Effects of High Temperature Drying on Rice Quality

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Keywords: Fluidised bed dryer, Rice quality, Ergosterol

Abstract
Recent research on a form of two-stage drying shows significant advantages in terms of energy saving and quality deterioration, especially fungal deterioration. In two-stage drying, the first stage uses high-temperatures (up to 150°C) to reduce grain moisture from field level to about 18% wet basis quickly. The first stage is followed by a second stage, usually performed at near-ambient temperature, which will reduce the moisture content to 14% wet basis, which is adequate for storage or milling of rice. There are obvious advantages in adopting the two-stage drying concept, such as an increase in drying capacity of the first-stage dryer and low energy consumption in the second stage resulting in a substantial overall energy saving. It was found that recent development of a commercial-scale fluidised bed dryer and current work on spouted bed dryers make these dryers suitable options for the a first stage dryer. The quality of both long and medium grain rice were compared over three drying strategies; fluidised bed drying at 80-90°C (single stage), fluidised bed and in-store drying (two stage) and in-store drying alone (single stage). Quality aspects measured were head rice yield, gel consistency, water absorption, volume expansion, amylose content, pasting properties, digestibility and ergosterol levels.

1. Introduction
Rice belongs to the major economic crops of Southeast Asia. At present, Thailand and Vietnam are among the main worldwide exporters of rice, with 6.4 and 3.8 million tonnes of milled rice respectively exported in 1998 (FAO, 2000). In Southeast Asia there are two or three crops of rice per year. The moisture content of paddy at harvest can be as high as 22-26% wet basis (wb), especially in grain harvested during the rainy season.

In order to prevent deterioration after harvest, paddy should be dried down to a level of water activity that will enable safe storage by reducing respiration, inhibiting mould growth and preventing production of mycotoxins. This corresponds to a moisture content of about 13-14%wb, which is considered adequate for safe storage, milling and further storage as milled rice (Hall, 1970).

Mechanical systems, especially those using hot air for rapid drying of high moisture grain are becoming increasingly popular throughout the region (Soponronnarit et al., 1996 and Hung-

Nguyen et al., 1999). Fluidised and spouted bed dryers are examples of high temperature dryers. Due to the high air temperatures used, residence time of grain in the dryer must be short to prevent heat damage.
The advantages of fluidised bed drying can be summarised as follows:

- uniform product moisture content due to complete mixing of grain,
- high drying capacity due to high ratio of air mass to mass of product and high surface contact area with the product,
- increased drying rate due to increased contact area of product with the drying air,
- fast handling of large amounts during harvest,
- small equipment footprint, and
- recycling of exhaust air which significantly reduces energy consumption

Fluidised bed dryer is most efficient in the range of moisture contents between 18-31%wb (Taweerattanapanish *et al.*, 1999), as below 18% the grain moisture requires time to diffuse to the surface, and grain brittleness increases rendering the grain prone to fissuring. Therefore, the most appropriate way of using this type of dryer is as part of a two stage drying system. This drying strategy enables the user to reduce costs and to optimise product quality. Two stage drying concept consists of an initial rapid stage followed by a slow drying stage. Rapid drying reduces moisture content from field moisture (as high as 30%), down to 18% wb using a high drying air temperature. During the first stage of drying, mostly surface moisture is removed from the paddy. During the second stage of drying, moisture is further reduced to 14%, using lower drying air temperatures. There are several options for this stage, one of them being ventilation of a deep bed with near ambient air. The moisture removal process during the second stage of drying is driven by diffusion of moisture in the endosperm. This process is slow and can be performed during storage of grain - hence the term in-store drying.

According to Morey et al. (1981) the main advantages of two-stage drying are as follows:

- Reduced energy requirement due to the increased air efficiency as compared with continuous-flow dryers alone, so that less heat is vented to the atmosphere.
- Increased drying system capacity. This point is related to the capacity of the first stage dryer, since discharge of the grain at a higher moisture content before cooling will free the dryer for next load of high moisture grain, which is where continuous dryers are more efficient.
- Improved grain quality. This point relates to the relaxation time during the second stage of drying. The moisture gradients within the grain will dissipate during that stage, preventing the outer layer of the grain from being overdried, and hence brittle and susceptible to cracking.

However, the use of high temperatures in paddy drying may affect some of the sensory and processing quality attributes that influence the acceptance of the commodity by the buyers at different stages of the marketing chain. The aim of this study was to determine the effects of high temperature drying on the physico-chemical properties of grain which may result in changes in cooking characteristics. The effects of high temperature drying on the level of fungal activity in grain were also studied. Fungal and particularly mould activity is likely to influence grain storability.

2. Materials and methods

2.1 Rice Samples

Two varieties of paddy, namely Amaroo, a medium and Langi, a long grain variety, were procured from the Murrumbidgee Irrigation Area in New South Wales. After harvest, paddy had been dried in aerated bins down to about 14% moisture content wet basis (wb). Samples of dry paddy were brought to the laboratory and stored at about 10°C.

2.2 Methods

Paddy rice was rewetted by adding calculated amounts of water and stored at a constant temperature of 4°C until moisture content rose to about 30% wb. Three drying strategies were used:

- Drying in a single stage in a fluidised bed dryer at a temperature of 85-90 ^{o}C for 11 minutes, resulting in a final moisture content of about 14% with an airflow rate of 66 m/min.
- Two-stage with a first stage in a fluidised bed dryer for 4 minutes until the moisture content reached about 18% under the same conditions as above. The second stage was carried out in an in-store dryer at ambient temperature until the moisture content was reduced to 14% with an airflow rate 6 m/min.
- Drying in a single stage in an in-store dryer only, under the same conditions as above.

Physical and chemical properties were measured before and after drying.

Rough rice was dehulled with a Satake bench dehusker and milled with a Satake bench mill. Milled rice was separated by an indent cylinder type grader in order to determine head rice yield and the amount of broken kernels. The percentage in weight of head rice and broken kernels was obtained by calculation.

Cooking qualities included water absorption and volume expansion. 600 g of milled rice were cooked in an automatic electric cooker (1:1.5 and 1:2 by weight rice/water ratio for long grain and medium grain respectively). These ratios were determined by sensory analysis. Volume expansion was calculated as the increase in volume by displacement, and water adsorption was calculated as the percentage increase in weight, both expressed in percent.

Grain was ground to flour, then passed through a 125-mesh sieve prior to analysis of physico-chemical properties. The amylose content was determined by the simplified assay method of Juliano (1991) and expressed on dry weight basis. The digestibility was determined according to the method of Chaudhry (1979). The gel consistency was determined according to the method of Cagampang et al (1973). Pasting properties were determined by rapid visco analyser (RVA), following the method of Thiewes and Peter (1997).

Ergosterol, which is the predominant sterol in most fungi, was used as an indicator of fungal invasion in grain. Ergosterol analysis offers the potential to measure live fungal biomass, because of its localisation in membranes and oxidation upon cell death. Solid phase extraction (SPE) followed by high performance liquid chromatography (HPLC) was used to determine ergosterol in the paddy extract according to procedures described in Gessner and Schmitt (1996) and Srzednicki et al. (2000).

Four replications were used in all experiments.

3. Results

3.1 Head Rice Yield

The results of the experiments are shown in Figure 1. The experimental data indicate that the drying method can affect the head rice yield. Long and medium grain batches that were dried in a fluidised bed down to 14%wb had lower head rice yield and a higher percentage of broken kernels than samples dried in the in-store dryer as well as the samples dried in a fluidised bed plus in-store dryer. This effect was more pronounced in long grain than in medium grain rice. The samples dried in the in-store dryer, with or without an initial drying in the fluidised bed, had a higher head rice yield, 70.0-77.8% and 78.3-83.4% for medium and long grain respectively (see Figure 1). This result confirms findings by Soponronnarit et al. (1996) and Taweerattanapanish *et al.* (1999) related to a moisture content of 18%wb as a lower limit for maximum head rice yield when using a fluidised bed dryer at high temperature.

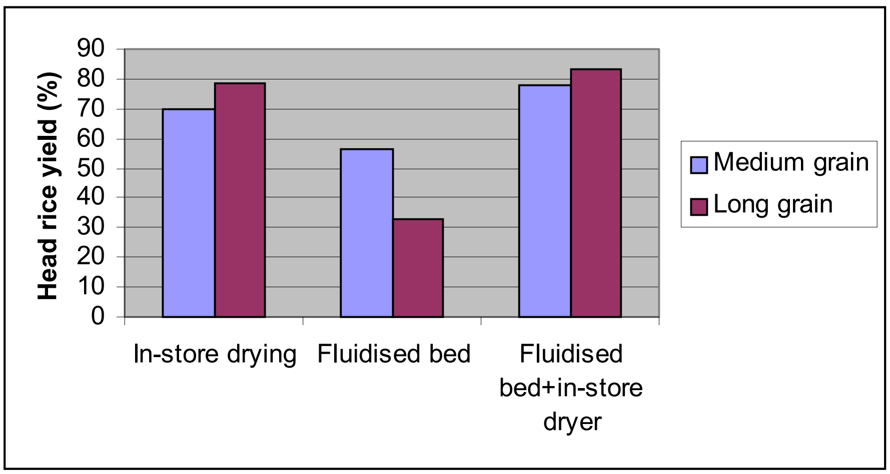


Figure 1: Effects of drying method on head rice yield in medium and long grain

3.2 Gel consistency

The results of this test can be seen in Figure 2.

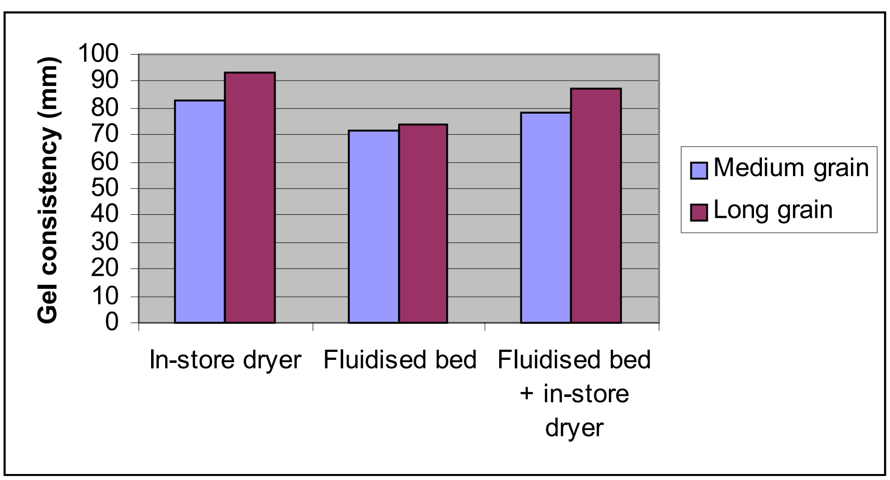


Figure 2: Effects of drying method on gel consistency in medium and long grain

The samples dried in the in-store dryer showed the highest gel consistency, 93 mm in long grain and 81 mm in medium grain. Samples dried in the fluidised bed showed the lowest gel consistency. Those dried in the fluidised bed followed by in-store dryer were showing 87 mm and 78 mm. for long and medium grain respectively. All of rice samples were characterised by soft gel consistency, however with medium grain showing consistently lower values. Soft gel consistency refers to values in excess of 60 mm.

3.3 Water absorption and volume expansion

Water absorption and volume expansion of cooked rice are presented in Table 1. The results show higher values for medium than for long grain for all treatments. This was expected due to larger amount of water added to medium grain samples. Drying in the fluidised bed plus in-store resulted in the highest water absorption for both varieties.

Table 1. Effects of drying method on volume expansion and water absorption in medium and long grain

Drying Method	Volume expansion (Δ volume, cm^3)		Water absorption (%)	
	Medium	Long	Medium	Long
In-store dryer	1137.5	1083.4	176.6	130.7
Fluidised bed	1087.7	973.6	173.1	128.3
Fluidised bed + in-store dryer	1115.4	950.4	179.3	134.4

3.4 Amylose content

The results of amylose content determination as a function of the drying treatment are shown in

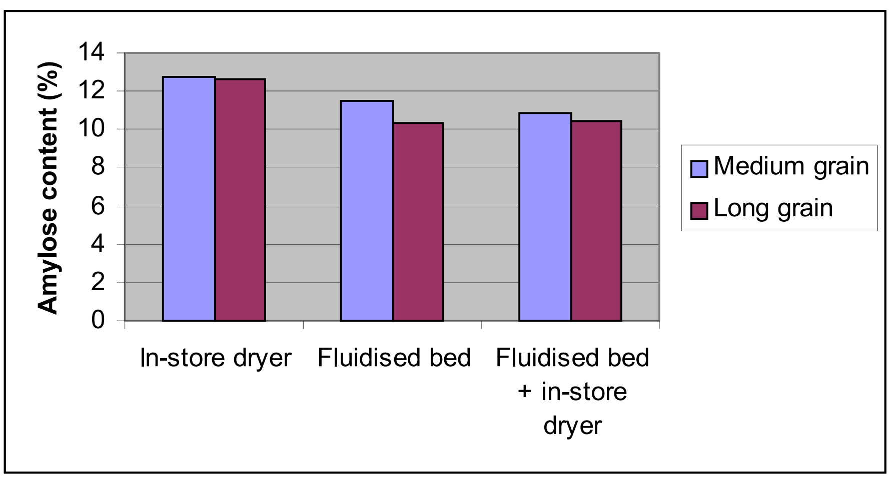


Figure 3.

Figure 2: Effects of drying method on amylose content in medium and long grain

The amylose contents decreased for both drying methods using hot air. Long and medium grain did not differ significantly with regard to amylose content. Amylose levels in rice samples dried in the in-store dryer were 12.6 and 12.7% in long and medium grain respectively. The levels in samples dried in the fluidised bed were 10.3 in long and 11.5 % in medium grain. The results indicate that the drying methods but not the varieties of rice had affected the amylose contents in dried paddy.

3.5 Digestibility

The results of the digestibility tests are shown in Table 2.

Table 2. Effects of drying method on the digestibility of medium and long grain

Drying Method	Digestibility (mg maltose/100 mg dry wt.)	
	Medium	Long
In-store dryer	56.0	60.6
Fluidised bed	58.3	57.0
Fluidised bed + in-store dryer	55.9	59.1

The digestibility does not appear to be affected by the drying method or the variety of rice used in the experiments.

3.6 Rapid visco analyser

The results of drying tests on the pasting properties of rice are shown in the Table 3. The peak viscosity of batches dried in the in-store dryer was higher than that of those dried in the fluidised bed followed by in-store dryer, which was higher than that of those dried in the fluidised bed for both varieties. The pasting temperatures showed the opposite trend.

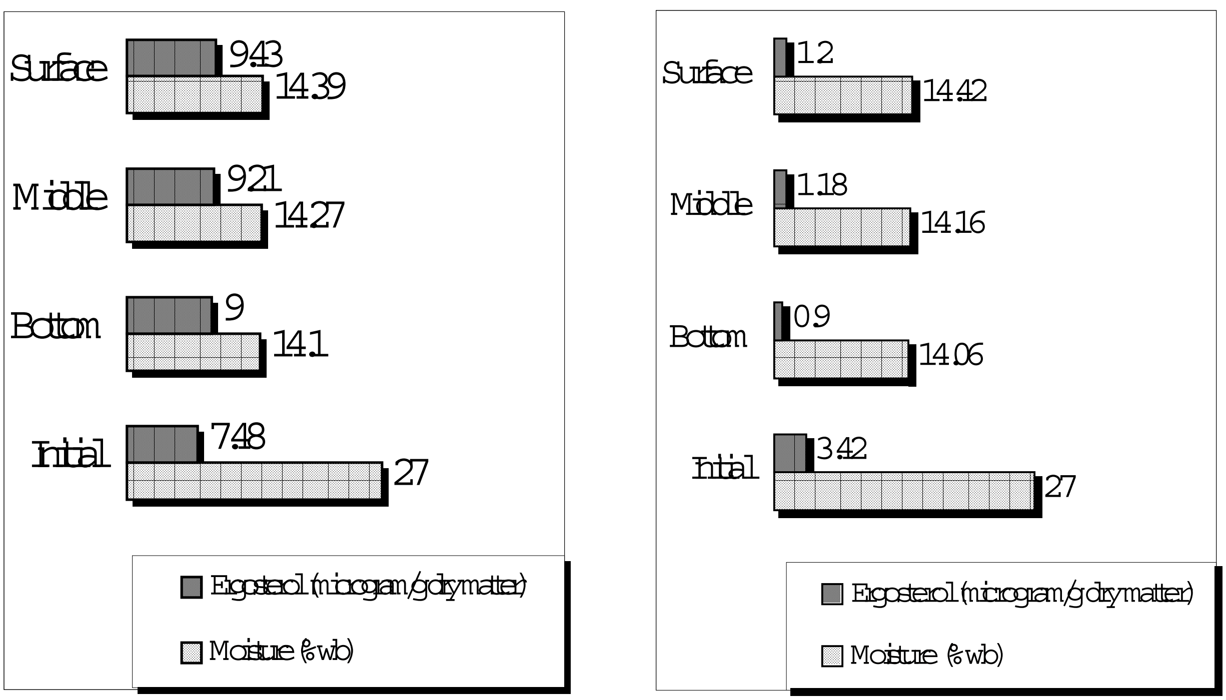
Medium grain showed higher peak viscosity after in-store drying whereas both varieties showed similar values for both treatments using high temperatures. The pasting temperatures were generally higher for long grain varieties irrespective of the drying method used.

Table 3. Effects of drying methods on the pasting properties of medium and long grain

Drying Method	Peak viscosity (RVU)		Pasting temperature (^{o}C)	
	Medium	Long	Medium	Long
In-store dryer	217.1	208.6	71.1	77.7
Fluidised bed	171.4	175.6	72.0	78.7
Fluidised bed + in-store dryer	204.2	203.0	73.3	79.0

3.7 Ergosterol determination in paddy

In this experiment only samples of long grain paddy variety Langi from in-store dryer and fluidised bed + in-store dryer treatments have been analysed. The results of the ergosterol determination in samples subjected to both drying treatments are shown in Figure 3.



a) in-store drying b) fluidised bed drying + in-store drying

Figure 3: Moisture and ergosterol content of dried paddy rice

The ergosterol levels in samples dried in the in-store dryer show an increase in ergosterol levels as compared with the initial levels. In contrast to that, the samples from the fluidised bed dryer followed by in-store dryer show a decrease in ergosterol levels. According to Naewbanij (1985), the ergosterol levels in paddy stored at 16%mc are between 4-5 μg/g dry matter. Furthermore, there is no marked difference in ergosterol levels between long and medium grain varieties stored at different temperatures at that moisture content. Although the initial levels in the samples investigated in this study showed low initial levels of ergosterol, a reduction of the initial levels may indicate either a thermal degradation of ergosterol or decrease in overall fungal activity. The exact mechanism is currently being investigated by the authors.

4. Conclusions

The above study on effects of two hot air drying methods as compared with in-store drying alone showed that the following properties have been affected:

- Drying by fluidised bed to 14% (one stage) resulted in decreased head rice yield. Drying by fluidised bed to 18% followed by in-store drying to 14% (two stage) resulted in the best head rice yield, superior to that obtained using in-store drying alone.
- Gel consistency was significantly affected by both methods which involved higher temperature (i.e. used the fluidised bed dryer). However, gel consistency remained within the soft gel range.
- Water absorption and volume expansion were both affected by drying in a fluidised bed to 14% moisture content. Water absorption was not affected by the combination of drying with a fluidised bed followed by in-store dryer. Volume expansion was affected by both methods which used high temperature.
- Amylose content was affected by both methods of drying using high temperatures.
- Ergosterol content decreased when paddy was dried in the fluidised bed as a first stage of drying, indicating reduced mould growth.

The two rice varieties did not respond in the same way to high temperature drying treatments:

- Head rice yield was higher for the long grain variety.
- Gel consistency was also observed to be higher for long grain rice.
- Water absorption was higher for the medium grain (also due to larger amount of water added) whereas volume expansion was higher than for the long grain variety.
- Amylose content was higher for medium than for the long grain variety.
- Digestibility was higher for the long grain variety. The opposite trend was observed for fluidised bed drying to 14%.

Acknowledgment

The authors of this paper would like to take this opportunity to acknowledge the financial support of the Australian Centre for the International Agricultural Research that has provided funding for this project. The support of the Royal Thai Government that provided scholarships for the Thai scientists should also be acknowledged.

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