The great achievement of grain storage scientific research in China

Li Lungshu\(^1\), Jin Zuxun\(^2\)

The 7th IWCSPP will be held in China. This is a great event for scientists of grain storage in China at the end of this century. Not only will we warmly welcome our friends from all over the world, but also we want to take advantage of the chance to introduce the achievement of scientific research of grain storage in China. We believe it is useful for each of our guests to know about the current development in China.

As you may have already seen, we published an English book named "Chinese Grain Storage" which was written by more than ten experts. Jin Zuxun's paper "A Retrospect of the Development of China's Grain Storage Scientific Research," published at 'Journal of the Chinese Cereals and Oils Association' special 1997, was also sent to each of you.

At present, the general condition is that China has an extremely long history of grain storage technique. During the past fifty years, China has made delightful achievements in the grain storage scientific research. The great progress in grain storage technique and facilities is due to scientific research achievements. I would like to give you a brief introduction on three topics as follows:

- **A Retrospect of History of China’s Grain Storage**
  - **1. Grain**
    - **1.1 The paddy which was first excavated is 10000 years ago in Dao County, Hunan Province**
    - **1.2 The millet which was first excavated is 8000 to 7500 years ago in Ci-shan County, Hebei Province**
    - **1.3 The wheat which was first excavated is 5000 years ago in Min-le County, Gansu Province**
    - **1.4 The sorghum which was first excavated 5600 years ago in Zhengzhou, Henan Province**
    - **1.5 The soybean which was first excavated 2300 years ago in Hou-ma County, Hubei Province**
    - **1.6 The maize which was first excavated 2000 years ago in Xing-yang County, Henan Province**
  - **1.2 Grain Storage Facilities (real object)**
    - **1.2.1 The ‘frame-style’ grain storage facilities (house made of wooden bars for the purpose of good ventilation and moisture control), which came into use 7000 years ago in Yu-yao County, Zhejiang Province**
  - **1.3 Grain Storage Implements (Funerary Objects)**
    - **1.3.1 Horizontal warehouse with windows on the top for ventilation and frame at the bottom for easy air circulation, beginning Han Dynasty, 206B C - 206B C**
    - **1.3.2 Multi-stoned grain warehouse. beginning Han Dynasty 206B C - 220A D (four-stoned house, excavated from Jiaozuo, Henan Province. Three-stoned house, excavated from Yiyang County, Henan Province. Two-stoned house, excavated from Pinggu County, Beijing City)**
    - **1.3.3 Dumpy grain bin, excavated from Henan Province originating in 206B C - 220A D**
    - **1.3.4 Dome style grain warehouse, excavated from Henan, Huns, Hubei, Anhui, Guangdong, Beijing, Jiangsu, Gansu Provinces originating in 206B C - 220A D**
  - **1.4 Experience of Management**
    - **In China's Xia and Shang Dynasties, grain production was already advanced. By the Qin and Han Dynasties, much experience had been accumulated concerning the grain storage management**
      - **1.4.1 Each Chinese dynasty paid attention to the grain accumulation**
      - **1.4.2 Each Chinese dynasty paid great attention to management and adjustment functions of the storage system**
      - **1.4.3 Each Chinese dynasty paid great attention to implementation of grain storage techniques and policies**

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XXXXX
ancient China proposed one year storage for three years cultivation

- On the minimum norm of grain preservation loss
- On the disposal of old grain and change for the new
- On the storage of paddy instead of rice

1.4.4 Each Chinese dynasty paid great attention to the development and improvement of grain storage technique

- The grain depot facilities for draft which came into use 7000 years ago
- Application of natural plant as protectants in stored grain (for the former, see book of Fan-sheng, for the latter, see the Rites of Zhou), the former starting in 206B C – 220A D, the latter starting in 1100B C – 771B C
- Technique of rodents control, beginning 2 6B C, – 220A D (Sichuan Province, Han Dynasty grain storage depots with pictures on the bricks)
- Design and construction of warehouse, see Agriculture Book of Wang-zhen in Ming Dynasty

Grain quality and quality control, beginning 206B C – 220A D

Table 1 Regional Fauna Investigation of Stored Pests

<table>
<thead>
<tr>
<th>Order</th>
<th>Researchers</th>
<th>Species</th>
<th>Investigation time</th>
<th>Publishing year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bureau of Grain Storage and Transport of the Food Minstry</td>
<td>43</td>
<td>1955</td>
<td>1957</td>
</tr>
<tr>
<td>2</td>
<td>Bureau of Grain Storage and Transport of the Food Minstry</td>
<td>59</td>
<td>1957</td>
<td>1959</td>
</tr>
<tr>
<td>3</td>
<td>The food Minstry and Research Institute of Entomology of the China Academy of Science</td>
<td>63</td>
<td>1956 – 1958</td>
<td>1959</td>
</tr>
<tr>
<td>5</td>
<td>The Food Minstry and the Minstry of Forestry and Agriculture</td>
<td>194</td>
<td>1980 – 1982</td>
<td>1983</td>
</tr>
</tbody>
</table>

By the end of 1995, 242 species of stored product insects had been found in whole China. The insects belong to the following 10 Orders, 52 Families and 143 Genes. Among these insects, 140 species are stored grain insects, in which 128 species are pests and 12 species are natural enemy insects.

2.1.1.2 Research on biology of stored grain pests

From the 1950's to present, many Chinese entomologists have been researching the insect biology, which includes insect life cycle, life span, generation number per year, feeding habits, place of living through winter, methods and behaviors of reproduction, etc. The following species' biology have been studied by Chinese specialists:

- *Sitophilus zeamais* (Motschulsky)
- *Sitophilus oryzae* (L.)
- *Sitophilus granarius* (L.)

2.1.1.3 Research on ecology of stored grain pests

From the 1930's, our entomologists had studied the influence of different entomological condition on growth and reproduction of stored grain pests. Since the 1970's, the research has been made more thorough, including:

- Entomological system of stored grain
- Physics entomology of stored-grain pests
- Community entomology of stored-grain pests
- Math entomology of stored-grain pests
- Economic entomology of stored-grain pests

2.1.2 The classification and identification of stored-grain pests

Chinese specialists have made lots of classification and identification for stored-product pests investigation and the related research:

- 1931 – 1973, classification and identification according...
to morphological observation
• 1974-present, applying comparative anatomy along with morphology observation
• Observing chromatin of pests and their hybrids
• Classification and identification by gas chromatography, scanning electron microscope
• Identification by enzyme chemistry

2 1 3 Research on stored-grain pests resistance
• Research on resistance of primary stored-grain pests to phosphine (PH₃)
• Studies on resistance of primary stored-grain pests to common pesticides in China
• Studies on cross-resistance of Sitophilus zeamais (Motschulsky) to a few organic phosphine protectants
• Studies on counter-measure of stored-grain pests resistance

2 1 4 Research on stored-grain mites

2 1 4 1 Investigation and classification of stored-grain mites
From 1957, some specialists have investigated stored-grain mites, and recorded principle stored-grain mites in China, which including
Tyrophagus putrescentiae (Schrank)
Aleuroglyphus oratus (Troupeau)
Suidasia neebitti Hughes
Carpropylus lactus (L )
Lepidoglyphus destructor (Schrank)
Cheyletus malaccensis Oudemans
More than 100 species stored-grain mites have been recorded in China, which belong to Acarida, Orbatida, Actinedida and Gamasida In these mites there are 60 species of acarid mites and 10 species of cheyletida mites

Table 2. The important mold of Chinese grain microflora

<table>
<thead>
<tr>
<th>Ecological type</th>
<th>Mold name</th>
<th>Paddy</th>
<th>Wheat</th>
<th>Maize</th>
<th>Peanut</th>
<th>Rape seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filled fungi</td>
<td>Alternaria</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Fusarium</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Phoma</td>
<td>3</td>
<td>+</td>
<td></td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Cladosporium</td>
<td>6</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Halmithosporium</td>
<td>5</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Nigrospora</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Epichium</td>
<td>+</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chaetomium</td>
<td>+</td>
<td>+</td>
<td>5</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Cephalosporium</td>
<td>+</td>
<td>+</td>
<td>2</td>
<td>+</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Trichotheicum</td>
<td>+</td>
<td>5</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Trichotheicum</td>
<td>+</td>
<td>+</td>
<td>6</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Rhiocchio</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stored fungi</td>
<td>Aspergillus</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Penicillium</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rhiopsus</td>
<td>4</td>
<td>4</td>
<td>+</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mucor</td>
<td>3</td>
<td>3</td>
<td>+</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

* * 1.2 Dominant genera and their order of importance
+ Common genera
2152 Studies on factors of rice yellowing and reddening
2153 Studies on the influence of various stored
techniques on succession patterns of grain
  microbe
  • Relation between stored-product fungi and grain
  quality
  • Succession patterns of stored-grain microorganism in
  controlled atmosphere storage
  The influence of fumigants on stored-grain microbe
  • The influence of protectants on stored-grain microbe
  • The influence of draft, cooling and drying on stored-
  grain microbe
216 Mycotoxins of stored grain
  Mycotoxins found in grain in China are mainly aflatoxins
  and fusarium toxins, sterigmatocystin (ST) and Ochratoxin
  A (OA) are found at intermediate frequencies.
  Research works on wheat scab has been developed in
  China since the 1950’s. Since the 1970’s, the main research
  works on grain mycotoxins are
2161 Studies on aflatoxins forming, damage degree,
detective methods, and mechanism and methods
of detoxification
2162 Isolation, purification and identification Don from
  gillerella damage wheat, setting up thin layer
  chromatography (TCL) for determination of Don,
  establishing enzyme-linked immuruty-sorbent
  assay (ELISA) for determination of T-2 in wheat,
  establishing monoclonal antibody and an
  immunological assay of wheat F-2 toxins
2163 Isolation, purification and identification of
  sterigmatocystin (ST) and establishing ST thin
  layer chromatography
2164 Establishing determination and methods of
  Ochratoxin A (OA)
217 Studies on grain quality
  Much research work has been done on quality of main
  grains since the 1950’s. Since the 80’s, comprehensive and
  system research has been done
2171 Comprehensive investigation on grain quality in
  China

Table 3. Comprehensive investigation on grain quality in China

<table>
<thead>
<tr>
<th>Kind of cereals</th>
<th>Investigation time</th>
<th>Investigation scopes</th>
<th>sample</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Commodity samples</td>
<td>Species samples</td>
</tr>
<tr>
<td>Paddy</td>
<td>1982-1984</td>
<td>14 provinces and regions</td>
<td>3223</td>
<td>920</td>
</tr>
<tr>
<td>Wheat</td>
<td>1982-1984</td>
<td>11 provinces and regions</td>
<td>2523</td>
<td>314</td>
</tr>
<tr>
<td>Maize</td>
<td>1985-1987</td>
<td>14 provinces and regions</td>
<td>615</td>
<td>113</td>
</tr>
<tr>
<td>Bean</td>
<td>1983-1985</td>
<td>13 provinces and regions</td>
<td>1335</td>
<td>195</td>
</tr>
</tbody>
</table>

2172 Studies on quality characteristic of Chinese grain
  • Paddy Major research on relation of amylase content
    and physical character between technological quality and
    edible quality
  • Wheat Main research on relation of wheat unit between
    flour yield, relation of wheat sedimentation value
    between edible technological quality, bringing forward
    regression equation for appraising quality
  • Soybean It is proved that 65% marks can be regarded as the standard
    for grain being out of granary in rotation, but if the fatty
    acid value > 25mg KOH/100g (dry sample) or viscosity
    value > 30 CST, it also can be regarded to be out of
    granary in rotation

218 Research on the index of deterioration
  Chinese experts had done lots of research works on
deterioration index of grain quality in the 1980’s, and
researched the possibility of valuing and controlling storage
grain quality of cereals and their processing products by regression
equation. Researchers had determined great deal of species
samplers from different areas, different number of storage
years and different storage conditions, got related data, and
obtained regression equation based on edible quality, of
which the best precision is

• Paddy
  Long-grain nonglutinous paddy
  \[ Y_L = 65.7 + 0.07X_{\text{gluten}} - 0.25X_{\text{fatty acid value}} + 1.70X_{\text{viscosity}} \]
  Short-grain nonglutinous paddy
  \[ Y_S = 80.63 + 0.005X_{\text{gluten}} - 0.61X_{\text{fatty acid value}} \]
  It is proved that 65% marks can be regarded as the standard
  for grain being out of granary in rotation, but if the fatty
  acid value > 25mg KOH/100g (dry sample) or viscosity
  value > 30 CST, it also can be regarded to be out of
  granary in rotation

• Maize
  \[ Y_{\text{cor}} = 75.5 + 0.10X_{\text{gluten}} - 0.34X_{\text{fatty acid value}} \]
  If the score over 80 marks is suitable
  for long storage, the score of 65 is the basic standard
  for corn being out of granary in rotation

• Soybean It is proved that PST (total of soluble
  phosphatide / total phosphatide ) can be used as staleness
It is known that PST has a positive relativity with NSI (water-soluble nitrogen index) and germination, but has a negative relativity with acid value, the relative coefficients were 0.89, 0.64 and −0.86.

Table 4. Lethal concentration and time of PH₃ to several stored-product insects

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature (°C)</th>
<th>Action time (h)</th>
<th>Lethal concentration (mg/l)</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitophilus oryzae (L)</td>
<td>30</td>
<td>72</td>
<td>0.029</td>
<td>Shanghai grain research institute</td>
</tr>
<tr>
<td>Sitophilus zeamaa (Motschulsky)</td>
<td>26–29</td>
<td>72</td>
<td>0.018–0.020</td>
<td>Zhengzhou grain college</td>
</tr>
<tr>
<td>Rhizopertha dominica</td>
<td>25–30</td>
<td>48</td>
<td>0.038</td>
<td>Shanghai grain research institute</td>
</tr>
<tr>
<td>Lasioderma serricornis (F)</td>
<td>20–29</td>
<td>72</td>
<td>0.020</td>
<td>Zhengzhou grain college</td>
</tr>
<tr>
<td>Tribolium castaneum</td>
<td>20–29</td>
<td>72</td>
<td>0.027</td>
<td>Zhengzhou grain college</td>
</tr>
<tr>
<td>Oryzaephilus surmimensis L</td>
<td>20–29</td>
<td>72</td>
<td>0.022–0.025</td>
<td>Zhengzhou grain college</td>
</tr>
<tr>
<td>Trogoderma granarium</td>
<td>25–30</td>
<td>48</td>
<td>0.040</td>
<td>Shanghai grain research institute</td>
</tr>
</tbody>
</table>

Table 5. Adsorption of various cereals to PH₃ (%)

<table>
<thead>
<tr>
<th>Name</th>
<th>Temperature (°C)</th>
<th>Action time (h)</th>
<th>Lethal concentration (mg/l)</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>89</td>
<td>0</td>
<td>65.1</td>
<td>Flour</td>
</tr>
<tr>
<td>Peanut</td>
<td>86</td>
<td>1</td>
<td>50.1</td>
<td>Rapeseeds</td>
</tr>
<tr>
<td>Long-grain non-glutinous paddy</td>
<td>82</td>
<td>8</td>
<td>41.4</td>
<td>Red bean</td>
</tr>
<tr>
<td>Kidney bean</td>
<td>80</td>
<td>7</td>
<td>33.8</td>
<td>Yellow bean</td>
</tr>
<tr>
<td>Glutinous paddy</td>
<td>79</td>
<td>3</td>
<td>31.2</td>
<td>Green bean</td>
</tr>
<tr>
<td>Sesame</td>
<td>68</td>
<td>4</td>
<td>28.8</td>
<td>Broad bean</td>
</tr>
</tbody>
</table>

Table 6. Synergism of lowering O₂ and increasing CO₂ in atmosphere to PH₃

<table>
<thead>
<tr>
<th>Insect species</th>
<th>Common atmosphere LC₅₀</th>
<th>O₂ 12% , CO₂ 4% in atmosphere</th>
<th>Synergism coefficient</th>
<th>O₂ 4% , CO₂ 8% in atmosphere</th>
<th>Synergism coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitophilus oryzae (Chuan F22)</td>
<td>0.0115 (0.0105–0.0125)</td>
<td>0.0089 (0.0078–0.0099)</td>
<td>1.29 (0.0028–0.0051)</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Sitophilus oryzae (Guang S12)</td>
<td>0.8638 (0.8321–0.8342)</td>
<td>0.5224 (0.5110–0.5338)</td>
<td>1.65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sitophilus zeamaa (Chuan F9)</td>
<td>0.0079 (0.0068–0.0089)</td>
<td>0.0063 (0.0053–0.0074)</td>
<td>1.25 (0.0037–0.0059)</td>
<td>1.64</td>
<td>1.64</td>
</tr>
<tr>
<td>Rhizopertha dominica (RRd4)</td>
<td>0.0058 (0.0048–0.0068)</td>
<td>0.0045 (0.0030–0.0060)</td>
<td>1.29 (0.0020–0.0041)</td>
<td>1.93</td>
<td>1.93</td>
</tr>
<tr>
<td>Rhizopertha dominica (RRd7)</td>
<td>0.0077 (0.0067–0.0086)</td>
<td>0.0054 (0.0037–0.0070)</td>
<td>1.42 (0.0024–0.0045)</td>
<td>2.20</td>
<td>2.20</td>
</tr>
<tr>
<td>Oryzaephilus serricornis (ROS1)</td>
<td>0.0057 (0.0046–0.0068)</td>
<td>0.0043 (0.0032–0.0054)</td>
<td>1.32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oryzaephilus serricornis (Res2)</td>
<td>0.0059 (0.0048–0.0070)</td>
<td>0.0041 (0.0031–0.0052)</td>
<td>1.44</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tribolium castaneum (RTc4)</td>
<td>0.0082 (0.0072–0.0093)</td>
<td>0.0071 (0.0061–0.0080)</td>
<td>1.15 (0.0042–0.0062)</td>
<td>1.58</td>
<td>2.22</td>
</tr>
<tr>
<td>Tribolium castaneum (RTc6)</td>
<td>0.0089 (0.0079–0.0099)</td>
<td>0.0065 (0.0055–0.0075)</td>
<td>1.37 (0.0030–0.0051)</td>
<td>2.22</td>
<td>2.22</td>
</tr>
</tbody>
</table>

1 Synergism coefficient = Common atmosphere LC₅₀ - Control atmosphere LC₅₀ 2 Intense resistance strain
### Table 7. Dosage, tightness time, releasing time and the lowest gram temperature of PH₃ fumigation

<table>
<thead>
<tr>
<th>Medicine name</th>
<th>Purity (%)</th>
<th>Dosage (g/m³)</th>
<th>The least time of freeing gas (days)</th>
<th>The lowest temperature of fumigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Space</td>
<td>Grain bulbs</td>
<td>Factory and apparatus</td>
<td>Tightness time after dispensing</td>
</tr>
<tr>
<td>Aluminum</td>
<td>56</td>
<td>3 - 6</td>
<td>6 - 9</td>
<td>4 - 7</td>
</tr>
<tr>
<td>phosphide(table)</td>
<td>1 - 5 - 2</td>
<td>over 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>85 - 90</td>
<td>2 - 4</td>
<td>4 - 6</td>
<td>3 - 5</td>
</tr>
<tr>
<td>phosphide(powder)</td>
<td>1 - 1 - 5*</td>
<td>over 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc phosphide</td>
<td>90</td>
<td>3 - 6</td>
<td>8 - 13</td>
<td>5 - 10</td>
</tr>
</tbody>
</table>

* low dosage fumigation, which uses low O₂, slow releasing, airflow and intermittent fumigation at long tightness time

### 2.2 Research on applied technique

#### 2.2.1 Technique of stored-grain control

##### 2.2.1.1 Technique of chemical control

**A Fumigants**

Our country usually used phosphine (PH₃) as fumigants, and have done great deal of research work since the 1960's. Chloropicrin had been used in the 1950's, it is seldom used at present. Methyline is mainly used in quarantine fumigation.

Research on PH₃ including:

- Efficient (dosage, tightness time, control result)
- Factors of effecting efficient (different species, various stage, different temperature, absorbability of grains to PH₃, granary of different sealed condition and performance, airflow in gran bulks)
- Gas diffusion law of horizontal warehouse and silos
- Toxicity of PH₃ to human being
- The synergism of lowering O₂ content and increasing CO₂ content to common pests
- Operational methods of different PH₃ fumigation techniques (controlled atmosphere fumigation, airflow fumigation, circulation fumigation, intermittent fumigation and slow releasing fumigation)
- Dispensing apparatus
- Combustion condition and preventing

**B Protectants**

The thorough research on protectants began from the 1950's. Protectants which we had researched in the 1970's were malathion, fenithrothion, pirimphos-methyl, deltamethrin and mixture of organophorous with dltamethrin. About the cereal protectants being used in China at present, please see table 8.

#### 2.2.1.2 Technique of non-chemical control

##### 2.2.1.2.1 Research on technique of physical control

**A. Low temperature control by refrigeration** At ~ 5°C ~ ~ 6°C and keeping the temperature about a week, pests in grain can be effectively killed.

**B. Pests control by electromagnetic wave**

- Applying solar energy
- Applying infrared ray
- Applying microwave

- Applying γ-ray

Lethal dose 40000R can kill eggs of *Callosobruchus chinensis* L, 20000R can inhibit its damage. The lethal dose for killing *Tribolium castaneum* Herbst and *T. confusum* Duval is 80000R.

Sterile dose 60000R can cause the sterilization of adult of *Sitophilus zeamais* Motschulsky.

Incomplete sterile dose 2500R can breed the incomplete sterile adult of *Plodia interpunctella* Hubner. Control by laser Control insects by YAG laser is proved that 5w/cm² or 8w/cm² have better lethality to *Sitophilus zeamais*, radiation time is 10 or 20 seconds.

#### 2.2.1.2.2 Research on biological control techniques

**A. Research on stored-product control by predatory insects** (*Xylocoris flavipes*, *Xylocoris sp*, *Mnottorrus signata*)

**B. Research on trapping and killing stored-product pests by pheromones**

- Research on space-time dynamic law and utilizing behavior technique of stored-grain pests
- Research on various kinds of trap inspection techniques of stored-grain pests

**C. Research on stored – product pests control by hormones (juvenile hormone)**

#### 2.2.1.2.3 Research on plant insecticides

**A. Study the stored-product pests control effect (including lethal, attractive killing repelling) of seeds, leaves and roots of Melliaceous plants and other wild plants**

**B. Study stored-product pests control effect of natural volatile plant oil and edible plant oils (Litsea cubeba, perfume plant oil)**

**C. Study stored-product pests control effect of perfume and acrid plants**

#### 2.2.2 Techniques of molds control

Since the 1950's Chinese experts have done lots of research work on molds control. On the one hand, experts deeply studied the relation of mold ecology between various ecological factors. On the other hand, mainly studied emergency control molds measure of high moisture grains.
Table 8. Several species of protectants by practices and experiments in China

<table>
<thead>
<tr>
<th>Agency name</th>
<th>Common dose</th>
<th>Application method</th>
<th>Pests kind by control</th>
<th>Efficiency</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malathion</td>
<td>State granary 10 - 20ppm, Rural granary 15 - 30ppm</td>
<td>Spraying or mixing with powder, mixing insecticide with husk</td>
<td>Wide spectrum insecticide, there are better effect on <em>Sitophilus</em> zeamais, <em>Oryzaephilus</em> and <em>cucujidae</em>, but worse effect on <em>Rhizopertha dominica</em> and <em>Prionus</em></td>
<td>1 year, but primary density of pests is below 4 /kg</td>
<td>The effect is better than malathion, the dose can be declined 1/2–1/3</td>
</tr>
<tr>
<td>Fenrothion</td>
<td>10ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, good effect on <em>Sitophilus zeamais</em> and <em>Tribolium castaneum</em>, better effect on <em>Rhizopertha dominica</em> at high dose</td>
<td>Over one year</td>
<td>The effect is better than malathion, toxicity of mites control is higher than pirimifos-methyl</td>
</tr>
<tr>
<td>Chlorpyrifos-methyl</td>
<td>10 – 20ppm, 5 – 10ppm</td>
<td>Spraying or mixing</td>
<td>Can effectively control stored beetles, moths and mites, 20ppm can effectively control <em>Rhizopertha dominica</em></td>
<td>Over one year</td>
<td>The effect is better than malathion, the effect on <em>Dermatophagoides farinae</em> is better than other protectants, stability is the best standing</td>
</tr>
<tr>
<td>Pirimifos-methyl</td>
<td>5ppm, 10ppm, 20ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, can control various stored pests, especial <em>Rhizopertha dominica</em></td>
<td>Half year or one year</td>
<td>The effect is better than malathion, the effect on <em>Dermatophagoides farinae</em> is better than other protectants, stability is the best standing</td>
</tr>
<tr>
<td>Deltamethrin</td>
<td>0 5 – 1 0ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, best effect on <em>Rhizopertha dominica</em>, unobviously effect on mites</td>
<td>One year</td>
<td>The effect is better than malathion</td>
</tr>
<tr>
<td>Piperonyl butoxide</td>
<td>0 5 – 1 0ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, obvious effect on <em>Rhizopertha dominica</em>, <em>Sitophilus zeamais</em>, <em>Tribolium castaneum</em></td>
<td>One year</td>
<td>Synergism, and lowering dosage</td>
</tr>
<tr>
<td>Malathion + deltamethrin</td>
<td>20ppm, 0 2ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, obvious effect on <em>Rhizopertha dominica</em>, <em>Sitophilus zeamais</em>, <em>Tribolium castaneum</em></td>
<td>One year</td>
<td>Synergism and reciprocal reinforce control spectrum, then lowering dosage</td>
</tr>
<tr>
<td>Fenrothion + deltamethrin</td>
<td>10ppm, 0 2ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, can control various stored pests</td>
<td>One year</td>
<td>Reciprocal reinforce control spectrum</td>
</tr>
<tr>
<td>Chlorpyrifos-methyl + deltamethrin</td>
<td>10ppm, 0 2ppm</td>
<td>Spraying or mixing</td>
<td>Wide spectrum insecticide, can control various pests and mites</td>
<td>One year</td>
<td>Synergism and reciprocal reinforce control spectrum</td>
</tr>
</tbody>
</table>
Research on stored-grain fungus and ecological factors

According to biological character of grain microbes, some experts in China studied the effect of various ecological conditions on fungus growth and development, to decrease fungus damage by controlling ecological environment. Different moisture rice were stored at different temperature and O₂ concentration conditions; succession law of stored-grain microbes is different. Studies proved that at the temperature of 30°C, rice with 14.5% moisture can prevent Aspergillus candidus growth, but can not inhabit Aspergillus glaucus, only by decreasing O₂ concentration to below 0.5% at the same time, growth of A. glaucus can be completely prevented.

Research on emergency treatment measure of high moisture grains

We had studied and experimented some fungistats, which were:

A. Ammonium sulfite 0 4 - 0 8 (w/w) ammonium sulfite treats paddy, rapeseeds and peanut 5 - 7 days
B. N-butanol 0 3%, 0 5% (w/w) n-butanol treats wheat, corn, paddy and peanut 15 - 20 days
C. Propionic acid and butyric acid 0 3% concentration has better effect of treating paddy
D. Propionic acid and ammonia water mixture of proportion 2:1, which can effectively control corn molds
E. Ozone (O₃) ozone concentration gets 0.80 - 1.07g/m³, which can effectively control molds of rice, wheat and corn

Research on grain storage techniques

Research on grain storage by temperature control

A. Low temperature and high temperature airtight storage
   - Low temperature storage in covered airtight enclosures. The proper time of putting on the covered material is at the end of winter when grain temperature is 0 - 5°C
   - High temperature storage in covered airtight enclosures. Wheat and peas with moisture content of less than 12% may be put into sealed enclosure after exposed to sunshine, getting to the temperature of 46 - 50°C, then stored 3 - 4 weeks, pests can be killed
B. Low temperature storage by refrigeration
   - Cooling storage by air-conditioner
   - Cooling storage refrigeration units. The type of refrigeration units are 2FV10, L-3 5, KD-10, Kd-20

Ventilation of grain storage

Ventilation has been the major technique of grain storage in China for 40 years, it has been rapidly developed in the 1980's and applied in practice. Main research work includes:

A. Selection on the type of horizontal warehouse blower
B. Selection on ventilation form (including single-pipe, multi-pipe, box-type, geosyncline ventilation by under-floor air duct, cage duct on the ground) and experiment
C. Electric simulation experiment and determination of the main parameters in mechanical draft room of grain bulks, and ventilation system design
D. Experiment and design of granary ventilation control system
E. Research and applied experiment of heat preservation and adiabatic materials
F. Application of computers for ventilation management and control
G. Research on mechanical draft parameters of silos
H. Designed equipment which combine silo draft with pesticide application outside the silo, and full granary experiment
I. Research and formulation of ventilation operation sheet

Research on controlled atmosphere storage

Controlled atmosphere storage has a long history in China, the thorough research has been carried out since the 1960's.

A. Research on natural oxygen-deficient atmosphere storage
   - Species of cereals paddy, wheat, rice, peas, oil-bearing material (rapeseed, peanut)
   - Sealed material polyvinyl chloride (PVC) or polyethylene (0.14 - 0.2mm)
   - Degree of lowering oxygen O₂ below 12%, CO₂ over 14%
   - Effect it can kill insects and control molds effectively, and has been spread and applied in our country
B. Storage by filling N₂
   - Oxygen is displaced by nitrogen which is generated by nitrogen producing machine, and oxygen concentration is lowered to 5%, after a week, N₂ increases from 95% to 98 - 99%, the effect of killing insects is better
C. Storage by filling with CO₂
   - Study methods of filling CO₂
   - Study the mechanism of rice absorbing CO₂ by filling CO₂ into small bags and applied effect
   - Study airtight material and filling CO₂ methods, effect of control insects and rice keeping fresh in horizontal warehouses
   - Study filling CO₂, seal material and fumigation effect
   - Study effect of filling CO₂ on rice and paddy quality at different moisture and temperature
   - Study stored-product insects and mites control effect by controlled atmosphere storage (special CO₂ and temperature) Physiology and biochemistry mechanism of some mites forming, recovering, heredity to controlled atmosphere resistance
3. Technique progress

Due to the great progress of grain storage research work in China in the past 50 years, especially the past 20 years, the Chinese grain storage facilities and techniques have made great improvement.

3.1 Before the founding of the P.R. China, in the whole country, the capacity of grain depots was 7500 kilo-ton and the capacity of plant oil depots was 5 kilo-ton. At the end of 1991, the capacity of grain depots in the country was more than 127000 kilo-ton, the capacity of vegetable oil depots got to 2600 kilo-ton. Although grain and oil storage facilities is still inadequate, outstanding progress has indeed been made in the modernization of Chinese grain and oil storage depots.

3.2 Our country has accumulated a complete set of effective grain storage management experience and technique, such as ‘Four without’ grain depots (when a depot and its stored grain can reach the standards of insects free, moldy grain free, birds and rodents free, and accidents free), then it can be rewarded the title of ‘Four without’ have been spread nationwide. ‘Double Low’ (low oxygen, low insecticide), ‘Three Low’ (low oxygen, low insecticide and low temperature) storage techniques have achieved satisfactory results.

3.3 Grain storage technique by low temperature has been extended nationwide.

3.4 Technique of stored-product pest control, especially protectants have made great progress in practice. According to the law of fumigants gas diffusion in different types of grain depots, application technique of its has been improved.

3.5 Improvement has been made in the design of silos and research on warehouse machine. Because of various types of grain dryers coming forth, drying of high moisture corn has been solved in China.

The application of electron computers in grain storage has pushed the grain depot management in our country a big stride forward to standardization, popularization, systematization, regularization and internalization.

We believe that China’s grain storage facilities and techniques will be sure to take a leap by the diligent work and using foreign advanced achievement for reference.

The above is a brief introduction of research progress of grain storage and control of stored-grain pests. Here in below, I would like to summarily introduce the work of the two authors.

Li Lungshu, who has published nearly 200 treatises and monographs since 1946, has published more than 30 research papers in the recent ten years, which mainly includes...
Description of several new species of mite;
Regional fauna investigation of food mites in whole China, several provinces and in Sichuan Province (putting forward name lists),
Lethality of temperature and controlled atmosphere against several species of stored-grain pests and mites, Influence of high carbon dioxide to resistance strain breeding of Lepuscelus entomophilus E
Biological and ecological research of Zabrotus subfasciatus, Ploida interpunctella and so on, glandularia morphology research of water mites
Research on control of grain-storage pests by fragrant oil of plant insecticide used with controlled atmosphere.
Research on ecology of grain bulk
Jin Zuxun, beginning engaged in the research work of potatoes since 1950’s, has carried out the work of exploring and sorting out the legacy of Chinese ancient grain storage techniques in succession. In 1965, he founded the Chinese Grain Storage Scientific Research Institute and presided over ‘the Sixth Five-year Plan’, ‘the Seventh Five-year Plan’ on tackling key problems of grain storage science and technique. In recent years, he mainly engaged in research about science and technology policy and scientific conceive of grain storage in China in 21st century