The development of grain storage scientific and technical research in China and relevant theory exploration

Jin, Z.[1], Song, W.[1], Guo, D.[2], Lan, S.[2], Xu, H.[2], Tao, C.[2], Wang, H.[2], Tang, P.[2]
[1] School of food science and engineering, Nanjing University of Finance and Economics, Nanjing 210003, China
[2] Chengdu Grain Storage Research Institute, Chengdu 610031, China

* Corresponding author
# Presenting author

DOI: 10.5073/jka.2010.425.290

Abstract

China is a major grain producer as well as a major grain consumer in the world. Grain storage was always highly regarded, and a long history and abundant management experience of grain storage and relevant theory has been accumulated in China. The development of grain storage scientific research in China in the twenty-first century had been summarized in this paper. Grain-storage safety theory and the establishment of Chinese grain storage ecological system is also discussed. New ideas on grain-storage research for the future are also introduced.

Keywords: Grain, Storage, Theory, China

1. Development of strategies of science and technology of grain storage in China

When China enters into WTO, Chinese grain markets are brought into the international marketing system. With the increase of grain production, the task of storing and moving grain is much more critical. With the increase of quality requirements for grain, Chinese experts need to consider the following ideas (Jin, 2007: 2009):

(1) Development of scientific strategies of grain storage in the twenty-first century was to protect and make good use of grain, to increase the living quality of human beings, and to develop techniques of grain storage that reduce losses, pollution and costs, and maintain high quality, high nutrition, and high benefit;
(2) The science and technique of grain storage in China must insist on “human center and sustainable development”;
(3) Consideration of ensuring health of human beings, China should attach importance to green technology in food storage;
(4) Consideration of maintaining high quality of grain storage and the health of human beings, we should think much of building ecological grain storage;
(5) The science and technique of grain storage should realize globalizing grain and green storage.

1.1. The exploration and innovation of a guiding theory in grain storage

Since founding of the new P.R. China, tens of thousands of grain-storage workers using their intelligence, based on learning experiences from China and abroad, achieved a great accomplishment. “Grain Storage Science in China” has become a specialized discipline.

Chinese experts have always attached importance to research related to ecological problems in grain storage. Li Longshu, a master in this area began to research ecology of stored-grain insects in the 1940’s. He has done excellent research in this field and published many articles on the ecology of stored-grain pests, the ecosystem of grain bulks, and stored-product insect ecology. Under his guidance, Li Guangcan, Zhang Qingchun, Fan Jingan, Qin Zonglin and Yan Jian have submitted many research papers on the ecosystem of grain bulks. Zhao Zhimo and Wang Jinjun wrote a book about the ecology of stored-product insects in 1997 (Song et al., 2009). Lu Qianyu (1999) wrote a chapter to discuss ecosystems of stored grain and oil in her book. She described the composition, basic character information, environmental factors and flow of energy in the stored-grain ecosystem.

Jin Zuxun suggested the idea of choosing suitable types of cellars and reasonable storage measures under different ecological condition’ based on the nationwide investigation on potato storage in 1950’s. Since 1990's, he has worked on the concept of Grain Storage Safety Science. With China's continuous

improvement of grain-storage facilities and recently the development of strategies of grain-storage science and technology based on the Safety Science in China and the achievements of international grain-storage ecosystem (Figure 1) (Song et al., 2009). “Security control system of grain storage ecosystem” was implemented based on Grain Storage Safety Science, combined with security measures in squat silos and large warehouses built after 1998 (Figure 2).

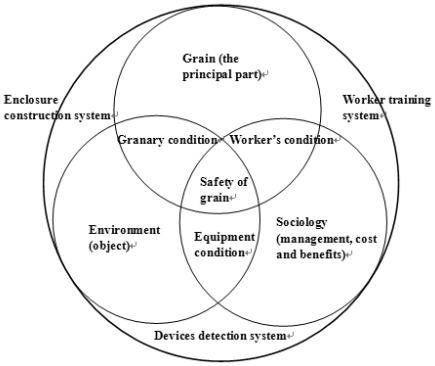

Figure 1 The schematic diagram of agricultural storage ecosystem

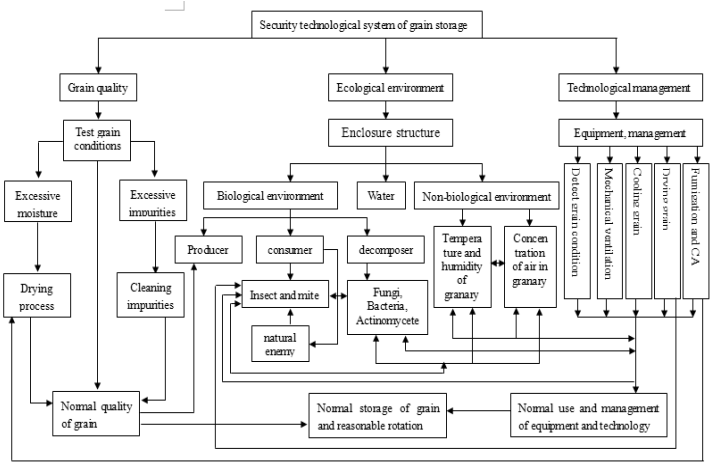

Figure 2 Security control system of grain storage ecosystem

Combined with bin construction and grain storage experience in China and Canada, and considering grain storage ecosystem and engineering ecosystem must be harmonious, Jin Zuxun suggested the idea of setting up “grain storage ecosystem theoretical system with Chinese characteristics“ (Song et al., 2009). Its main contents include:

(1) Definition of different ecological regions of grain storage in China;
(2) Scientific methods to select and designing the type of grain-storage warehouse in different ecological regions of grain storage;
(3) Scientific selection of grai- storage equipment for different ecological regions and different warehouse types;
(4) Development of science-based grain-storage technology and the optimal mode of economic operation in different ecological regions, different warehouse types and different grain species;
(5) Economic evaluation (management, cost-effectiveness and ecology) in different ecological regions, different warehouse type, different grain types and different storage technology;
(6) Security Technology Evaluation System of grain storage.

According to Jin Zuxun's advice, dozens of experts and scholars from research institutes and colleges studied the grain-storage ecosystem in China organized by the State Administration of Grain in the period of the tenth "five year plan", and achieved a number of gratifying results. The results have been the basis for constituting and revising the technical standards of grain storage in China (Song et al., 2009). The following are the main results:

1.1.1. Division of ecological regions of grain storage in China

Based on the climate, growing conditions, accumulated temperature and the relative humidity, China was divided into seven ecological regions. A schematic diagram had been designed as following Figures 3-6 and Table 1.

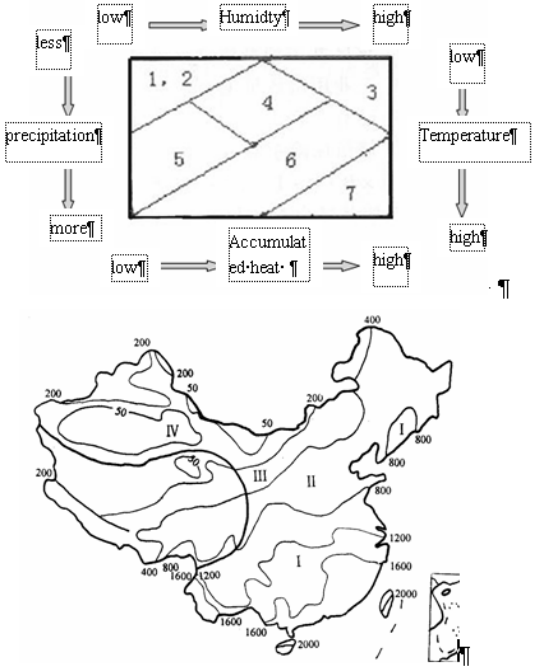

Figure 3 The climatic map of dry or wet based on climate and geographical conditions

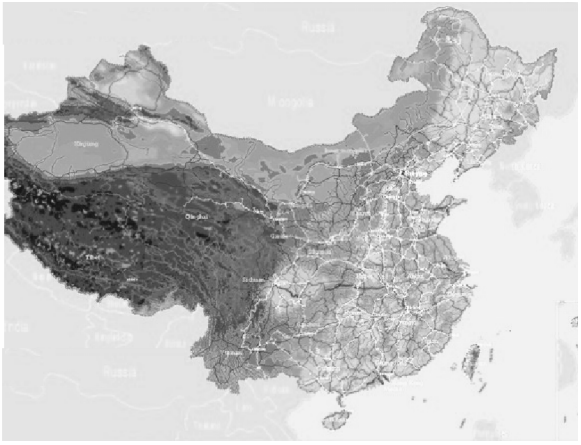

Figure 4 The geographic map based on climate and geographical conditions

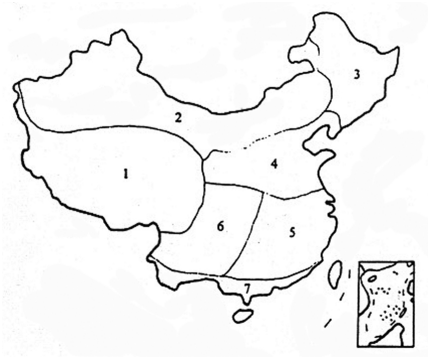

Figure 5 The climate regions based on accumulated temperature more than or equal to 10°C

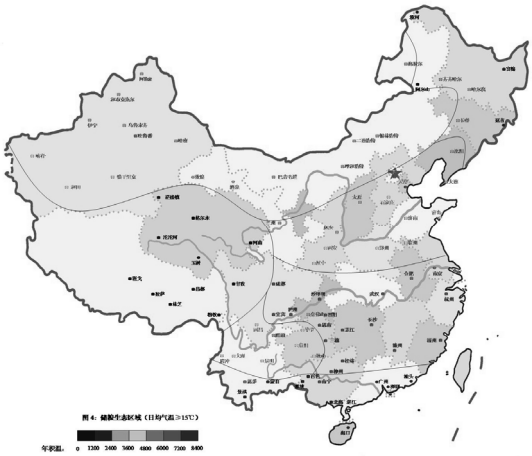

Figure 6 The ecological regions of grain storage based on daily average temperature more than or equal to 15°C

Table 1 The division of ecological regions of grain storage in China

	Region name	Ecological characters	Main technology of grain storage
1	Quite cold and drying region	The effective accumulated temperature that is higher than 15°C is 0~178 D·D. There are 112~194 d that temperature is higher than 15°C throughout the year. Annual precipitation less than or equal to 400 mm. The annual average relative humidity is in the range of 10%~90%. The temperature in January and July is in the range of -8~~20°C and 18~24°C , respectively. The main grain and oil crops are spring wheat, winter wheat and maize. The representational stored-grain pests are *Tribolium castaneum*, *Attagenus brunneus*, *Trogoderma variabile*, *Niptus hololeucus*, *Gibbium psylloides*, *Ptinus japonicus*, *Sitophilus granaries*. It is the most arid region in China. Sunshine and solar radiation is second only to the Qinghai-Tibet Plateau. Very cold and strong wind in winter and spring, is the most appropriate regions to store grain.	1. Drying with wind, airing and natural ventilation; 2. Low-temperature storage in drying season; 3. Waterproofing in rainy season.
2	Low-temperature and drying region	The effective accumulated temperature that higher than 15 °C is 626~2280 D·D. There are 0~70 d the temperature higher than 15°C. Annual precipitation less than 800 mm. The annual average relative humidity is in the range of 28%~90%. The temperature in January and July is in the range of 0~~16°C and 6~18°C , respectively. The main grain and oil crops are spring wheat, winter wheat and highland barley. The representational stored-grain pests are *Attagenus brunneus*, *Trogoderma variabile*, *Niptus hololeucus*, *Gibbium psylloides*. Thin air, solar energy and wind energy resources are extremely rich. Cold throughout the year, dry in dry season. It is one of the most appropriate regions to store grain, however, there is insufficient time to reduce moisture of high-moisture maize.	1. Drying with wind, airing and natural ventilation; 2. Natural low-temperature; 3. Treating high moisture grain with drying with wind, airing and ventilation at the end of spring or the beginning of summer; 4. Airproofing after using protectant before summer; 5. Using grain cooler in special regions of Xinjiang if necessary.
3	low-temperature and high humidity region	The effective accumulated temperature that higher than 15°C is 223~819 D·D. There are 55~122 d with temperature higher than 15°C throughout the year. The annual average relative humidity is in the range of 22%~90%. The temperature in January and July is in the range of -12~~30°C and 19~24.5°C , respectively. The main grain and oil crops are wheat, maize and soybean. The representational stored-grain pests are *Sitophilus zeamais*, *Oryzaephilus surinamensis*, *Tenebroides mauritanicus*, *Tribolium castaneum*. It is the coldest region in China. The climate is cold and wet. There is insufficient time to reduce moisture of high-moisture maize.	1. Mechanical ventilation and tumble dry; 2. Natural ventilation; 3. Drying with wind, airing, ventilation and tumble dry at the end of spring or the beginning of summer; 4. Waterproofing after using protectant before summer.
4	middle temperature and drying region	The effective accumulated temperature higher than 15°C is 828~1690 D·D. There are 143~192 d the temperature higher than 15°C throughout the year. Annual precipitation is in the range of 400~800 mm. The annual average relative humidity is in the range of 13%~97%. The temperature in January and July is in the range of 0~~10°C and higher than 24°C , respectively. The main grain and oil crops are winter wheat, maize and soybean. The representational stored-grain pests are *Sitophilus zeamais*, Gelechiidae, *Plodia interpunctella*, *Oryzaephilus surinamensis*, *Tenebroides mauritanicus*, *Tribolium castaneum*. Cold and dry in winter are favorable conditions to store grain, but high temperatures and wet are unfavorable conditions.	1. Drying after harvest in summer; 2. Airing, ventilation and tumble dry the high-moisture maize; 3. Natural low-temperature; 4 Treat the high-moisture maize with air-cure and ventilation next summer; 5 Waterproofing after using protectant before summer; 6 Pay attention to the situation of stored grain in summer.

	Region name	Ecological characters	Main technology of grain storage
5	middle temperature and high humidity region	The effective accumulated temperature higher than 15°C is 1029~3180 D·D. There are 121~253 d the temperature higher than 15°C throughout the year. Annual precipitation is in the range of 800~1600 mm. The annual average relative humidity is in the range of 34%~98%. The temperature in January and July is in the range of 0~~10°C and near 28°C , respectively. The main grain crops are winter wheat and paddy. The representational stored-grain pests are *Sitophilus zeamais, Rhizopertha dominica*, Gelechiidae, *Cryptolestes pusillus*, *Oryzaephilus surinamensis*, *Tenebroides mauritanicus*, *Tribolium castaneum*. The most rain of China occurs in spring, and the hottest period of the eastern hemisphere is in summer. The high temperature and moisture is unfavorable to grain and oil storage. there is insufficient time to reduce the moisture content of late paddy.	1. Mechanical ventilation and tumble dry after harvest; 2. Ventilation to lower the temperature in spring and winter; 3. Drying high moisture grain next spring; 4. Waterproofing after using protectant before the temperature rise; 5. Fumigation; 6. Pay attention to the situation of stored grain in summer, and take measures timely.
6	middle temperature and low humidity region	The effective accumulated temperature higher than 15°C is 724~1037 D·D. There are 173~224 d the temperature higher than 15°C throughout the year. Annual precipitation is about 1000 mm. The annual average relative humidity is in the range of 30%~98%. The temperature in January and July is in the range of 2~10°C and 18~28°C , respectively. The main grain and oil crops are winter wheat, maize and paddy. The representational stored-grain pests are *Sitophilus zeamais, Rhizopertha dominica*, Gelechiidae, *Cryptolestes pusillus*, *Oryzaephilus surinamensis*, *Tenebroides mauritanicus*, *Tribolium castaneum*. Winters are warm, and summers are hot. More rain and fog in a humid climate; high humidity with little sunshine.	1. Mechanical ventilation and tumble dry after harvest; 2. Fumigation; 3. Ventilation to lower the temperature in spring and winter; 4. Waterproofing after using protectant before the temperature rise; 5. Pay attention to the situation of stored grain in Sichuan Basin, and take measures timely.
7	high temperature and high humidity region	The effective accumulated temperature higher than 15°C is 1566~3476 D·D. There are 289~352 d the temperature higher than 15°C throughout the year. Annual precipitation is in the range of 1400~2000 mm. The annual average relative humidity is in the range of 35%~98%. The temperature in January and July is in the range of 10~26°C and 23~28°C, respectively. The main grain and oil crops are winter wheat, maize and paddy. The representational stored-grain pests are *Sitophilus zeamais, Rhizopertha dominica*, Gelechiidae, *Cryptolestes pusillus*, *Oryzaephilus surinamensis*, *Tenebroides mauritanicus*, *Tribolium castaneum*. Long summers without winter. This is the wettest and hottest region in China. Stored-grain pest problems are serious and it is the most difficult region for grain storage.	1. Ventilation or high temperature drying timely; 2. Fumigation timely if find pests; 3. Ventilation to lower temperature and moisture in dry season, then using protectant; 4. Using special facilities to lower temperature and dehumidification; 5. Using the warehouse with the functions of lower temperature, dehumidification and fumigation.

1.1.2. Scientific selection of warehouse type based on the grain storage region

After much research, the design institutes recommended for the first, second, third and fourth grain-storage regions in China that the squat silo and large warehouse should be built; however, in shipping ports or terminal elevators, the squat silo and upright silo should be built. Considering that the most important source of heat to the grain bulk will come from the roof of the warehouse, we must attach great importance to the issue of warehouse roof insulation.

1.1.3. The machines and special equipment needed

The machinery and special equipment in different types of granary ensure the high quality of stored grain (Table 2).

Table 2 The machines and special equipments in different type of granary

Type of granary	machines and special equipments in granary
Large warehouse	Handling equipment, Conveying equipment, Weighing equipment, Cleaning equipment, Palletizing equipment; Detection system, Ventilation system, Fumigation system, Cooling system, Controlled atmosphere system, Security system, Granary management and pest and mold controlling expert system.
Squat silo	Conveying equipment in the top and bottom of granary. Hoisting equipment, Weighing equipment, Cleaning equipment, Dust removal equipment and Control equipment in the tower. Binning equipment, Cleaning equipment, Conveying equipment, Cleaning equipment, Measurement and control system, Ventilation system, Recirculation fumigation system, Cooling system, Security system, Granary management and pest and mold controlling expert system.

1.1.4. The best pattern of economic operation

The best pattern of economic operation in different grain-storage regions, different types of granaries and different grain species is shown in Table 3.

The best pattern of economic operation is to make full use of natural and mechanical ventilation to lower grain temperature, insulation to keep the grain cool during the summer, fumigation if necessary. To prevent condensation, timely ventilation will lower temperature and moisture when weather turns colder throughout the entire country.

Table 3 The reasonable technology of grain storage and the best pattern of economic operation in different grain storage region

Ecological region	The reasonable technology of grain storage and the best pattern of economic operation
1	Cold and dry throughout the year in the region, and wind energy resource is rich, so it is necessary to take full advantage of natural ventilation and low temperature storage. To improve the insulation of the warehouse. Mainly using natural ventilation, supported by mechanical ventilation. The grain temperature is always below 15°C throughout the year. Local fumigation can be carried out, and also can use grain protectants in order to prevent local heating or vermin (natural ventilation + mechanical ventilation + local fumigation + protectant).
2	Taking full advantage of low temperature conditions, low temperature grain storage was carried out in this region. Mainly using natural ventilation especially in winter, at the same time, protectant can be used in whole bin or the surface of grain bulk to control pest. If necessary, the techniques of mechanical ventilation and so on can be used. Grain storage underground is a good method to store grain. The temperature underground about 15 m is 8°C, and it is a nice environment to low temperature grain storage.
3	Three time natural or mechanical ventilation from late September to next January. Grain surface gland, heat sealed to keep cool from June to September. Keeping grain temperature in low-temperature (under 15 °C) or quasi-low-temperature (under 20 °C) throughout the year. If find grain temperature rising in the whole bin or just in local, grain cooler should be used to cooling grain temperature.
4	The best pattern of economic operation in this region: Mechanical ventilation in winter and heat insulation in summer (wheat, paddy and maize); Mechanical ventilation in winter, protectant and heat insulation in summer (wheat, paddy and maize); Mechanical ventilation in winter, heat insulation in summer and fumigation (wheat, paddy and maize); Natural ventilation in winter, heat insulation in summer and fumigation (wheat); Natural ventilation in winter, protectant and heat insulation in summer (wheat); Mechanical ventilation in winter, heat insulation in summer and grain cooler (special requirements on the quality).
5	Natural ventilation, Mechanical ventilation, aeration with grain cooler and detection of grain conditions. Keep grain temperature under 15 °C or 20 °C through Natural ventilation and Mechanical ventilation. If necessary using grain cooler or large-scale air-conditioning to keep grain safety.
6	Mainly mechanical ventilation, if necessary, complemented by grain cooler in the State depots. Natural ventilation with a combination of mechanical ventilation to reduce power consumption in other depot. Automatic-control systems were used in mechanical ventilation.
7	Large warehouse: natural ventilation, fumigation with low dose phosphine, protectant and detection of grain conditions; Squat silo: natural ventilation, mechanical ventilation, aeration with grain cooler, recirculation fumigation, protectant and detection of grain conditions.

1.1.5. Economic evaluation in different grain storage regions and grain storage technology

The economic evaluation of grain-storage techniques can not be separated from management, cost and benefit analysis. The choice warehouse type also can not be separated from economic evaluation. Scientific and economic management is the key to lowering grain-storage costs and increasing economic, social and ecological benefits.

1.1.6. Research on evaluation system for grain storage security technology

Using the theory of grain-storage ecosystems and grain-security science as a guide, with consideration of the condition of the stored grain, climate of the grain-storage region, condition of storage facilities and ecological environment conditions of the grain bulk, we conduct a comprehensive evaluation of the grain-storage security technology using specific scientific guidelines. The evaluation methods proposed by scientists in this project are credible and have been validated in the field in different granaries and different grain-storage regions.

2. A proposal about worldwide ecological grain storage

According to Jin Zuxun's proposal (2007), an information platform about the stored-grain ecosystem should be developed. The main components should include:

(1) Grain ecology (the character and quality of grain, ecological factors): Characterize the effects of different ecological factors on preserving grain quality;
(2) Ecological environment of grain bulks (grain bulk and ecological factors): Characterize the effects of different ecological factors and different physical methods, such as aeration on preserving grain quality;
(3) Grain-storage ecology: research on the effects of storage structures, ecological factors, physical techniques and management measures on preservation of grain quality and rule of energy changing on the process of grain storage;
(4) Long-term research on grain storage ecology.

i. Chemical ecology of grain storage: Research on the relationships between grain and other biological factors or among the biological factors, the structures and functions of natural substances and their effects on safety of stored grain in the stored-grain ecosystems;

ii. Mathematical ecology of grain storage: Research on the relationships between grain and ecological factors or among the ecological factors, and the mathematical expression of the dynamics of relationships of matter and energy in the stored-grain ecosystems;

iii. A branch of engineering ecology: Research on the harmony of natural ecosystems and engineering ecosystems. Engineering ecology is the branch of applied ecology that focuses on the application of ecology in the area of engineering planning, construction and management. Grain-storage project ecology focuses on the harmony of natural ecosystems and engineering ecosystems and makes them harmonious to ensure the preservation of stored-grain quality;

iv. Grain-storage ecology and health: The purpose of stored-grain ecosystem research is not only to reveal the relationships of stored grain and ecological factors, but also to characterize the flow of material and energy, to decrease postharvest losses of grain (include the loss during storage) but also urging ecosystem and engineering systems to harmonize, allowing better use of natural resources and protecting the environment, enhancing the stability of stored grain, maintaining high quality and ensuring health of people by controlling ecological factor and managing engineering ecology.

We have designed many cooperative projects to exchange information. We hope that all the colleagues in the world can cooperate and support each other to contribute to reduce post-harvest of grain losses in the world. China is the developing county with the largest population in the world, and we deeply hope to get your supports and help in the project of stored grain.

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