

Crop Post-Harvest: Science and Technology

Volume 2

Durables

Case studies in the handling and storage of durable commodities

Edited by

Rick Hodges and Graham Farrell

**Blackwell
Science**



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Dr Rick Hodges has worked with durable commodities for over 25 years, as manager of the British Government's grain storage project in Mali after the severe Sahel drought of the early 1980s and then as a pest and quality control adviser to the Indonesian National Logistics Agency (BULOG). His research has focused on improvements in commodity management, especially on more cost-effective and environmentally acceptable approaches to insect control, and on helping African smallholder farmers tackle the larger grain borer. He is currently Reader in Post-harvest Entomology at the Natural Resources Institute, University of Greenwich, and Secretary of the Global Post-harvest Forum (*PhAction*).

Dr Graham Farrell trained in plant pathology and pest management. He worked in Africa for 10 years in natural resources project management and technical support, particularly in the design, implementation, monitoring and institutionalisation of demand-driven participatory programmes for the British Government, and in the logistics of food aid for the European Union. Dr Farrell's professional interests revolve around crop protection extension and translating outputs of research into materials used by dissemination agencies to strengthen the abilities of farmers and growers in articulating their technical and information needs. He is currently director of Plant Clinic Limited, a UK company providing advice on plant health, based on sustainable principles.

Preface

Durable commodities are the raw products from which food can be made and are the staples on which most humans rely; with but a few exceptions they are the seeds of plants. The storage and handling of durable commodities has been practised by man for millennia and has enabled mankind's populations to become sufficiently dense to support urban development and our current civilisation. In the modern world, appropriate storage and handling of durable commodities facilitate effective marketing chains and there underpin economic wellbeing and food security.

The development of grain storage has been a battle against biodeterioration; this is caused by adverse temperature and moisture conditions and mediated by micro-organisms (especially fungi), arthropods (particularly insects and mites) and to a lesser extent rodents and birds. While the problems are biological in nature, from the earliest times solutions have mostly been found in the realms of engineering. In the twentieth century, the use of pesticides of one sort or another blossomed. However, consumer demand in the late twentieth and the early twenty-first century has led to a strong move away from pesticides and a resurgence of engineering solutions to deliver products free of pests and pesticide residues, with the characteristics required by the end-user, and increasingly products are becoming traceable back to source.

Volume 1 in this series, on the principles and practice of post-harvest technology, provides details of how crops should be dried, handled, protected from pests and stored by smaller-holders or large-scale enterprises. In contrast, this second volume presents a series of case studies on how durable crops are actually stored and marketed. Authors were asked to contribute manuscripts covering a specific range of issues so that comparisons could be made between post-harvest systems used for the same

commodities in different countries. Thirty-eight authors contributed to this volume; all have practical knowledge of the systems they are describing but their backgrounds are quite varied, as would be expected of a subject that requires a multidisciplinary approach. Authors also differ in the amount of information available to them and the extent to which they are involved in managerial or developmental aspects. The result of this is a difference in emphasis between contributions, adding to the richness and interest of the text.

Many of the chapters present contrasting approaches to the storage of the same commodity. For example, the volume begins with rice storage in three different countries. In China, several storage methods are used across a range of climatic conditions with the objective of ensuring sufficient food supply to its large population. In Japan, rice storage is highly specialised and designed to provide a product quality specifically demanded by the Japanese consumer, while Australia provides high-quality products prepared according to the requirements of various domestic and export markets. Different approaches are taken to the same commodity according to a blend of economic, social and cultural requirements. The intention of this juxtaposition is to demonstrate differences in the degree of development and sophistication of these systems and the diversity of technology that can enable successful handling and storage of durable commodities. This approach is adopted for several commodities, but for the remainder it has only been possible to present single accounts. With the exception of cured fish, all are plant products; Chapter 14 on cured fish also differs in providing a detailed consideration of pest management issues alongside a profile of the cured fish industry of Senegal. Two sections, relating to peanuts and cured fish in Senegal, were translated from French by one of us (RH).

Many of the techniques and issues mentioned here are presented in detail in Volume 1 and, where appropriate, cross-references are made. For information on the common, scientific and family names of pests, pathogens and plants of importance to post-harvest technology, the reader should refer to Appendices 1, 2 and 3 of Volume 1.

The moisture content of commodities is a very important issue for correct handling and storage. In this volume where moisture contents are quoted these should be

assumed to be on a wet weight basis (Vol. 1 p. 74); if they are on a dry weight basis this will be stated.

Every effort has been made to contact the copyright holders of photographs and diagrams. However, the editors would be pleased to make amendments in future editions.

Rick Hodges and Graham Farrell
Chatham, UK
November 2003

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Chapter 1

Rice

J. Zuxun, Q. Weifen, Y. Seo, J. Darby and R. Bowman

Rice is believed to have originated in China and India. This crop has fed more people over a longer period than any other, making its domestication one of the most important developments in human history. There are two species of cultivated rice, *Oryzae sativa* and *Oryzae glaberrima*. Of the two, *O. sativa* is by far the more widely grown. *Oryzae sativa* is a complex of seven forms with a strong divergence between South Asian *indica* rices, which are usually long-grain types grown in the tropics or subtropics, and *japonica* (or *sinica*) rices of Chinese origin that are usually round-grain types grown in the subtropics or temperate zones. Both types may be either normal savoury rice or glutinous rice: the latter becomes sweet and sticky on cooking and is used in making deserts and confectionery.

The rice plant develops grain clusters called panicles; the plants are cut and threshed to release the grains. The intact grain has an abrasive, silicaceous seed coat or husk and is called paddy or rough rice (Plate 1). Dehusking reveals the brown bran and germ that underlie the seed coat, and in this state the grain is called brown rice (Plate 1). Most people prefer to eat white rice (Plate 1) and this is prepared by milling or 'polishing' to remove the bran and germ, leaving just the endosperm of the grain (Vol. 1 p. 384, Wood 2002). Further specialised polishing produces a shinier, whiter-looking rice. Unlike most other cereals, rice is mostly eaten as whole grains and for this reason physical properties such as size, shape, uniformity and general appearance are very important. The quality of the product is affected by its physiochemical properties as well as factors such as the proportion of broken grains, which must be minimised for best eating quality and price premium.

This chapter deals with rice storage in China, Japan and Australia. The situations in these countries contrast strongly. Rice growing is an ancient tradition in both

China and Japan but only began in Australia in the 1920s in New South Wales (NSW). In China, a very large and diverse storage system is engaged to meet the food security needs of a population of about 1.3 billion. China is the largest of about 100 paddy-producing countries worldwide with an annual production of about 166 million tonnes or approximately 37% of world output (FAO 2000). Both *indica* and *japonica* rice are consumed and, as paddy is a seasonal crop, storage is extremely important. The rice is generally stored in bins, silos or horizontal stores of Soviet design, with an increasing emphasis on low-temperature and controlled atmosphere storage.

Japan produces about 9 million tonnes of paddy annually and has a system that is highly specialised and developed to provide a product quality specifically demanded by the Japanese consumer. *Japonica* varieties are favoured, and freshness is very important as the Japanese eat boiled rice by itself. In order to preserve freshness, rice is stored using advanced methods to control conditions of temperature and humidity, in particular. Freshness is also achieved by storing and distributing mostly brown rice that is then milled and polished just before consumption.

Australia has an annual production of paddy of only about 1.6 million tonnes, of which 80% is *japonica* and the rest *indica*. In the early days the rice industry used a bag storage system where rice was harvested at low moistures (16.5%) prior to further drying, storage and milling. But today, only bulk systems are found, employing large-scale machinery, advanced aerated storage facilities, automatic control and purpose built *in situ* moisture sensing systems. The paddy crop is aeration dried in 6–7.5 m deep bins using either ambient or burner-heated inlet air and then stored for periods of up to one year before shipment to the millers and then the market. This capital-intensive industry provides high

quality products prepared according to the requirements of various export and domestic markets and so delivers various quality requirements. These include minimised kernel breakage, a range of polished rice appearance and presentation characteristics, cooking textures and performances, and eating qualities.

China

Historical perspectives

Chinese archaeological excavation at the Yu Zanyan ruins (Hunan Province) has revealed 10 000-year-old carbonised paddy rice (Jin Zuxun 1984). It is believed that Chinese people began to store paddy from ancient times: at He Mu Du ruins, Zhejiang Province, 7000-year-old carbonised paddy was stored on frames made of branches (Li Lungshu & Jin Zuxun 1999).

Grain storage science was established in China at the beginning of the last century. In 1965, the State Science and Technology Committee formally approved a national grain storage research institute to meet the growing needs of grain production and storage (Tang Weimin & Hu Yushan 1997). Since then, paddy storage research has developed very quickly. China stores both *indica* and *japonica* rice that may be ‘normal’ or glutinous and may also be classified according to harvest time – early, medium or late season.

Physical facilities

The three main types of paddy warehouse in China are horizontal warehouses of Soviet origin (Fig. 1.1), silos (Fig. 1.2) and bins. In some places there are also under-



Fig. 1.1 Soviet-style warehouse for the storage of paddy and milled rice in China.



Fig. 1.2 Reinforced concrete grain silo used for the storage of paddy in China.

ground storage facilities of various designs (Lin Zaiyun & Wu Lina 1999). The general horizontal warehouse in China can house paddy in bag stacks 4 m high, 21 m wide with length chosen according to circumstances. In large horizontal warehouses bag stacks may be 6 m high, 24–27 m wide and more than 50 m long. Paddy storage bins are roughly 15–18 m high and 30 m in diameter and hold about 500 tonnes.

China has a large territory and paddy grows in wet to semi-arid tropical regions through to warm temperate areas, and in earth ranging from heavy clay to poor sandy soils. In these widely differing ecological conditions, appropriate storage facilities need to be chosen to ensure the safe keeping of paddy. Thus Chinese territory can be divided into the following seven types for the purpose of grain storage (Tang Zijun *et al.* 1999):

- (1) The cold arid region of the Qingzang plateau
- (2) The arid region of Monxin
- (3) The cold humid region of northeast China
- (4) The warm temperate, sub-humid and semi-arid area in the north
- (5) The subtropical, humid monsoon region of central China
- (6) The subtropical area of the southwest, and
- (7) The hot humid region in the south

Horizontal warehousing is used for paddy storage in the south in areas 5, 6 and 7 while horizontal warehouses or round bins are chosen for paddy in areas 1, 2, 3 and 4. Silo complexes are used at ports and railways. The facilities used for paddy storage include cleaners and balances, dryers, transporters, aerators, cooling equipment, fumigation equipment, electronic grain inspection and

control equipment, sampling equipment, computerised control systems and expert systems that automate grain management.

The status of milled rice storage varies in different parts of China. With the establishment and development of the grain market, milled rice began to be processed, handled and sold at the same time. Large and medium-sized cities have to store a certain amount of rice to guarantee supplies. Milled rice is usually stored in horizontal warehouses where effective storage techniques are easily applied. The equipment for rice storage is the same as that for paddy except that rice storage needs facilities for packaging rice for the consumer market (Jin Zuxun & Yu Yingwei 2000).

Grain cooling is an important strategy to achieve good quality preservation. Warehouses, bins, silos or underground stores may be defined as low temperature, when they are maintained below 15°C, or quasi-low-temperature which are at 15–20°C (Lu Qianyu 1998). Low-temperature storage requires that stores are reasonably airtight and insulated. The degree of insulation influences the effectiveness and cost of storage. Normal insulation materials are dilated perlite, polystyrene foam, chaff, and so on, to give an overall coefficient of heat conduction below 0.5 kcal m⁻² h⁻¹ °C⁻¹. The cooling is usually achieved by using air conditioners or special refrigeration units (cereal coolers). The units are installed close to the ceiling of the store so that the cold air does not play directly onto the stock, which otherwise might result in moisture condensation. Where possible grain is pre-cooled by exposure to cool weather conditions before placing it in store and/or opening the ventilators and doors during cold weather.

Objectives of storage

Rice milled from paddy is primarily for domestic consumption and supplies often exceed demand. As a consequence, paddy and rice storage is a long-term strategy within the country. With the reform of domestic

grain circulation and China's entry into the World Trade Organization, international and local trade for paddy and milled rice are expected to increase.

Major sources of quality decline

The outer husk of paddy makes it particularly resistant to both insect damage and changes in humidity and temperature. Under normal storage conditions, newly harvested paddy respire strongly, although after one year the rate of respiration decreases and keeping quality improves. Paddy respiration gives out heat and moisture that can result in condensation. This leads to mould growth and grain sprouting in the upper portions of stacks (20–30 cm below the surface). Even if paddy is received at an acceptable moisture content, the temperature of the upper part of the stack often rises abruptly, usually about 10–15°C above ambient. Paddy may crack if dried in the sun or at high temperature, or if subjected to rapid absorption or desorption of moisture, leading to grain breakage. If maintained in store at high temperatures then paddy may become rancid as a result of the accumulation of free fatty acids (Table 1.1).

Paddy that is not dried or cooled in a timely manner after harvest will yield yellowed grains at polishing. Extensive research has shown that the higher the temperature and moisture, the more severe the yellowing (Table 1.2). Besides a change in colour, the quality of yellowed rice differs significantly from unyellowed rice in a number of other respects (Table 1.3), resulting in an overall lower quality rating for yellowed rice (Table 1.4). However, no mycotoxins such as aflatoxin (Vol. 1 p. 128, Wareing 2002) have yet been detected in yellow rice.

China's storage loss of paddy is about 0.2% in national reserves while rural household storage losses are around 7–13%. In general, the main causes of grain storage loss in China are insects in the south and moisture in the north. Paddy is the principal crop in the southern part of China where the temperature and moisture are very suit-

Table 1.1 Effect of temperature on the fatty acid value of paddy after 3 months of storage.

Moisture content (%)	Original FFA*	Final FFA*		
		15°C	25°C	35°C
13.2	13.8	21.1	21.7	25.7
15.2	14.6	22.1	23.3	23.3
17.2	16.9	24.4	23.5	44.5
19.6	18.9	24.6	46.8	43.3

*Free fatty acid (mg KOH/100 g dry basis).

Table 1.2 Yellowing of rice grain endosperm related to paddy storage period, temperature and moisture of *indica* rice.

Temperature (°C)	Moisture (%)	Period		
		1 month	2 month	3 months
30	13.1	No yellowing	No yellowing	No yellowing
30	13.6	No yellowing	No yellowing	No yellowing
30	14.7	No yellowing	No yellowing	No yellowing
30	15.7	No yellowing	No yellowing	No yellowing
35	13.1	No yellowing	No yellowing	No yellowing
35	13.6	No yellowing	No yellowing	No yellowing
35	14.7	No yellowing	No yellowing	Yellowing starts
35	15.7	No yellowing	No yellowing	Yellowing starts
40	13.1	No yellowing	No yellowing	Yellowing starts
40	13.6	No yellowing	No yellowing	Yellowing starts
40	14.7	No yellowing	No yellowing	Yellow discoloration
40	15.7	No yellowing	No yellowing	Yellow discoloration
45	13.1	No yellowing	Yellow discoloration	Yellowing darkens
45	13.6	No yellowing	Yellow discoloration	Yellowing darkens
45	14.7	Yellowing starts	Yellow discoloration	Yellowing darkens
45	15.7	Yellowing starts	Yellow discoloration	Yellowing darkens
Control (15°C)	13.1–15.7	None	None	None

Data from Zaoqing Grain Bureau, Guangdong Provincial Grain Bureau.

Table 1.3 Quality changes when *indica* rice has yellowed during paddy storage.

	Sprout rate (%)	Moisture (%)	Brown rice rate (%)	Acid value (%)	Fatty acid value*	Reducing sugar (%)	Viscosity (η)
Control	86	10.00	78.75	1.63	11.08	0.233	1.30
Yellowed (22%)	39	10.40	77.30	1.66	111.30	0.414	1.20
Yellowed (45%)	35	10.45	77.00	120.50	120.50	0.520	1.11

*mg KOH/100 g dry basis.

Temperature (°C)	Moisture content (%)			
	13.1	13.6	14.7	15.7
Original	84.6	84.6	85.0	84.2
30	75.8	75.6	72.9	68.1
35	66.1	65.0	63.4	63.6
40	64.4	63.5	61.4	59.7
45	60.9	60.9	59.5	59.5

Table 1.4 Evaluation scores* of *indica* rice that has become yellowed during paddy storage.

*Rice with evaluation score of 70 or below is considered unsuitable for storage. See text for the quality control equation used to calculate the evaluation score.

able for storage insects. The principal pests of paddy and milled rice are the beetles *Sitophilus oryzae*, *Sitophilus zeamais*, *Rhyzopertha dominica* and *Oryzaephilus surinamensis* and moths *Sitotroga cerealella* and *Plodia interpunctella* (Vol. 1 p. 96, Hodges 2002). Moulds are the most significant micro-organisms attacking paddy (Table 1.5) and their growth and propagation is closely related to moisture content and temperature. Paddy harvested around the lake area of south China will usually have high moisture content due to frequent rainfall.

China's paddy storage loss is low in terms of quantity since grain storage experts have accumulated extensive

experience on the storage of this form of rice. Nevertheless, quality loss of paddy and milled rice is substantial. Long storage periods due to bumper harvests in consecutive years lead to quality deterioration. Paddy shows a sharp fall in quality by the end of the second year in storage and further deterioration occurs during the third year for both *indica* and *japonica* rice (Table 1.6). There is also some decline in nutritional values over exceptionally long periods, particularly in protein and vitamin B3 (niacin) (Table 1.7).

Milled rice keeps less well than paddy for two reasons. Its nutritious components are exposed to biodeteriora-

Table 1.5 Fungi associated with paddy in China.

Species	Detection rate (%)	Species	Detection rate (%)
<i>Aspergillus flavus</i>	36.6	<i>Alternaria</i>	1.61
<i>A. niger</i>	4.78	<i>Penicillium</i>	19.86
<i>A. ochraceus</i>	3.19	<i>Fusarium</i>	13.75
<i>A. versicolor</i>	19.40	<i>Rhizopus</i>	2.91
<i>A. candidus</i>	16.45	<i>Mucor</i>	3.90
<i>A. oryzae</i>	14.30	Other moulds	2.63
<i>A. glaucus</i>	5.34		

Table 1.6 Influence of storage period on the quality of *indica* and *japonica* paddy. Source: *Seed Storage and Inspection*, Zhejiang Agriculture University (unpublished).

	<i>Indica</i> rice				<i>Japonica</i> rice			
	Year 0	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2	Year 3
Viability (%)	97.5	93.0	47.0	0	97.5	89.0	4.0	0
Lipid (%)	2.9	2.5	2.0	1.9	3.8	3.0	2.6	2.4
FFA*	15.0	16.4	18.2	45.5	182.0	182.0	195.0	255.0
Salt-soluble N (%)	0.34	0.21	0.22	0.17	0.22	0.22	0.19	0.14

*Free fatty acids (mg KOH/100 g dry basis).

Table 1.7 Effect of storage time of paddy on nutrient value.

Years	Moisture (%)	Carbohydrate (%)	Lipid (%)	Protein (%)	FFA*	Vitamin		
						B1	B2	B3
1	13.3	73.9	2.36	8.6	26.8	0.27	0.08	3.28
2	12.5	72.1	2.48	9.03	52.1	0.26	0.08	—
3	13.3	73.9	2.45	9.20	42.1	0.26	—	—
4	12.8	71.2	2.43	8.46	44.4	0.25	0.08	—
5	11.7	72.6	2.40	9.18	60.0	0.25	—	3.16
6	13.2	68.9	2.55	9.39	54.0	0.26	0.08	3.16
7	13.2	67.8	2.43	7.44	43.0	0.24	—	2.08
8	13.6	68.2	2.41	7.10	63.9	0.25	0.06	2.08
9	13.5	—	—	8.75	54.0	—	—	—
10	13.5	—	—	5.1	54.0	—	—	—

Data from Sichuan Provincial Grain Bureau. *Free fatty acid (mg KOH/100 g).

tion and it absorbs moisture quickly, since it is rich in hydrophilic colloids such as starch and protein. Moist rice is easily attacked by fungi and insects. Milled rice is also susceptible to ageing, leading to discoloration, increase in acidity value, natural flavour loss, viscosity reduction and deterioration in cooking qualities. If the rice has not been well polished then some bran layer may remain. This is rich in lipids, and oxidation resulting from unfavourable storage conditions will lead to rancidity through the formation of free fatty acids. The flavour of cooked rice is connected mostly with carbonyl compounds. After long periods of storage, grain will have an altered carbonyl profile and hence altered flavours on cooking (Table 1.8).

Commodity and pest management regimes

Management of paddy

Quality control of paddy entering a store is extremely important. Before entry into store, paddy must conform to safe moisture content standards. These standards vary according to the type of paddy, harvest season and temperature of storage (Table 1.9). In China, early and

middle season harvested paddy are easily within the safe storage moisture limit for they are harvested when the air temperature is high. However, late harvested paddy always has a relatively high moisture content as it is harvested when air temperatures are relatively low. Therefore, when the late harvested paddy is stored it is necessary to reduce the moisture in winter and spring. Generally speaking, moisture limits for *japonica* are higher than for *indica* rice. Late harvested paddy limits are higher than those for early harvested paddy, limits for winter harvested paddy are higher than for summer harvested and limits for paddy grown in the north are higher than for that grown in the south.

If paddy is above the safe limit then there are four ways of reducing the moisture content: drying at ambient air temperatures, mechanical ventilation, hot air drying and in-store drying (Vol. 1 p. 157, Boxall 2002). Grain depots are dependent on sun drying for about 50% of their drying capacity (Ren Yonglin & van S. Graver 1996); the rest is provided by other means. When using hot air drying, for example by rotary grain dryers, if the paddy is at below 18% m.c. then it can be reduced to 14.5–15% m.c. in a single step. The air temperature should be roughly 200°C and the temperature of the paddy at output from the dryer below 55°C. To avoid cracking, grain moisture should not be reduced by more than 3% in any one step of a drying process; for paddy at above 18% m.c., drying will require at least two steps with tempering and convection cooling after each step. Since the end of the 1980s, in-store drying has been undertaken in China. In-store drying at low temperature by slow aeration can maintain paddy quality cheaply as heating costs are avoided and, because it is done in store, there are no transportation, loading or unloading costs (Zhao Simeng 1996; Dai Tianhong & Cao Chongwen 1996).

Provided paddy is at an acceptable moisture content then its suitability for storage can be assessed using the following quality control equations that have been

Table 1.8 Change in proportions of volatile carbonyl compounds of cooked rice stored at different temperatures.

	Carbonyl compounds (%)	
	5°C	40°C
Acetaldehyde	50.8	25.1
Acetone	31.0	42.1
Butanone	11.0	8.9
Pentyl aldehyde	—	4.9
Hexyl aldehyde	7.2	19.1

Temperature (°C)	Limits of moisture content (%)			
	<i>Indica</i> type		<i>Japonica</i> type	
	Early season	Middle and late season	Early season	Middle and late season
30	< 13	< 13.5	< 14	< 15
20	~ 14	~ 14.5	~ 15	~ 16
10	~ 15	~ 15.5	~ 16	~ 17
5	< 16	~ 16.5	< 17	< 18

Table 1.9 Safe storage moisture limit of paddy according to rice type, harvest season and prevailing storage temperature.

devised to give an 'evaluation value' for *indica* and *japonica* rice:

$$Y_{\text{indica paddy}} = 65.7 + (0.07 \times \text{germination rate}) - (0.25 \times \text{free fatty acid value}) + (1.7 \times \text{viscosity})$$

$$Y_{\text{japonica paddy}} = 86.3 + (0.005 \times \text{germination rate}) - (0.25 \times \text{free fatty acid value}) + (1.7 \times \text{viscosity})$$

Grain is considered unsuitable for storage if the evaluation value falls below 70 or if the FFA value is above 25 mg KOH/100 g or the viscosity less than 4.5 mm² s⁻¹ (Table 1.10).

Conventional storage in warehouse, silos and bins

Most paddy is stored in conventional warehouses in jute or polypropylene bags. These bags are thoroughly cleaned before they are filled. In bulk or bag storage, foreign matter should be removed before the paddy is stored. Foreign matter can accumulate in 'belts' when conveyors are used to load paddy into a horizontal warehouse, or in 'hoops' if loading into bins or silos that do not have a cloth funnel. Organic foreign material is a hidden danger because of its high moisture absorption and high fungal load. Fine bran reduces the gap between the grain kernels and so any heat generated will disperse more slowly. The impurity limit is strictly enforced although there are different limits for horizontal warehouses (1%) and bins (0.5%).

Particular attention should be paid to early aeration and, once aeration is complete, making the store airtight. Timely aeration can prevent the paddy stack from forming dew, giving out heat and going mouldy. The warehouse should be made hermetic once the paddy has been

aerated in winter so that it can be kept at low temperature during the summer. Natural aeration in winter is widely employed in China's horizontal warehouses, and sometimes use is also made of mechanical aeration. Axial and mixed flow fans are usually employed in horizontal warehouses while centrifugal fans are used in bins.

In conventional storage, both fumigants and residual insecticides are used for insect control. The most widely used fumigant is the gas, phosphine, which must be applied at concentrations of at least 70–100 ppm over extended periods to be effective. The dosage can be raised if *Rhizopertha dominica* or pests that have developed some resistance to phosphine are present. Conventional fumigation under gas-tight sheet is applied to the bag stacks in horizontal warehouses. Circulated fumigation is applied in large horizontal warehouses or bins where these can be made sufficiently airtight. The pressure half-lives of the stores (500 Pa to 250 Pa) should be not less than 40 s in the horizontal warehouses and no less than 60 s in silos. Residual insecticides such as malathion, fenitrothion, pirimiphos-methyl, decamethrin or a mixture of decamethrin and malathion are sprayed onto paddy bag stacks.

Low-temperature storage

In smaller horizontal warehouses, natural-air low temperature and mechanical low temperature ventilation is used. Paddy in other stores may be chilled using air conditioners, refrigeration units or cereal coolers. Refrigeration units are the most expensive due to rigid requirements for insulation and the high cost of maintenance (Ju Jinfeng 1997).

Table 1.10 Quality control classification for storability of *indica* and *japonica* type paddy.

	<i>Indica</i> type			<i>Japonica</i> type		
	Suitable for storage	Unsuitable for storage	Aged	Suitable for storage	Unsuitable for storage	Aged
Evaluation value	≥ 70	< 70	—	≥ 70	< 70	—
Fatty acid value*	≤ 25	25–32	> 32	≤ 25	25–32	> 32
Viscosity (mm ² s ⁻¹)	≥ 4.5	4.5–2.5	< 2.5	≥ 10	10–4	< 4
Taste score	≥ 70	< 70 ≥ 60	< 60	≥ 70	70–60	< 60
Colour	Normal	Normal	Abnormal	Normal	Normal	Abnormal
Flavour	Normal	Normal	Odour	Normal	Normal	Odour

Data from National Grain Reserve Bureau and National Quality and Technology Monitoring Bureau, July 1999 (unpublished).

*Free fatty acids (mg KOH/100 g dry basis).

Cereal coolers for low-temperature paddy storage have been adopted in large horizontal warehouses and bins. They are movable cooling ventilators that can also reduce humidity (Fig. 1.3). The coolers consist of a chilling system and temperature and humidity regulating systems and come in three cooling capacities: 100 kW, 50–100 kW and less than 50 kW. They work by drawing air into an evaporator through a filter net and cooling it by heat exchange. When the humidity of the cooled air is excessive, the back heating installation will warm it and reduce the relative humidity to a specified level. The cooled air is then pumped into the paddy pile through ventilation ducts and air distributors to lower the temperature and to control the humidity of the pile. Effective results can be achieved by cooling the grain in winter using natural cold air and timely mechanical aeration, and in the second year, when it becomes warm, giving supplementary cooling using the cereal cooler.

Air conditioners are used to cool paddy in many large and medium-sized cities. The temperature of this kind of quasi-low-temperature air-conditioned warehouse is controlled at 15–20°C. It can inhibit respiration, limit



Fig. 1.3 Cereal cooler used for cooling paddy or milled rice stocks, shown here attached to a sealed warehouse in China.

damage by insects and moulds and maintain rice quality.

Controlled atmosphere storage

The gas changes occurring in paddy stored hermetically, at different moisture contents and temperatures, have been researched in China. The moisture content and temperature of freshly harvested paddy is usually high and, as there are also usually insects in the paddy, oxygen becomes depleted rapidly to levels that prevent insect population growth (Table 1.11). However, paddy that has already been well dried reduces oxygen concentrations much more slowly. Thus, in practice, paddy should be contained in an airtight enclosure and oxygen needs to be displaced by filling the enclosure with carbon dioxide or nitrogen. Generally, carbon dioxide is preferable to nitrogen as it is more readily available and, unlike nitrogen, is toxic to insects. Experiments have shown that even when paddy, at less than 13% m.c., is stored under carbon dioxide for more than four years, loss in grain viability is only slight.

Open-air storage

Open-air storage is needed when there is insufficient warehouse capacity. It is a temporary storage method to protect paddy from sunlight, moisture ingress, insects, mice and squirrels. The paddy may be stored in bags or in bulk and placed on a plinth made of bricks, earth or concrete. The size and shape of the plinth depends on the amount of grain to be stored; there are several common sizes to support various quantities of grain (Table 1.12). The materials used to cover the paddy vary. Bags stacks may be covered by reed mats, straw, bamboo, fibreboard or polypropylene, while the circular cone of bulk paddy may be covered with straw, tarpaulin, PVC polyvinyl alcohol fibre, double-coated plastics or reed matting. Open-air storage has improved due to the development

Temperature (°C)	Moisture (%)	Length of hermetic sealing (days)	O ₂ concentration (%)
31	17.0	10	0.2
21	17.0	15	0.2
21–22	17.6	10	0.2
21–22	16.7	20	0.2
21–22	15.6	30	0.2
13	17.0	30	8.4

Table 1.11 Factors affecting oxygen concentration of paddy under hermetic conditions.

Table 1.12 Size of open-air storage plinths and the amount of paddy that can be stored on them.

Shape of plinth	Size of plinth (m)	Piling type	Storage height	Amount (tonnes)
Round	7 (diam.)	Bulk	6 m	100
Round	8 (diam.)	Bulk	4.5 m	150
Square	6 × 10	Bulk	4 m	—
Square	10 × 10	Bag	15 layers	200

of suitable materials and, provided reasonably gas-tight covers are used, can be combined with fumigation and cooling by ventilation as and when necessary.

Management of milled rice

The quality of the incoming rice must be ensured, and milled rice of different grades and variety should be distinguished. Rice with moisture content and impurity levels above the national limits is not generally accepted into store. The safe moisture content varies according to temperature of storage (Table 1.13), and this becomes particularly important if rice is to be stored through the summer as in southern parts the maximum temperatures may reach at least 35°C. The standards enforced vary according to the period of harvest and the grain type (Table 1.14).

Table 1.13 Safe moisture contents of milled *indica* rice under different storage temperatures.

Temperature (°C)	Moisture content (%)
0	18
5–10	≤ 16
20	≤ 14
25	≤ 13.5
30	≤ 13
35	≤ 12
40	≤ 11

Table 1.14 Moisture content standard for milled rice stored through the summer according to rice type and season of harvest in China.

Type of milled rice	Moisture standard		
	Safe grain	Semi-safe grain	Unsafe grain
Late season <i>japonica</i> 'normal' and glutinous	< 14.5	14.6–15.0	> 15.1
Early season <i>japonica</i>	< 13.5	13.6–14.0	> 14.2
Late season <i>indica</i> 'normal' and glutinous	< 13.0	13.1–13.5	> 13.6
Early season <i>indica</i>	< 12.5	12.6–13.0	> 13.1

Milled rice should be monitored during storage. Moisture content, temperature, insect damage and quality decline indexes should be checked regularly. When controlled atmosphere storage is being used then gas composition concentration should be checked regularly.

Conventional storage

Conventionally, milled rice is stored at ambient temperature and humidity but for long-term storage timely aeration and sealing with a cover is necessary to maintain quality. Heat and moisture can be reduced by ventilation in the cold season when the rice is received and the cooled rice then insulated by sealing under a cover. Newly processed milled rice should be cooled to ambient temperature before it is stacked in a store. If the moisture of the milled rice is too high then it should be ventilated before it is sealed under covers.

Low-temperature storage

Low temperature can ensure the freshness of the milled rice, prevent insect damage and maintain its natural colour, flavour and taste. Stored milled rice can be chilled cheaply by allowing cold winter air to enter stores through ventilators and open doors. This can reduce temperature quickly but is slow to reduce moisture content. The same effect can be achieved using mechanical ventilation. This method, although quick in reducing temperature and less expensive than air conditioning, may

cause excessive moisture loss and is entirely dependent on the prevailing climatic conditions. Sometimes, window air conditioners are installed in warehouses to keep the temperature around 20°C. This technique is less expensive than refrigeration but the rate of temperature drop is slow, especially in the middle and bottom layers of bag stacks. Cereal coolers, mentioned earlier, have been adopted for low-temperature milled rice storage. These machines are very effective in maintaining milled rice at high quality and have a bright future.

Controlled atmosphere storage

There are four types of controlled atmosphere approaches applied in milled rice storage: storage under naturally low oxygen conditions created in an hermetic environment, filling with nitrogen, filling with carbon dioxide or storage under vacuum. These may be used for bag stacks where hundreds of tonnes of rice are sealed into plastic envelopes – a similar technology has been developed for milled rice storage in Indonesia (Nataredja & Hodges 1989) – or for small quantities sealed into packets made of special films such as polyester/polyethylene composite. Safe hermetic storage of milled rice depends on appropriate m.c., temperature and oxygen content. Rice at 13.5% m.c. at 30°C can be stored safely in air with a normal oxygen concentration. Rice at 14.5% m.c. should be stored in an atmosphere containing only 0.5% oxygen. If the moisture content of the rice is above 15.5%, it cannot be stored safely even if the oxygen concentration is kept as low as 0.5%, unless the temperature is reduced to 20°C.

If nitrogen or carbon dioxide is to be used then bag stacks of milled rice are sealed into a plastic envelope and air is extracted to create a partial vacuum. The envelope is then gassed with either nitrogen or carbon dioxide. Generally speaking, the nitrogen concentra-

tion should be more than 95%, the moisture content of the milled rice should be less than 16.5% and the room temperature should be under 20°C. This method is effective in killing insects and inhibiting micro-organism growth. Using the same technique, but instead applying carbon dioxide at the rate of 1 kg per tonne of rice, insect and mould attack can be restrained and grain quality maintained. For the domestic market, 5 kg and 10 kg packets of milled rice filled with carbon dioxide are available. The carbon dioxide concentration in the pack at the time of sealing is about 70% but falls to about 40%. Since carbon dioxide is strongly adsorbed onto milled rice, the rice packed this way appears to be under vacuum. This method is very effective in preserving freshness.

For storage under vacuum, polyester/polyethylene composite of 0.13–0.14 mm thickness is used as the material for vacuum packs. Milled rice with a moisture content less than 15.5%, packaged in a vacuum and held this way for two years, maintained better quality than rice stored in conventional sacks (Table 1.15). However, the choice of packaging material is important: polyester/polythene mix works well whereas polyvinyl chloride appears a little less effective. Materials vary considerably in their gas permeability and this needs to be taken into account when planning modified atmosphere or vacuum storage (Table 1.16).

Economics of storage

Evaluations of the cost of grain storage are very difficult to obtain. However, the estimated annual cost of paddy storage in horizontal warehouses, including fumigation and handling, is relatively low, up to about RMB40 (\$US5) per tonne. If ordinary mechanical ventilation for lowered temperature is included this rises to about RMB80 (\$10) per tonne (Table 1.17); milled rice is

Table 1.15 Quality comparison of vacuum-packed and conventionally packed *japonica* rice.

Variety	Packaging material	Weight (kg)	Sensory evaluation
Special 2	Polyester/polyethylene	20	Normal flavour, no insects or moulds. A little yellow when opened
Standard 1	Polyester/polyethylene	20	Normal flavour, no insects or moulds. A little yellow when opened
Special 2	Polyvinyl chloride	20	Both quality and colour aging
Standard 1	Polyvinyl chloride	20	A little rancid odour and discoloration
Special 2	Open weave sack	50	Strong rancid odour and insects present
Standard 1	Open weave sack	50	Strong rancid odour and insects present

Plate 5 Freshly harvested sorghum grain (*Sorghum bicolor*) in good condition (left), infested, discoloured sorghum after eight months of inadequate farm storage (right).



Plate 6 Common or dry beans (*Phaseolus vulgaris*).





Plate 7 Cowpeas or blackeyed beans (*Vigna unguiculata*).



Plate 8 Bulk canola seed (*Brassica napus* or *B. rapa*) in storage. The seed is small (usually about 1.5 mm diameter) and depending on variety 1000 seeds may weigh only 2.5–5.0 g.



Plate 9 Peanut pods and kernels
(*Arachis hypogaea*).



Plate 10 Dried coconut kernel
(*Cocos nucifera*) – copra.