The Current Status of Fumigation and Controlled Atmosphere Storage Technologies in China

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Abstract

This paper provides a brief outline of the current status of fumigation and controlled atmosphere technologies in China.

Phosphine is the most important fumigant for the control of stored grain insects. More than 90% of the fumigations undertaken in national storages are done with phosphine. In order to produce moderate concentrations and long exposure periods phosphine is generated from zinc phosphide and, in some cases, applied intermittently. Phosphine fumigation combined with controlled atmosphere is widely practiced. Research work had confirmed that it is economic and practical to synergise phosphine with appropriate concentrations of oxygen and carbon dioxide.

Controlled atmosphere storage by purging with nitrogen or carbon dioxide is restricted by cost and shortage of materials. It is used only in some large cities for long-term storage of milled rice. Most stored paddy and wheat is treated by the method of natural deoxidation (hermetic storage). The effectiveness of different oxygen and carbon dioxide concentrations was determined in laboratory simulations of natural deoxidation. The influence of relative humidity, the effect of controlled atmospheres on the quality of stored rice, and the temperature range over which safe storage is possible were also determined.

Suggestions are made as to priorities for future research.

THE use of fumigation and controlled atmospheres (CA) for grain storage in China has come some way since 1980. Improvements in fumigation technology have focussed on the very widely used phosphine, though chloropicrin and methyl bromide are still applied in certain circumstances. Controlled atmosphere storage was first put into practice in 1979. Because of the restricted availability of materials, it is basically natural airtight storage (also called 'deoxidated storage' in China). However, some papers dealing with other measures have been published.

In this paper, the author does not intend to present the result of research without practical significance. Rather, technologies in general use are covered. Also, some existing problems and the views of the author are expressed.

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Fumigation Technology

Fumigation is an important measure for the control of stored grain insects in China. It occupies a critical position in the system of integrated pest management (IPM), especially for pest control in national storages.

Owing to the cost of treatment and the demand for simplicity and convenience of application, almost 90% of fumigation treatments are conducted using phosphine. In some cases phosphine is generated by reacting zinc phosphide with sulphuric acid. Chloropicrin is used occasionally as a component part of combined fumigation with phosphine or as an alternative for the control of phosphine-resistant insects. There have been no developments in application technology in recent years. Methyl bromide has, for many years, been used for quarantine treatment only.

Research and development has been

concentrated on the technology of phosphine fumigation, especially since the 'Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests' published in 1976 (Champ and Dyte 1976) and the appearance of phosphine-resistant insects in China.

Generally Recognised Principles of Phosphine Fumigation

The generally recognised concepts and principles of phosphine fumigation in China are based on long-term practice and the results of overseas research.

The following are judged as essential criteria for phosphine fumigations even in the absence of formal regulations:

- Efforts must be made to accomplish good sealing conditions.
- Both bagged and bulk grain should be covered with plastic sheeting for fumigation.
- The outer surface of the fumigated grain must be disinfested.
- Slow-release methods are better for relatively poor conditions and long-exposure times.
- Exposure time should never be less than 120 hours.
- In routine phosphine fumigations for control of normal insect populations, the Ct product should exceed 150 mg.hr/l.
- If fumigation failure recurs continuously, reasons must be sought and live insects collected for resistance discrimination.
- A fumigation is judged as successful if no live insects appear within three months.
- Contact insecticides should be used to prevent reinfestation.
- The fumigant used should be varied from time to time if possible.

Use of Zinc Phosphide for Phosphine Generation

Sulphuric acid reacts with zinc phosphide to produce phosphine. Though the reaction is flammable, if the acid is diluted with water to a concentration less than 10% (w/w) and the zinc phosphide is wrapped in strong, water permeable paper, combustion may be prevented and phosphine generated slowly. In order to give added assurance of safety, the zinc phosphide may also be mixed with sodium bicarbonate. If this is done, phosphine and carbon dioxide are generated simultaneously, and the carbon dioxide produced can not only prevent flame and explosion but also synergise the effectiveness of phosphine. However, the rate of phosphine generation by this method is much faster than from Phostoxin, so it is not suitable for long exposure periods unless the total dosage is divided in two or three portions applied intermittently.

The best formulation for this method of generating phosphine is:

$$Zn_3P_2:NaHCO_3:H_2SO_4:H_2O = 1:1:1.3:15 \text{ (by weight)}$$

$$\text{or} = 1:1:2:20 \text{ (by weight)}$$

Supplementary Method for Retarding the Rate of Phosphine Release by Phostoxin

Phosphine toxicology decrees that the gas must be used at moderate concentrations over long exposure periods for stored grain insect control. In some circumstances, for the purpose of keeping moderate phosphine concentrations in treating high moisture content grains, the rate of generation remains too rapid. An experiment to retard the rate of phosphine release by using small polyethylene bags for longer exposure periods was successful. The thickness of polyethylene film was 0.03–0.06 mm. Fewer than five tablets of Phostoxin were put into each bag and applied separately in and around bagged milled rice stacks. By this method, phosphine concentration could be maintained within the range of 0.01–0.05 mg/L for nearly three months. This range of phosphine concentration is ineffective against developing insects, but any adults emerging will be killed during the long exposure period (Guangzhou Institute of Cereal Science Research 1985).

Although this method is successful in long-term milled rice storage, the author believes that it would be better to improve Phostoxin formulations to meet the need for slower release rather than improving the method of application by users. The production of further varieties of Phostoxin is warranted.

Combined Use with Controlled Atmosphere

It is well known that the atmosphere within stored grain may be changed by the respiration of insects, microorganisms, and the grain itself.

Indeed, this modification of the storage atmosphere has also played a role in fumigation. However, it was not until the 1970s that research to exploit this phenomenon to enhance the effectiveness of fumigation was undertaken. The results of research carried out in China (Liang Quan et al. 1980) confirmed that both low oxygen and carbon dioxide rich atmospheres can increase the effectiveness of phosphine against common stored grain beetles. The results of a series of biological determinations showed that when oxygen is lowered to 12%, the toxicity of phosphine begins to rise and this tendency continues progressively as oxygen concentration is further lowered to 5% (Figs 1 and 2).

It was also shown that the starting synergistic concentration of raised carbon dioxide is 4%. Above 8%, however, the synergistic effect remains unchanged (Fig. 3).

Therefore, the synergistic range of concentrations was recommended as oxygen lower than 12% and carbon dioxide 4%–8%. Very low oxygen or very high carbon dioxide atmospheres are impractical in China at present because it is not possible to attain them under general conditions of natural deoxidation. On the other hand, lower than 5% oxygen in phosphine fumigation is unnecessary, because insects can be killed by low oxygen only over long exposure periods.

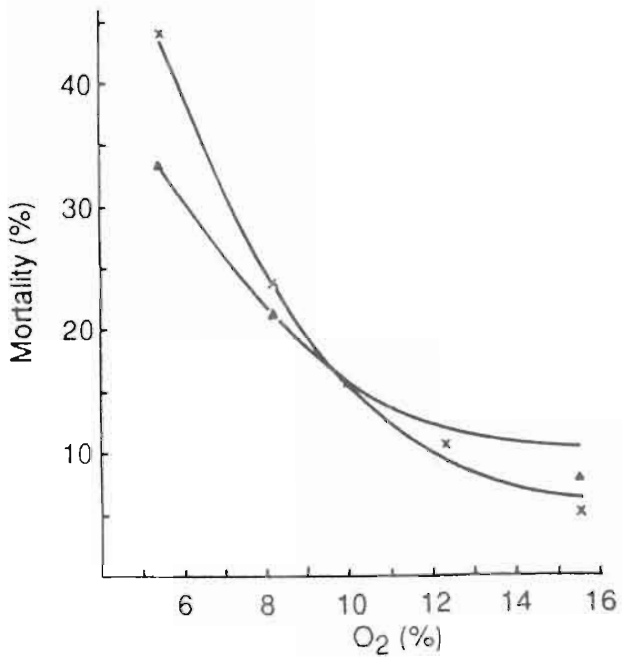

Fig. 1. Synergism of phosphine activity by lowered oxygen concentration (*Tribolium castaneum*: CO_2 4%; PH_3 0.006 mg/L; 28°C; 20 hours) (Liang Quan 1981).

Intermittent Application of Phosphine

As noted earlier, most of the existing storages in China are not gastight. Although some remedial measures to improve the level of sealing are undertaken, the concentration of phosphine cannot be maintained, and the required Ct product is usually not attained. The principles of permeability and the toxicity characteristics of phosphine, mean that it is essential to generate the gas uniformly and to maintain effective concentrations for longer.

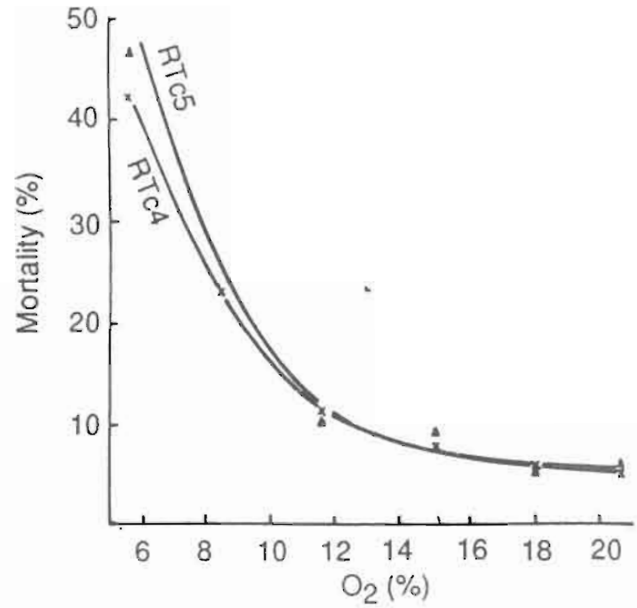

Fig. 2. Synergism of phosphine activity by lowered oxygen concentration (*Tribolium castaneum*: CO_2 0%; PH_3 0.007 mg/L; 28°C; 20 hours) (Liang Quan 1981).

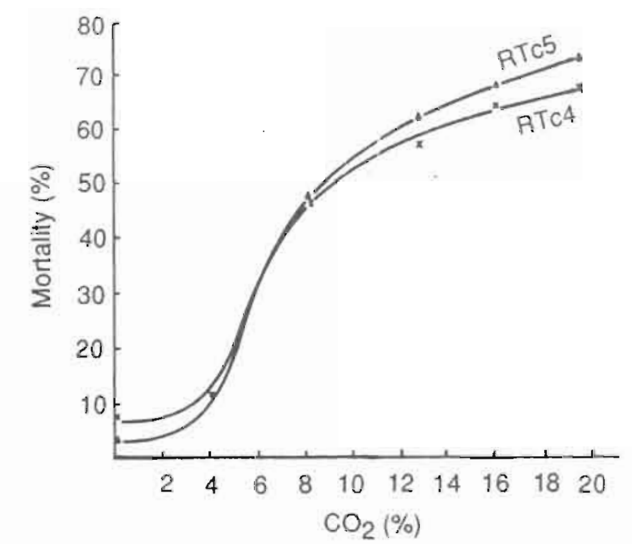

Fig. 3. Synergism of phosphine activity by increased carbon dioxide concentration (*Tribolium castaneum*: O_2 21%; PH_3 0.007 mg/L; 28°C; 20 hours) (Liang Quan 1981).

Some reports have suggested that when the total phosphine dosage is applied in batches at one-or two-day intervals, the Ct product attained — over the same exposure period — is higher than when it is all applied at the one time (Liu Bao-kui 1982; Nanyuan Research Groups 1985).

This method is especially suited to zinc phosphide generation of phosphine. It has been to some extent commercialised.

Use of Convection Currents for Phosphine Fumigation

Research work on convection currents in stored grain was carried out in China in the mid-1970s (Guzhuang Storage 1976). Although the results were obtained from field experiments, they are basically identical to the later theoretical findings of Nguyen in Australia (see, for example, Nguyen 1986).

The research demonstrated that the direction of flow in bulk grain varies with position in the grain mass. The flow is driven by temperature differences, with the rate of flow determined by the degree of these differences. In addition, it was shown that the direction of the current may also be influenced by insolation and wind. So that an effective application position for fumigant can be selected, it is essential that variations in current direction be known.

The Guzhuang Storage later reported (Guzhuang Storage 1985) that about 130,000 yuan (renminbi) had been saved in its own facilities by using this method over the previous fifteen years.

The Problem of Phosphine Resistant Insects

Phosphine resistant strains of stored grain insect species were first found in China in 1979 (Liang Quan 1979), and resulting failures of routine phosphine fumigations appeared shortly afterwards. The first report of a local survey (Liang Quan 1975) verified that resistant strains occurred among all the major grain beetles except *S. zeamais*, and were widely distributed in Guangdong Province. However, the resistance ratios were limited (1.3–7.4). A strain of *S. oryzae* with a pronounced resistance ratio (63.7) was found in the eastern part of Guangdong. In the meantime, a nationwide survey had begun to reveal the overall situation. The results of this survey were published in 1983 (Research Institute of Grain Storage, Ministry of Commerce 1983). They showed that phosphine resistant strains were widely distributed but mainly in southern areas of the country. The most noticeable species was again *S. oryzae* in which resistant strains amounted to 18% of total samples.

Although the resistance levels do not reach the degree at which phosphine is generally ineffective, they are a warning signal to develop long-term strategy as there is no foreseeable alternative to phosphine in the immediate future. The occurrence of phosphine resistance is therefore seen as a latent crisis in the control of stored grain insects.

As elsewhere in the world, much research has been carried out to delay the development of phosphine resistance and to eliminate resistant populations. Nevertheless, the situation could be further improved. The above-mentioned tactical viewpoint has been neither recognised nor accepted widely in practice. Rules and regulations have still not been drawn up and neither has a monitoring system for resistance been established. Much work on dissemination and in organisation therefore remains to be done.

Controlled Atmosphere Technology

As is well known, controlled atmosphere storage is one of two components of modified atmosphere storage, the other component being natural airtight storage i.e. natural deoxidation storage. In China, the current situation is that almost 90% of airtight storage relies on natural deoxidation. The technique of purging with nitrogen or carbon dioxide has been adopted in some large cities for the storage of bagged rice, but is too expensive for rural use. In order to meet the needs of rural storage, since the late 1970s much work had been done to investigate measures for supplementing deoxidation, such as by using micro-organisms, nitrogen-producing machines, and molecular sieves and deoxidants. The results suggest that most of these measures have no widespread viability and that natural deoxidation will remain as the most practicable approach.

Sealing Materials and Methods

There are no fully sealed storages used for CA storage in China, basically because problems with the materials and technology have not yet been solved. CA storage is therefore always undertaken with the aid of plastic sheeting, most usually polyethylene or PVC. Laminated films are used for packing small quantities of high quality rice or other foods.

In the larger cities, if the storage period is more than three months, the stacks of bagged rice or flour are usually covered with 0.2 or 0.4 mm thick polyethylene or PVC sheets on all sides for natural deoxidation. If the moisture content is 13–14%, the concentration of oxygen will fall to 5% or so and carbon dioxide will increase to 8–10%.

In bulk-stored grain, only the surface can be covered with plastic sheeting. In many cases, the operator links up the sheets and the wall with the aid of a wooden trough and rubber piping. The wooden trough is fixed on the wall around the surface of bulk grain. The hem of the sheet can be placed into the wooden trough by the use of rubber pipe. It is a simple and convenient method.

Given the conditions just described, it is easy to predict that most of the 'airtight' storage in China is leaky, so it is difficult to control insect pests using CA alone. In many cases it needs to be combined with phosphine fumigation.

The need to improve the gastightness of existing storages in China has a high priority, together with the development of sealing materials and methods.

Monitoring of Airtightness

Technology for monitoring airtightness has lagged behind in China. At present the most widely used method is to measure the changes in oxygen or carbon dioxide concentration during the process of deoxidation. The pressure attenuation method is used only in some experimental situations.

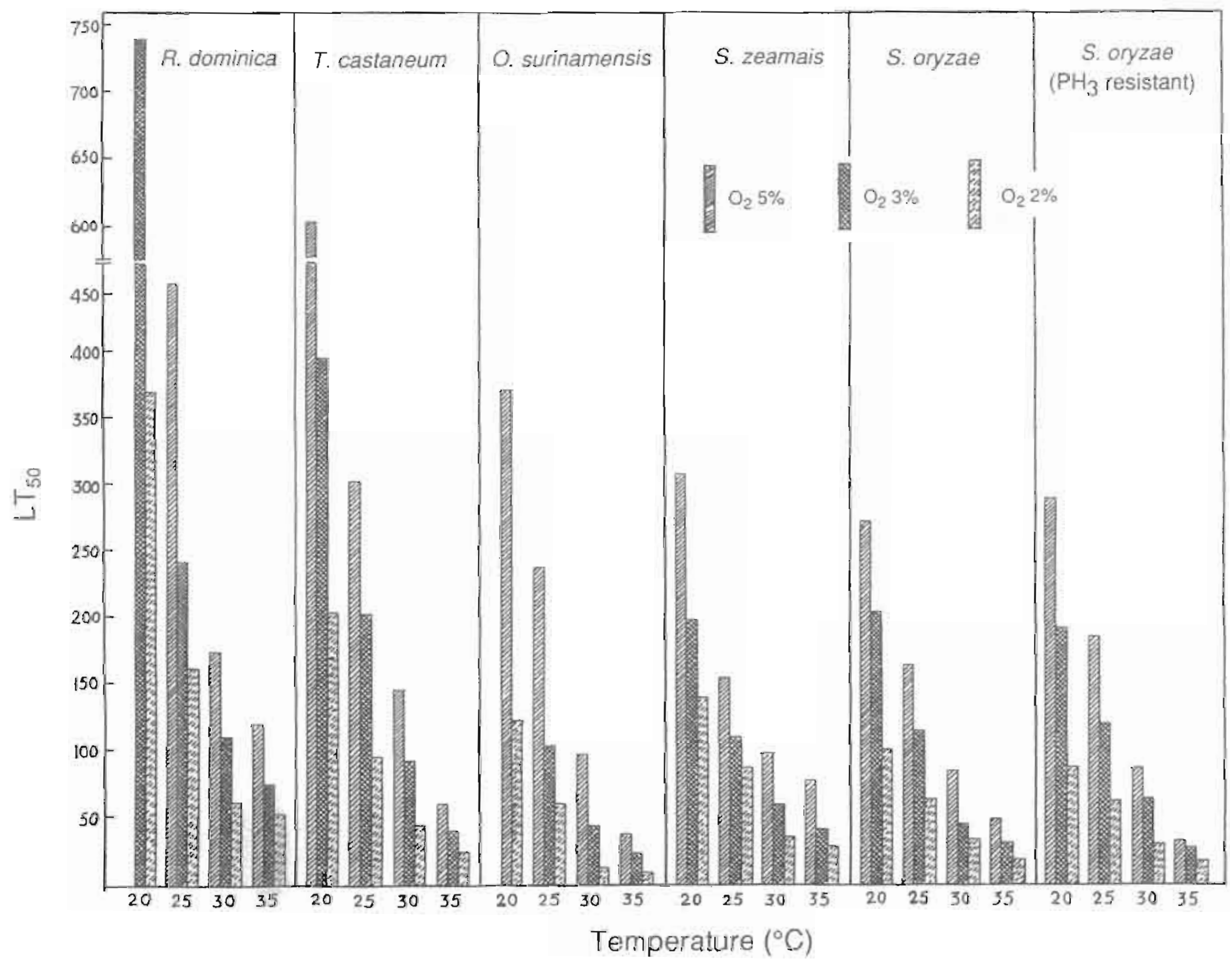

Fig. 4. Tolerance of stored grain beetles to low oxygen concentration at various temperatures (Liang Quan 1981).

Effect of Controlled Atmosphere on the Quality of Milled Rice

A cooperative study (Research Institute of Grain Storage, Ministry of Commerce et al. 1981) of the effects of normal periods of CA application on the quality of milled rice was carried out. The conditions of CA and temperature required for safe storage were defined by a series of determinations of peroxidase, fatty acid, water soluble acid, and reducing sugar as well as taste evaluation. The conclusions were:

- Oxygen concentration has no effect on the quality of milled rice at moisture contents lower than 13.5%.
- At an oxygen concentration of 5% and moisture content of 14–14.5%, milled rice can be stored safely for 6 months.
- At moisture contents of 15–15.5% or 16%, if milled rice is stored in lower than 0.5% oxygen concentrations the temperature must be lowered to 25°C or 20°C, respectively, for safe storage.
- The viscosity of milled rice following storage is correlated with oxygen concentration during storage rather than temperature.

Susceptibility of Stored Grain Insects to Controlled Atmospheres

A series of laboratory tests was carried out to evaluate effectiveness of different CA conditions (Liang Quan 1981). The susceptibilities of adults of common stored grain beetles were found to be as follows.

- The LT_{50} under 2%, 3%, and 5% oxygen conditions is *R. dominica* > *T. castaneum* > *S. zeamais* > *S. oryzae* = PH_3 resistant *S. oryzae* and *O. surinamensis* (Figs 4 and 5).
- Lowered temperature can increase the efficacy of a fixed low oxygen concentration. For *T. castaneum* in 2% oxygen at temperatures of 20°C, 25°C, 30°C, and 35°C, the LT_{50} are 204, 94, 46, 22 hours, respectively. It seems that the susceptibility of insects may increase 100% as the

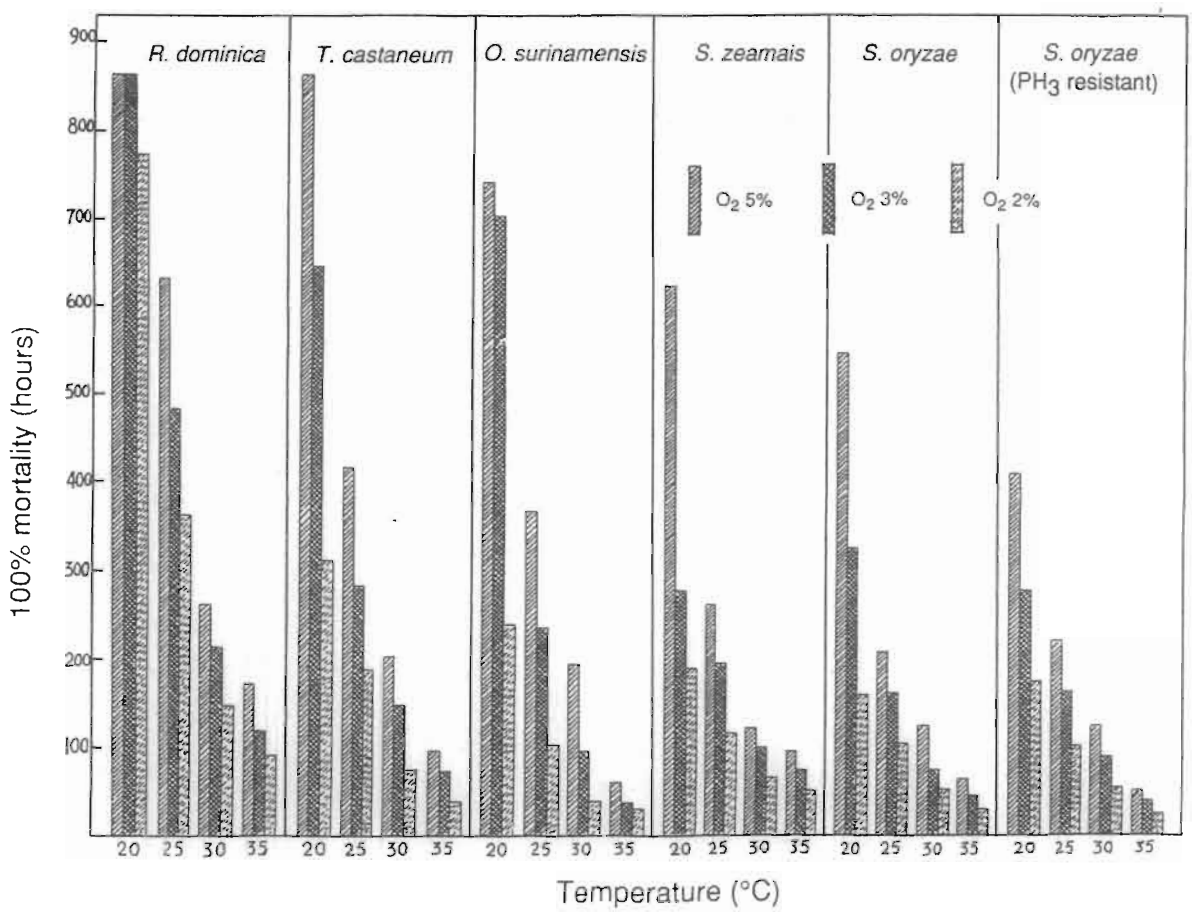

Fig. 5. Time to 100% mortality of stored grain beetles at various temperatures in different low oxygen atmospheres (Liang Quan 1981).

temperature is raised by 5°C steps in fixed low oxygen concentrations.

- Increasing the concentration of carbon dioxide in CA can increase the effectiveness against insects (Fig. 6).
- Relative humidity is an important factor in CA control of insects (Fig. 3) especially in the control of *S. zeamais* and *R. dominica*. The mortality of insects under low RH conditions is much higher than under high RH conditions in CA (Fig. 7).
- Once CA-treated insects are exposed to normal atmospheres their death may be accelerated.

Future Requirements

The use of fumigation and controlled atmospheres for the control of stored grain insects in China is advancing steadily. While many international and national achievements have played an important role in increasing the social and economic benefits of the technologies, much basic work remains to be done.

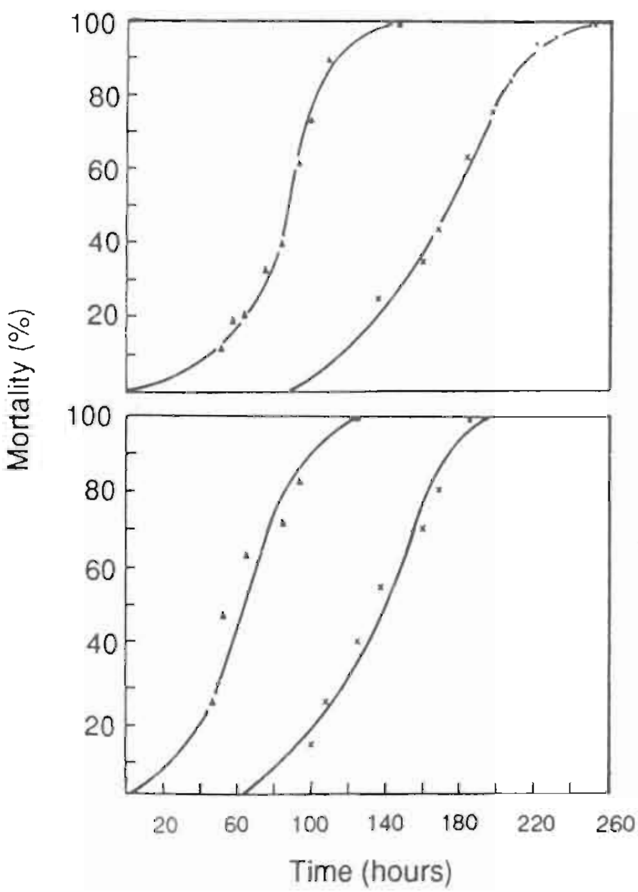

Fig. 6. Synergism of the effect of low oxygen atmospheres on stored grain beetles by carbon dioxide (30°C, O_2 5%) (Liang Quan 1981). Δ, CO_2 10%; ×, CO_2 0%.

- A practical and effective method suited to rural stored grain insect control is needed.
- Effort should be made to improve the gastightness of existing storages.

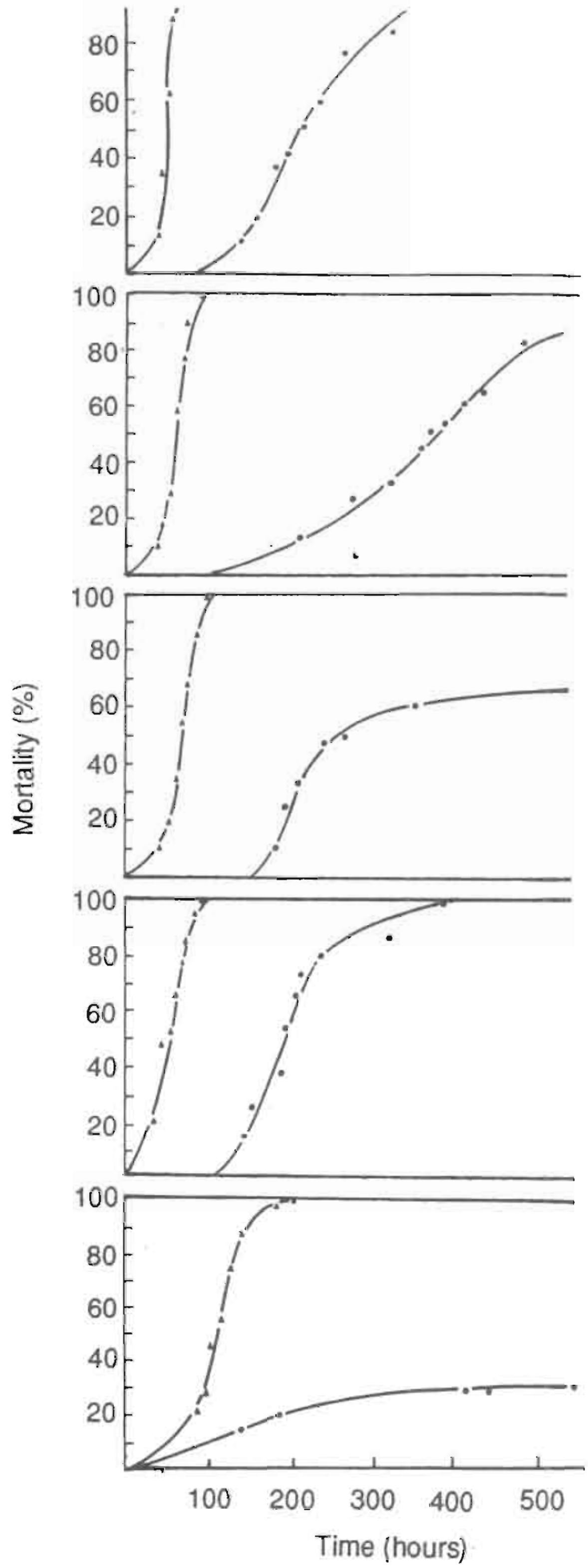

Fig. 7. The influence of relative humidity on the effectiveness of low oxygen atmospheres against grain beetles. (O_2 3%, N_2 97%, 30°C). Δ, RH 50–70%; ×, RH 80–90%.

- The international flow of scientific information needs to be promoted, as does increased international research cooperation.
- Rules and regulations concerning the management of fumigant application need to be developed, promulgated, and enforced.
- Monitoring of phosphine resistance and the development of counter-measures to phosphine resistance are high priority activities.

Acknowledgment

The author expresses appreciation to Dr B.R. Champ, ACIAR, Australia for inviting and supporting the production of this paper.

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