grain discarded was 0.36 tonnes, representing 0.0088% of the total bulk, and in Platform 2 a total of 4.70 tonnes were discarded, representing 0.185% of the total bulk.

1.5 *Gas composition*

Although CO_2 and O_2 concentrations of the intergranular air within the platforms was not measured on a regular basis, significant differences were recorded between the two platforms. In Platform 1 (with the underliner), the CO_2 concentration reached 10.2% after 4 months of storage, whereas in Platform 2, without the underliner, the CO_2 concentration was only 3.6%. These differences reflect the importance of the underliner in CO_2 retention and can be related to the differences in levels of live insect infestation and damage by molds at the end of storage.

1.6 *Grain temperatures*

The average temperatures of grain at 3 different depths beneath the apex of Platforms 1 and 2 are given in Figs. 1 and 2 respectively. The figures show that while temperatures after loading were uniform at 34-36°C, the influence of seasonal fluctuations in the ambient temperatures was pronounced at 0.3 m within the grain bulk and progressively less so at 1.0 m and 3.0 m. This resulted in the establishment of temperature gradients within the grain bulk that reached a maximum after 169 days of storage (Jan.-Feb.). Clearly, these temperature gradients were responsible for convection currents that caused moisture transfer to the peak area of the bulks.

Temperature measurements taken before unloading after the overliners had been removed revealed that temperatures at 0.3 and 1.0 m depths, half way up the northern slopes of both platforms were 2-3°C lower than those in the southern slopes, with both being lower than those measured at the apex.

2. The Israeli bunkers

The following information relates to quality parameters as compared with those of the Cyprus platforms.

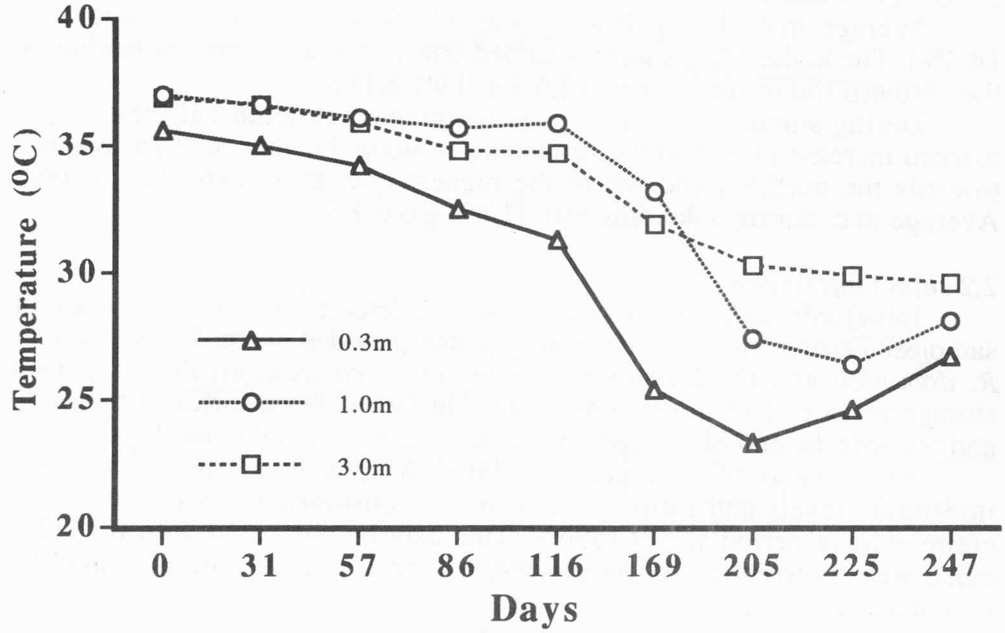

Fig. 1: Temperatures in Platform 1 (Cyprus) during storage.

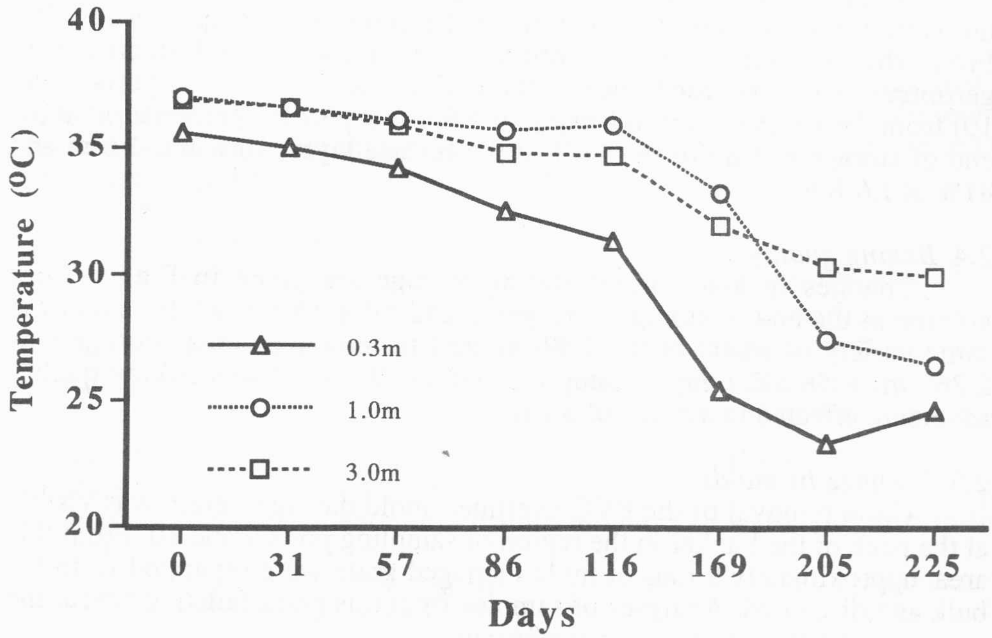

Fig. 2: Temperatures in Platform 2 (Cyprus) during storage.

2.1 *Grain moisture content*

Average m.c. during loading was 11.4% ± 1.0% S.D. (range: 8.7-14.3%). The highest m.c.s were recorded during the last 2 days of loading at the northern end of the bunker (12.6% ± 0.9% S.D.).

During storage, low m.c.s were maintained at depth but there was a marked increase in m.c. at the surface layer along the apex, and particularly towards the northern end where the highest m.c. grain had been loaded. Average m.c. during unloading was 11.4% ± 0.6% S.D.

2.2 *Insect infestation*

Initial infestation was low and could be detected only by incubation of samples. During storage, the major pests recorded were *T. castaneum*, *R. dominica* and *O. surinamensis*. Samples taken from all depths during storage revealed live infestations mainly in the northern sector of the bulk, and towards the end of storage, live insects were confined to the top 3 m.

At the end of storage, calculated weight loss based on insect infestation levels and estimated dry matter consumed by insects over the entire storage period was 0.1596%. This may be compared with 0.1472% calculated as weight loss by insects in samples taken during unloading (count and weigh method).

2.3. *Grain germination*

Germination levels during storage are given in Fig. 3. During unloading, the average germination of the composite samples was 95%. From the periodic in-site samplings, the only marked decrease in germination was recorded towards the northern apex (sampling ports 9 and 10) from the surface layer to a depth of 1.6 m. At port 10, germination at the end of storage had dropped to 0% at the surface layer, 10% at 0-1.6 m and 81% at 1.6-8 m.

2.4. *Baking quality*

Changes in loaf volume during storage are given in Fig. 4. Loaf volume at the end of storage averaged 2,252 ml ± 18 SE, while that of the same variety of wheat of the 1980 harvest from conventional storage was 2,263 ml ± 58 SE. Only at sampling stations 9 and 10 was baking quality adversely affected to a depth of 3.2 m.

2.5. *Damage by molds*

Upon removal of the PVC overliner, mold damaged grain was visible at the peak of the bunker in the region of sampling ports 9 and 10. From this area, approximately 9 tons of mold damaged grain were separated from the bulk and discarded. Analyses of samples from this grain failed to reveal the presence of either aflatoxin or ochratoxin.

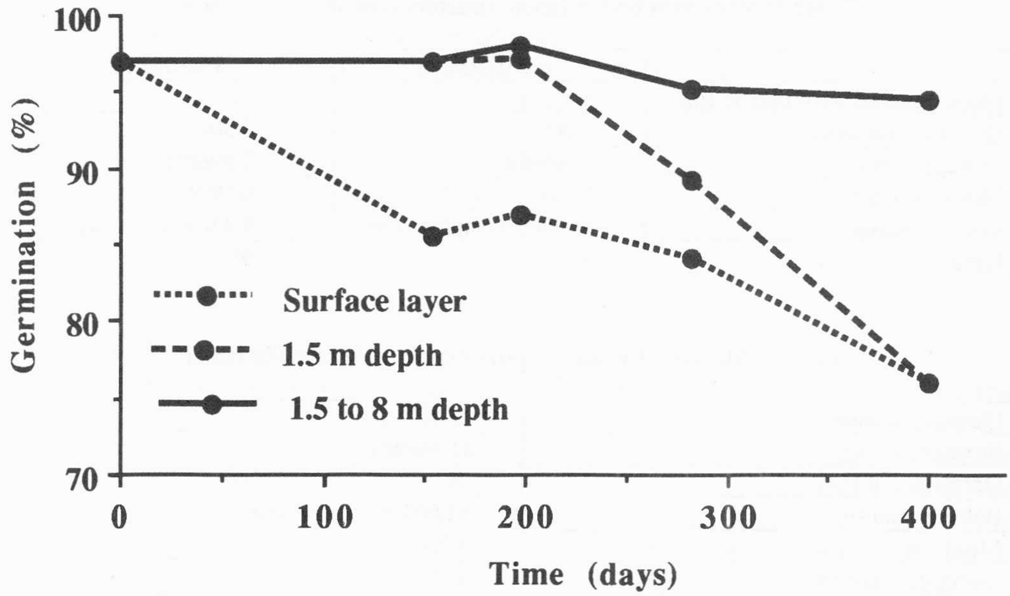

Fig. 3: Germination of wheat samples taken from different depths in the Israeli bunker during the storage period..

2.6. *Gas composition*

A rapid decline in O_2 and rise in CO_2 concentrations over the first 3 months of storage can be attributed mainly to insect metabolism. Minimum O_2 was recorded in December (5% O_2) followed by a gradual increase in O_2 and decrease in CO_2 concentrations .

2.7. *Grain temperatures*

The extensive monitoring of temperature throughout the grain bulk revealed that while the initial temperature was fairly uniform at 30-33°C, the surface layer was strongly affected by ambient temperature fluctuations and in January had dropped to 16°C. Temperatures within the bulk were affected progressively less by ambient temperatures, and at 50 cm average temperatures in January were 24°C and at 1m, 28°C. These figures serve to indicate the significant temperature gradients that occurred during storage and explain the phenomenon of moisture migration towards the apex of the bunker.

Summaries of quality parameters of storage in the Cyprus platforms and the Israeli bunker are given in Tables 1 and 2.

Table 1: Storage of barley (approximately 10% m.c.) in Cyprus.

	Platform 1	Platform 2
Floor covered with plastic liner:	yes	no
Quantity (tonnes):	4,000	2,500
Storage period:	9 months	7 months
Mold damage (%):	0.0088	0.1874
Insect control:	virtually complete control	0.3 live insects/kg
Germination (%):	95	95

Table 2: Storage of wheat (approximately 11% m.c.) in Israel.

Quantity (tonnes):	15,567
Storage period:	15 months
Germination (%):	95
Baking quality:	>2,000 ml loaf volume
Mold damage (%):	0.058
Insect damage (%):	0.147
Insect control:	complete

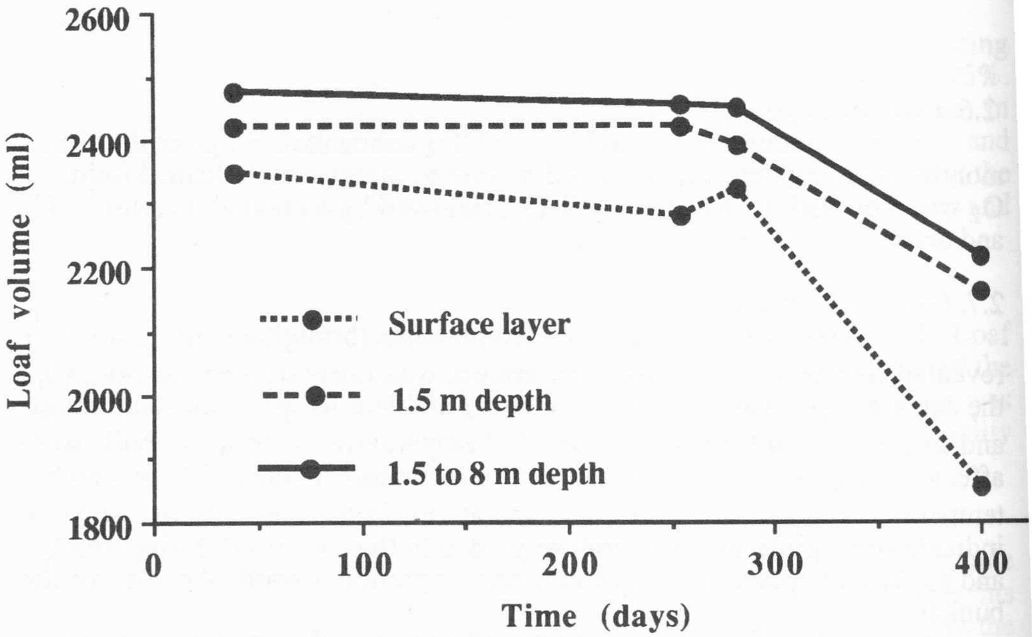

Fig. 4: Changes in baking quality of wheat samples taken from different depths in the Israeli bunker during the storage period.

In conclusion, the results of the above trials show clearly that these types of structure are suitable for prolonged storage of dry grain. Storability was improved using an underliner, and the hermetic conditions arrested insect activity, resulting in losses from insects of less than 0.15% and losses from molds of less than 0.05%. The major problem encountered was the establishment of temperature gradients in the upper layers of the bulk that promote moisture migration towards the apex. This resulted in small quantities of mold damaged grain that had to be separated from the rest of the bulk before unloading.

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