Experimental report of grain storage in underground earth granary

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Abstract

Underground granary is suitable to be constructed in an area where the temperature in a year round is lower, the climate is continent and dry, and the groundwater is lower. This storehouse is a kind of flaring granary with an entrance on its top for entering gran, and an underground channel to discharge gran. It forms a circumstance of low temperature, low oxygen and low moisture due to some special design, such as drainage, damp-proof layer and airtight doors and windows, which segregate outside air influence. The experiments proved that the temperature in 4 meters beneath the earth’s surface is always kept at about 12°C, which is the key factor for safe storage. The grain condition in this storehouse depends on the thickness of the covering layer upper granary. The maximum variation in grain temperature was in August and September. The grain temperature was lower than 15°C in the upper layer and about 10°C in middle and bottom layer. Under lower temperature the safe moisture content of corn can be raised about 1.5 - 2.0%. Low temperature, lack of oxygen and free off sunlight were helpful to the keep freshness of grain for a long time. Moisture and dust content were almost unchanged, but the germination rate and gluten content decreased slightly and the fatty acid value increased a little. All of these changes did not affect the quality for seeding and food. High moisture rice stored in underground granary is very safe in summer. When wheat with insects is stored in underground granary, the behaviours of insects will be contained by low temperature. The optimal entering time is in February and March and the optimal transferring and overturning time is from the beginning of October to the middle of November. The results tested showed that the quality of stored grain, the safe storage time and the quality of finished product in underground barns were better than that in ground surface barns. The longest storage time of wheat stored in underground barns reached 15 years. The advantages of underground deposit are low cost of construction, easy construction, less occupation of cultivable land and longer service life. In the routine management, labour and power consumption and grain loss and were reduced.

Introduction

It is both ancient and novel storage mode to store grain in underground granary. Low temperature and sealing circumstance controls and restrains the generation of pest and mould, and delay deterioration

Underground granary has the advantages of concealment, strong, fireproof, low temperature, sealing and light shielding, less insecticides to be used and lower loss.

The underground granaries are mainly the underground earth granaries and rock underground barns in China now. This paper described a granary in Yuanbaoshan and its regional climate, topography, geography, soil condition, and its construction technology. The experimental results are described as below.

General Situation

Climate

Yuanbaoshan lies in 118°93'E, 42°67'N, where belongs to cold zone and sub-dry continent climate with 23.7°C of maximum averaged monthly temperature, minimum monthly temperature is -30.1°C, lowest daily temperature is -31.2°C, and top daily temperature is 42°C. The averaged annual temperature is 6.7°C. There are 130 days with mean temperature 0°C. The annual mean rainfall reaches 394.7mm while the evaporation reaches 1880mm. The deepest frozen soil layer is 1.3 meter thick. The constant temperature of the layer 15 meters beneath the earth is 8.0 - 9.0°C, resulting in stable low temperature in this granary.

Topographical and geographical condition

Yuanbaoshan areas belong to the extension of Yanshan Mountains. The western part of this area is higher and the eastern is lower. The height above sea level is from 503.6 to 476.6 meters, the averaged head is 20 meters in accords with the construction height of underground granary. The granary floor is 15 meters from the groundwater level in accord with the requirement of granaries construction.
Earth situation

The soil in Yuanbaoshan District is loess-and-larclazyte combined soil. The white larclazyte powder appears in the vein that constructs vertical holes and vertical veins. In loess area there are some steeps with high intensity and stable structure. By practical examination the water content of the earth layer below 10 meters is 11.8%, in accord with the requirement of granary construction.

Experimental Granary, Materials and Methods

Granaries used for the experiments

The structure of granary

The granary has been constructed in flaring Expansion. The bottom and top diameter are 10 - 12 meters and 15 meters respectively. The height of granary is 14 – 18 meters, with a one-meter wide entrance hole on the top cover. As far as the bottom pit, there is a discharge door (2 meters high x 1.2 meter wide). The door is connected to a main trunk through a channel, two meters wide, 2 meters high and 4 meters long as shown in Figure 1.

![Figure 1](image1.png)

Fig. 1. Structure of underground granary in cutaway view.

The damp-proof bottom and walls are constructed with 2 layers of bitumen, asphalt felt and dry bricks each. The barn ceiling is made with 4 layers of bitumen, 2 layers of asphalt felt and 2 layers of dry bricks. Then it is covered by steel reinforced concrete with 0.5 – 5 meters thick soil in the top as shown in Fig. 2.

![Figure 2](image2.png)

Fig. 2. Structure of underground granary top in cutaway view.

All the flaring bins in two rows are arranged in respecting structure along the main channel, each bin have 10 meters from the center the main channel and opposite to the other one in the other row. The bins are separated with 25 meters. The main channel is 4 meters wide and 260 meters long, and the top vault is 5.52 meters high with earth covered thickness of 4 – 8 meters. The transportation vehicles can run in the channel, as shown in Figure 3.

Monitoring instrument in the granary

Temperature, humidity, insect development and mildew were inspected by means of computer control. (See Figure 4)

The detection system in the granary consisted of some detecting points along the vertically laid wire. The samples tested were collected by means of electrical wind sampler. The humidity in granary and main channel was remotely tested with a self-made resistance tester. There were arranged some hollow resistance earth thermometers in 4 – 6 meters long to detect the earth temperature in different stratum and to control the bin temperature by comparing grain temperature.

The transferring equipment in the granary

The transportation of the experimental grain was carried out with fixed or mobile equipment. There were three transporting lines in the granary, which can transport grain to special-purpose railway line through fixed conveyor belt combined with mobile or other vehicles.

Materials

Maize: Maize stored was in standard grade, and was 34000 tons in total. The moisture content was 15.4%, 15.7%, 16.2%, 16.5% respectively from 1981 to 1991, the dust content was less than 1.0%.

Wheat: 1300 tons of Canadian wheat was entered in 1981. Its moisture content, dust content, germination rate, gluten content and fatty acid value were 11.8%, 0.8%, 98%, 28.5% and 19.7mg KOH/100g, respectively. The wheat came from Canada.

Rice: Rice with high moisture was stored in the granary in 1985 and exited in 1988. The details refers to the experiment result.

Methods

In the north of China, the temperature changes in the scope of 5 – 20°C. Moreover the granary was constructed with integrated waterproof and damp-proof barrier and airtight door to form a well sealing condition. The effect from external humidity was completely segregated, thus the granary remained in a stable low temperature and low humidity all the year round.

Results and Discussion

Changes in earth temperature

Ground temperature was measured at points of 1, 2 and 4...
meters beneath the earth for average value. The co-ordinate system for temperature was shown in Fig. 5.

Fig. 5 showed that the highest temperatures for layers 1 or 2 meters deep in the ground reached 20°C and 15°C in August and September respectively. The temperature at layer 4 meters deep was very constant, normally about 12°C.

**Relationship of grain condition with the thickness of granary coverage**

The vault of the flaring underground granary looks like a spherical shell with coverage of 0.5 – 5.0 meters thick. Their relationship is shown in Fig. 6.

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**Fig. 3.** Layout of the underground granary.

**Fig. 4.** The Computer determining system in store

**Fig. 5.** The variety of the earth temperature and air temperature
Where \( H \) represents the total thickness of the coverage earth, normally 4.5–5.0 meters \( h \) means the thickest earth coverage on the arch, normally 0.5–1.8 meters. \( P \) is the grain level from bin arch \( L \) means the thickness of arch concrete plus damp-proof barrier (0.7 meters).

Table 1. Top layer grain temperature variation (°C).

<table>
<thead>
<tr>
<th>Bin No</th>
<th>Material</th>
<th>Moisture (%)</th>
<th>Entering time</th>
<th>( h )</th>
<th>Grain temp. variation (top layer) °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. E</td>
<td>Maize</td>
<td>17.1</td>
<td>Mar 1983</td>
<td>0.45 m</td>
<td>10 11 12 15 18 24 28 34</td>
</tr>
<tr>
<td>No. 4 W</td>
<td>Maize</td>
<td>17.1</td>
<td>Mar 1983</td>
<td>1.8 m</td>
<td>10 11 11 12 13 15 17 19</td>
</tr>
</tbody>
</table>

Table 1 showed that there is different temperature at different height \( (h) \) in same grain with same moisture.

Table 1 and Figure 6 showed that if granary is small, the distance \( (H) \) should be expanded and the grain level should be lowered.

Based on our many-year experiments, a formula was got as follows:

\[
S = H + L + P = 4.2 \text{ (meters)}
\]

\[
H + L = 2.3 \text{ (meters)}
\]

This is the best condition for practical grain storage. If maize moisture content is 15.5\%, it is more important for longer safe storage, because it can overcome the shortage of thinner coverage of the top layer during construction, expand the storage volume reasonably to ensure the storage stability.

**Temperature variation in stored grain temperature**

Variations in granary temperature was dependent in following four items, i.e., atmosphere, granary, top layer grain and middle and bottom layer grain temperature. The law of variation was as follows: air temperature affected earth temperature, earth temperature affected granary temperature and granary affected surface layer grain temperature. The grain temperature in middle and bottom layers of the barn was not affected by external condition. The result is shown in Fig. 7.

![Fig. 7](image)

Figure 7 showed the variation of four temperatures. When the atmospheric temperature reached more than 35°C in August and September, the temperature of the barn and the upper layer of stored grain reached maximum value. But the temperatures of barn and the top layer grain did not exceed 20°C and 15°C respectively. The temperature in the middle...
layer grain was kept at 10°C.

Maize stored in Yuanbaoshan underground granary should have 14.0% of safe moisture. Moisture content of maize during entering into the granary is 15.5%, 16.5%, 17%, 18%, respectively. From 1981 to 1991, the total experimental maize was 3400 tons. The experiment results are shown in Table 2.

<table>
<thead>
<tr>
<th>Year</th>
<th>Moisture content when entering (%)</th>
<th>Standard moisture content (%)</th>
<th>Quality (tons)</th>
<th>Moisture increase (%)</th>
<th>Grain weight increase (tons)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981-1985</td>
<td>15.7</td>
<td>14.5</td>
<td>27,000</td>
<td>1.2</td>
<td>324</td>
<td>average in 5 years</td>
</tr>
<tr>
<td>1986</td>
<td>15.5</td>
<td>14.5</td>
<td>7,000</td>
<td>1.2</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>15.4</td>
<td>14.5</td>
<td>5,000</td>
<td>0.9</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>16.2</td>
<td>14.0</td>
<td>10,000</td>
<td>2.2</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>15.4</td>
<td>14.0</td>
<td>6,000</td>
<td>1.4</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>16.5</td>
<td>14.0</td>
<td>8,000</td>
<td>2.5</td>
<td>72</td>
<td>exit in the second year</td>
</tr>
<tr>
<td>1991</td>
<td>15.3</td>
<td>14.0</td>
<td>1,0000</td>
<td>1.3</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>68,000</td>
<td>1.4</td>
<td>948</td>
<td></td>
</tr>
</tbody>
</table>

Practice and data tested have demonstrated that maize with moisture content below 15.5% could be safely stored for more than three years. Maize with moisture content between 15.5 - 16.5% could be stored for one year. Maize with moisture of 17.0 - 18% only could be stored for about half a year, and it was generally hard to spend summer.

**Storing experiment of maize**

Maize was stored in 1981 in low temperature seasons. Its moisture content was 15.8%, but that in top layer was 15.0%. After entering, it was distinctly sealed and was exported abroad in September 1985. Its moisture content tested during delivery was 15.7%, and was very fresh with normal tincture although it was stored about 5 years. The changes in maize in five years are shown in Figure 8.

Figure 8 showed that the top temperature is 15°C in the first year, 12°C in the second year, and below 10°C for the last three years. This temperature was kept constant at about 10°C.

![Fig. 8. The variation of the grain temperature in 5 years](image)

**Long-term storing experiment of wheat in underground granary**

We stored 1300 tons of wheat (moisture content 11.8%) imported from Canada to No 4 granary in April 1981. After being stored for 15 years, this wheat was took away at the end of 1994. During the storage period, this wheat had not been transferred from the granary to another. Figure 9 showed that wheat condition was very stable. Due to good airtight condition of the granary, although the air temperature in summer reached or exceeded 30°C, the grain temperature always kept at 10°C only a little variation as shown in Figure 9 and Table 3.
It was showed in Table 3 that wheat stored for 15 years had almost no changes in moisture and dust content, and had slight decrease in germination rate and gluten content and fatty acid value. All the above factors did not affect the usage for seeding and eating.

**Storing experiment of high moisture rice in underground granary**

*Storing high moisture rice in underground tunnel*

There was a tunnel with 200 meters long in No. 1 barn to be used to stored grain. But there was no damp-proof structure in the tunnel and the damp would enter easily. The relative humidity in air reached 90% in summer and maintained this value for about 2-3 months. We used polythene film (0.2mm thick) to seal the rice. The high moisture grain stored for one year was still good for scattering due to low temperature. The quality factors such as soluble nitrogen index, peroxide value, acidity, fatty acid value, viscosity, reducing sugar content, dry material in rice-cooking water and so on almost remained at the original level.

Rice with safe moisture content had been stored for 2-3 years, its moisture content, hardness, scatter features, colour, and taste were in accord with storage precondition. *Storing high moisture rice in underground granary*

Experiment for storing high moisture rice was began from 1985. High moisture rice is easily to be hot in summer, so that it became a key to safely store rice not use any cooling equipment.

**Storing experiment of sun-cured hot wheat in underground storehouse**

1400 tons of Canadian wheat with 12.1% of moisture was loaded into granary in August 1985 after curing. The averaged air temperature during entering was 28°C. After entrance, the average wheat temperature was about 30°C, the highest temperature is about 36°C. In the middle of October, the wheat temperature kept no change. In late October, wheat in the bottom or close to the wall became lower temperature and finally to 8-12°C at the end of October 1987. The results are shown in Figure 10.

![Figure 10](image-url)  
*Fig. 10. The change in temperature of sun-cured wheat entered in underground granary*
Storage in underground granary to prevent grain from damage by insects and rodents

Long term storage of grain in underground granary can control the insect. 1250 tons of exported wheat with averaged temperature of 29°C were stored in a surface storehouse in 1980. Before entering, the inspection report showed that there were no insects. But the grain temperature rose rapidly in December that year, then the top temperature reached 35°C and 43°C in January 1981. It was found that there were many insects like Sitophilus zeamais (Motschulsky) and Cryptolestes pusillus (schonherr) in the wheat. Thus we had to transfer the grain into another granary to reduce temperature in piles. In the middle of February, we stored the wheat screened in underground granary when the wheat temperature was 4°C. The population of zeamais and Cryptolestes pusillus was 10 - 12 heads/kg. In last 10 days March that year, temperature became 3°C, there were little Cryptolestes pusillus and 1 - 2 heads Sitophilus zeamais per kg. The top wheat temperature were kept at 5°C till 1982 and there was no any insects. This batch of wheat was taken away without any insects.

Prevention of evil by rodents

The breeding experiments with mice showed that rodents may live and breed if the stored grain with high moisture but mutual murdering and eating immature rodents often occurred. If moisture of the stored grain were less than 17%, the rodents entering the granary sometimes would die near the sealing door in one month because of lack of water. Optimal time for entering grain into granary and overturning or shifting

It is essential to select optimal time to enter the grain into the granary, to have grain over-turning or shifting either for high moisture grain stored. The temperature of the grain, atmosphere, upper layer earth and inner storehouse should be in good co-ordination. We Figure 11 showed some useful results from our study.

![Fig.11. Changes of 'Four' temperatures in the underground granary in 1 year](image)

Figure 11 showed that the intersection point of the four kinds of temperature in the big circle is the best optimal time in February and March for entering. In that period, the grain was in stable low temperature state which approached to the constant temperature (8 - 12°C), formed an ideal basic temperature without big temperature jump. This condition gave additional safety factor for long term storage in underground granary.

There is another temperature intersection point during the period between the beginning of October and middle of November in the right circle point in Fig 11. There was no new grain to be loaded at that time, so it is the best time for grain overturning and shifting.

The intersection point of the four kinds of temperature is the optimal opportunity for fill in silos and shift grain from silos to silos can be controlled by adjusting air and grain temperature based on earth temperature. The best time may be forward or backward to facility the grain temperature. For example, in winter when the grain temperature approached to earth temperature, about 7°C, the bottom door was closed and the upper opening was opened to let cold air into the barn. In this way the four factors would accord with or nearly accord with the demands of safe storage. The stored grain would have a stable basic temperature condition.

Application Vistas

Underground granary is a kind of very useful storehouse. It is very suitable to keep the freshness of grain and to long term grain storage, especially in big cities, it can be used for stored food grain in summer or for remaining fresh.

The advantages of the underground granaries are in its obvious economical and social benefits. The mountain areas,
especially in the loess plateau in China, have good condition to construct such granaries, but one should consider various factors, such as the traffic, grain production and grain exchange around it.

References


