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Effects of chilled aeration on grain quality

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Abstract

Grain drying trials with refrigerated and ambient air were conducted to study the effects of chilled aeration on grain quality. The paper discusses the experimental procedures and the changes in quality attributes of rice and corn. The quality attributes measured in this study were: milling yield, cooking properties, pasting properties and germination. The average grain temperature during in-store drying was 28 °C whereas temperature as low as 6 °C was maintained for chilled aeration. Rice grains were dried from 18.3 % to 12.6 % using chilled air and from 18.5 % to 13.4 % using ambient air. Similar reduction in moisture contents was obtained for corn: 19.3 % to 12.4 % for chilled and 19.3 % to 11.5 % for in-store dried grain. Milling yield of rice was not significantly affected by the drying treatments. Significant differences in pasting properties of rice and corn were observed. The peak viscosity of corn varied by as much as 40 RVU between the two treatments. A highly significant difference in germination was observed. Chilled aeration proved to better preserve the grain viability. A significantly reduced cooking time was observed for rice treated with chilled air. Lower gruel solid loss was observed for ambient air drying treatment. Technological relevance can thus be derived from the differences in various quality attributes arising from both treatments.

Key words: grain chilling, in-store drying, rice, corn, milling yield, pasting properties, germination.

Introduction

Cereal grains are amongst the main staple foods in the world. For some countries the economic importance of cereals is greater than any other merchandise. In order to meet year round demand for cereal grains, the latter is stored from one harvest to the next. Grains produced in one part of the world may also be shipped to other parts. Storage and transportation of grain face challenges like insect infestation, microbial spoilage, respiratory losses and moisture migration. The most practiced and widespread method of storage involves drying the grains to a safe moisture level.

Wheat, rice and corn are mostly grown cereal crops in the world. The economic value of these grain crops comes from the end use they are put to. The better the quality of raw cereals, the higher are the rewards to the producers and processors. In order to maintain the quality of grain, adequate storage techniques must be devised. Therefore, postharvest handling, including drying and storage or cereal grains, have been an area of intense scientific and technical studies.

The most common drying methods employed for drying cereals use natural, low temperature and/ or high temperature air which comes in contact with grain through a bin dryer, column dryer or a combination drying processes.

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Increasing consumer demand combined with global food safety reforms makes grain quality an important and critical parameter in evaluating drying strategies. A considerable number of studies have been conducted and published on the conventional drying techniques and their effects on grain quality. In comparison, less published studies are available on the effects of low temperature treatment on grain quality.

Cereal grains are subjected to stringent inspection prior to export to ensure complete absence of insects. The intricacy of maintaining these requirements is compounded by growing demand of residue free grains. In this context grain chilling has evolved as an attractive physical method of insect control.

As a result, the aeration with refrigerated air has attracted research interest among grain scientists and engineers. Studies conducted so far (Barth, 1993; Maier, 1994; Maier et al., 1997 and Mason et al., 1997) postulate significant advantages of chilled aeration over ambient air aeration in terms of pest management as well as some quality attributes of stored grain. However, more thorough studies on the effects of these two techniques on the technological properties of grain still remain to be done.

Therefore, the current study attempted to experimentally determine and identify the differences in grain quality attributes from the perspective of the user of the end product due to ambient and chilled aeration of paddy and corn.

Materials and methods

Grain samples

Samples of Amaroo, a medium grain cultivar of Australian paddy, were procured from Sunrice Australia Ltd in Leeton, (NSW). The waxy corn samples (variety 33A63) were procured from Penford Australia Ltd in Lane Cove (NSW) plant. The grain samples were originally in-store dried to about 13 % wb (wet basis) by the supplier and stocked in bulk. Immediately after receipt, the grains were stored in a cold room at 10 °C.

Sample conditioning

The purpose of rewetting is to obtain grain with moisture content of around 19 % wb. The rewetted grains exhibit physically and functionally similarity to the freshly harvested grains if rewetting is done carefully. Calculated amount of water was added to dry paddy. Regular mixing and stirring was carried out in order to facilitate uniform moisture distribution through the bulk sample. The rewetted grains were stored in the cold room (4.5 °C). In order to prevent the risk of mould growth, the grain samples were surface treated with 2 % chlorine solution.

Chilled aeration

Grain samples with an initial moisture content of around 19 % wb were placed in a refrigeration unit equipped with a dehumidifier. Ambient air was conditioned by being passed through the evaporator coil in the refrigeration unit and then through the dehumidifier. This air was directed into a 40 cm high grain bed. The chilling air conditions were set to 10 ºC and 75 % relative humidity (RH) initially. The grain was allowed to come to equilibrium with these conditions for a period of 3 days. Subsequently the conditions in the chiller were changed to 5 ºC and 55 % RH. Moisture content in grain was monitored every 5-6 days using a convection oven method (ASAE, 1988).

The chilling treatment was applied until a final moisture content of 12-13 % wb was obtained. The grain bulk and chiller temperatures were measured and logged using calibrated thermocouples placed at various locations. In order to measure wet bulb temperature a wet wick arrangement with continuous air flow provided by a miniature fan was made.

After the chilling treatment was completed, the samples were stored in a closed container at 4 °C. Prior to final sample analysis, a second aeration treatment was given for 4 days in order to ensure uniform moisture distribution.

In-store drying

The grain samples were dried using ambient air at a relative humidity not exceeding 70 %. A laboratory scale in-store dryer equipped with a radial fan with backwards curved blades (Kongskilde, 1.5 kW), electric heaters and a variable speed drive were used in this study. The dryer was equipped with a PC based control system (Advantech, ADAM 5000; Lab View) using a PID control algorithm. At the desired relative humidity, as set by the software, the control system turned on the fan. When the RH exceeded the setpoint, the control system turned on the heaters until the required RH was provided. If the ambient RH was greater than 95 %, corresponding to the rainfall; the fan was shut down in order to prevent excessive energy consumption. The in-store drying system consisted of a plenum chamber covered with a perforated metal plate. Air ducts were situated below this base and were used to supply air at a set velocity. Temperature and relative humidity measurements were recorded using thermocouples and RH probes placed at various locations, including ambient air intake, plenum and exhaust ducting.

Rewetted grain samples (18-19 % wb) were placed as a 40 cm deep bed on the perforated metal plate. A thermocouple was inserted in the middle of the grain bed. Once the grain temperature reached the dry bulb temperature of the ambient air, grain was sampled for moisture content analysis. A sampling during the drying run was avoided in order to avoid the risk of forming channels that would affect the airflow through the bulk of grain.

Grain quality tests

Milling

Milling is a mechanical procedure during which brown rice is subjected to abrasive or friction pressure to remove bran layers from the endosperm to yield white rice. Prior to milling, grains need to be hulled, a stage where husk is removed from the paddy. Care must be taken while hulling so as to ensure minimum damage to bran layer.

A Satake roll rice rubber huller (0.2-0.4 kW, 1900 RPM) was used for dehulling of dried paddy samples (with an initial weight of RR for rough rice). This process was producing a certain weight of brown rice (BW). A Satake abrasive whitener was used for removal of bran from brown rice producing a weight (WR) of white rice. The percent ratio of brown rice (BW) in the total amount of paddy (RR) milled defines brown rice recovery (BRR). The percent ratio of white rice (WR) to the initial amount of paddy (RR) defines the milling yield (MRY).

Pasting properties

In granular form, starch is insoluble in cold water and only slightly hydrated. Thus, starch granules can be dispersed in water, producing low viscosity slurries that can be easily mixed and pumped (Francis, 1999). Upon heating above a particular temperature starch gelatinises. Gelatinisation is the collapse (disruption) of molecular orders within granules resulting in irreversible changes in properties such as granule swelling, native crystallite melting, loss of birefringence, and leaching of soluble components, primarily amylose (Atwell, 1988). Pasting is the phenomenon following gelatinisation when starch slurry containing excess water is heated. It involves further granule swelling, additional leaching of soluble components, and eventually, especially with the application of shear, a total disruption of granules, resulting in molecules and aggregates of molecules in dispersion or solution (Morris, 1990). Starch molecules in an unordered state will undergo a process called retrogradation. Retrogradation (setback) is the reassociation of starch polymer molecules. It occurs when molecules that have become disordered during cooking begin to reassociate in an ordered structure (Hood, 1982). In the initial phases of retrogradation, linear segments of two or more starch chains may form a simple juncture point that may develop into more extensively ordered

regions. Ultimately, under favourable conditions, a crystalline order appears which results in gelation or precipitation (Francis, 1999). The cooking behaviour of starches and the viscosity of the resulting pastes can be studied with an instrument called Rapid Visco Analyser (RVA). A starch suspension is cooked under a defined time, temperature and shear protocol, and its viscosity is continually recorded. The resulting curve reveals the pasting temperature, rate of viscosity development, peak viscosity, rate and extent of viscosity breakdown, and rate and extent of viscosity development during paste cooling (Deffenbaugh and Walker, 1989).

Pasting curves of flour samples (sieved through 100 mesh screen) were obtained using a Rapid Visco Analyser (Series 3) and Thermocline™ software.

Cooking tests

The cooking tests included the determination of minimum cooking time, water uptake ratio and gruel solid loss.

The cooking time was determined by boiling 2 g of whole rice kernels from each treatment in 20 ml distilled water, removing a few kernels at different time intervals during cooking and pressing them between two glass plates until no white core was left.

The water uptake ratio was determined by cooking 2 g whole rice kernels from each treatment in 20 ml distilled water for a minimum cooking time in a boiling water bath and draining the superficial water from the cooked rice. The cooked samples were then weighed accurately and the water uptake ratio was calculated as the ratio of final cooked weight to uncooked weight.

The gruel solid loss was obtained by cooking 2 g whole rice kernels from each treatment in 20 ml distilled water for a minimum cooking time in a boiling water bath. The gruels were transferred to 50 ml beakers with several washings and made to volume with distilled water. The aliquot having leached solids was evaporated at 110 °C in an oven until completely dry. The solids were weighed and percentage of gruel solids was recorded.

Germination tests

The aim of the germination test is to determine the percentage of seeds that develop into normal seedlings under specified conditions in a specified period of time (Schmidt, 2000). The germination tests were carried out in triplicates with 100 seeds per replication in an environmental chamber with controlled temperature and relative humidity.

Both 'normal' and 'abnormal' germinating seeds (germinants) were counted and at the end of a 7 day period. A normal seed is that which develops with all essential structure of a seedling. Abnormal seed is the seed that has germinated during the test period but the germination is abnormal or unhealthy e.g. seedling lacks essential structure such as cotyledons, is discoloured or infected by seed-born pathogens (Schmidt, 2000). Ungerminated seed is the seed that has not germinated by the end of the test period and can be expressed as hard seeds. The percentage of germinated seeds was then calculated as the percent ratio of normal germinants to the total number of seeds used in the test.

Results and discussion

Milling tests

Table 1 shows the results of milling tests carried out on in-store and chilled aerated paddy. Prior to tests, the samples were left to equilibrate with ambient air for 12 hours.

The brown rice recovery (BRR) for chilled aerated samples varied between 79.5 and 83.3 %. A similar range was observed for the in-store dried samples (79.9 to 80.7 %). The average BRR obtained in the experiment was 80.6 ± 1.5 and 80.5 ± 0.4 for chilled and in-store aeration respectively.

The milled rice yield (MRY) ranged between 74.1-76.7 % for the chilled treatment whereas it varied between 72.3 and 76.1 for the in-store dried samples. No significant differences were however detected for the brown rice recovery and milling rice yield between the two treatments.

Table 1. Rice milling data from chilled and ambient air aeration treatments.

	Weight of fraction (g)			Recoveries (%)		Average ± standard error	
Treatment	Paddy	Brown rice	White rice	BRR	MRY	BRR	MRY
Chilled aeration	200	166.6	148.3	83.3	74.2	80.6±1.5	75. 4±1.3
	200	159.9	148.2	80.0	74.1		
	200	159.8	153.3	79.9	76.7		
	200	159.9	151.1	79.5	75.6		
	200	160.1	153.1	80.1	76.6		
In-store dryer	200	161.4	152.2	80.7	76.1	80.5±0.4	73.9±1.6
	200	160.8	144.6	80.4	72.3		
	200	161.6	149.6	80.8	74.8		
	200	159.8	147.8	79.9	73.9		
	200	161.0	144.6	80.5	72.3		

Pasting properties

Rapid Visco Analyser (RVA) was used to characterise the pasting properties of flours obtained from treated samples. The target parameters that were recorded include peak 1, trough 1, breakdown, final viscosity, setback, peak time and gelatinisation temperature. The RVA profile is generally used as one of the indirect indicators for eating quality in rice sensory evaluation (Champagne et al., 1999).

Table 2 shows the data obtained from the RVA tests of rice and corn flour respectively. A very good repeatability in the experiments was also seen and is supported by the low values of the standard deviations observed.

From the test results, we can conclude that the peak viscosity of the chilled rice is lower than that of rice subjected to ambient aeration treatment. The technological significance of these results can be put as follows; the chilled aeration decreases the water binding capacity of rice. On contrary, we notice that the peak viscosity of corn flour increases when applying chilled air aeration.

The statistical analysis substantiates the fact that all the pasting properties (except gelatinisation temperature of rice) differ significantly between treatments. A two way ANOVA carried out on treatment x grain basis revealed that chilled air aeration lead to significant differences in pasting properties. This is also clearly visible in Figure 1.

Cooking properties

The cooking characteristics of the milled rice samples are shown in Table 3. The cooking time varied from 19:17 min to 20:42 min. The ambient aerated rice had a higher cooking time than the chilled aerated samples. Chrastil (1990) reported cooking times from 15–25 min for short and long grains of milled rice from different North American varieties. A cooking time of less than 20 minutes for rices with low gelatinisation temperature and more than 20 minutes for those with intermediate gelatinisation temperature have been reported by Singh et al., 2005.

The water uptake ratio for both the samples was similar. An average if 2.99 was found for chilled air treatment and a similar value (3.02) was observed for ambient air aerated rice.

An important result is obtained from the gruel solid loss test. Earlier studies reported that the samples with a longer cooking time had a higher gruel solid loss than those with a shorter time. The results obtained from the test here show that chilled aerated samples had a lower gruel solid loss (9.23 %) than the in-store dried paddy (8.78). It is worth noting that the minimum cooking time for ambient air aerated rice was more than the chilled counterpart.

The statistical analysis of the minimum cooking time of rice samples from two different treatments shows a significant difference in minimum cooking time at 95 % confidence level. Similarly there was a significant difference in the gruel solid loss of two samples. However, no significant effect of treatments was observed on the water uptake ratio of rice.

Germination

The results of germination test for both corn and rice are presented in Table 4. A contrast appears between the germination values for rice and corn. Day 3 germination counts for rice were very low as compared to corn. Before germination, the seeds must pass through a stage known as imbibition (Bradbeer,

Table 2. Average values and standard error of pasting properties of grain samples subjected to chilled and ambient air aeration

	Property						
	Viscosity (RVU)					Peak	Gelatinisation
Treatment	Peak 1	Trough	Breakdown	Final viscosity	Setback	time (minutes)	temperature (°C)
Rice (chilled)	96.4 ±1.5	60.6±0.9	35.8±0.6	127.3±1.9	30.9±0.6	5.5±0.0	82.8±1.2
Rice (in store)	106.6±3.5	65.9±2.0	40.6±1.5	156.2±3.8	49.6±0.5	5.6±0.0	84.8±1.9
Corn (chilled)	159.6±1.8	83.5±1.1	76.1±1.4	106.2±0.7	-53.5±1.5	4.0±0.0	73.6±0.1
Corn (in store)	106.9±1.0	67.6±0.7	39.4±0.5	82.0±1.0	-25.0±0.3	4.3±0.0	75.0±0.4

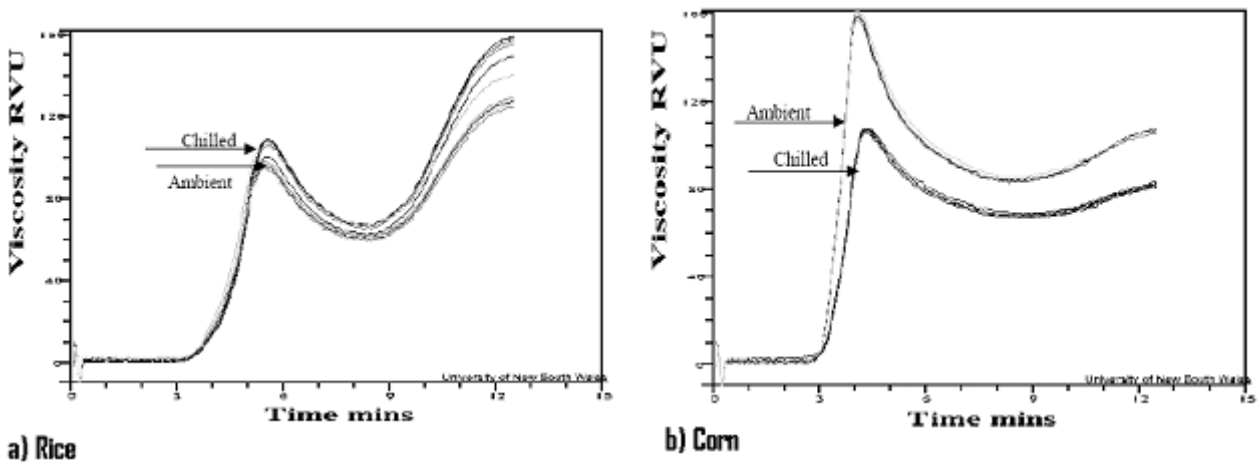

Figure 1. Pasting curves for rice and corn.

Table 3. Cooking properties of milled rice subjected to chilled and ambient air aeration.

Treatment	Minimum cooking time (min:sec)	Water uptake ratio	Gruel solid loss (%)
Chilled aeration	19:19	3.05	9.58
	19:20	2.99	9.03
	19:31	3.00	9.04
	19:18	2.94	9.36
	19:30	2.98	9.16
Average	19:24	2.99	9.23
In-store drying	20:19	2.98	8.33
	20:21	3.05	9.09
	20:21	2.98	8.27
	20:27	3.06	8.82
	20:42	3.08	9.41
Average	20: 26	3.03	8.78

1988). Different seeds need different initial moisture for germination. Given the same amount of moisture, rice is expected to absorb moisture at a slower rate due to the presence of husk.

Chilled air treated grains showed a higher percentage germination ratio as compared to ambient aeration. A higher germination count for chilled aeration was earlier postulated in studies by Barth (1992). On an average, 83 % germination was observed for chilled air treated rice where as the ambient air aeration resulted in 57 %. Similarly, the chilled and in-store dried corn exhibited 94 and 85 % of germinated seeds respectively.

A statistical analysis on each crop revealed that there were significant differences in the percentage germinants after both treatments. It can be postulated, in view of these results, that chilled aeration is a better preserver of seed viability. A significant difference in germination across both rice and corn grains (2 Way ANOVA) further supports this statement.

Table 4. Effects of chilled aeration and in-store drying on seed viability.

Treatment	Germination (%)		Abnormal germinants	Germination (%)
	Day 3	Day 7		
Rice (chilled)	3	87	1	86
	2	83	3	80
	4	86	1	85
Rice (in-store)	1	56	2	54
	1	60	3	57
	2	62	0	62
Corn (chilled)	99	99	5	94
	96	97	3	94
	98	98	3	95
Corn (in-store)	91	91	4	87
	91	91	9	83
	89	90	5	85

However, the abnormal germinant counts for corn were higher than for rice. Neither chilled nor ambient treatment seemed to affect these counts, as apparently the same number of abnormal germinants was reported in each kind of treatment.

Conclusions

In the experiments presented in this study, ambient and chilled aeration were employed to bring about reduction in moisture content of rewetted samples of corn and rice. A bulk of grain (40 cm high bed) was aerated with ambient and chilled air. Upon achieving safe storage moisture content, the grains were evaluated for effects of these treatments on quality parameters such a milling yield, pasting characteristics, cooking properties and germination. Both the aeration treatments successfully brought down the moisture content from approx 19 % wb to approx 13 % wb. Both treatments offer the advantage of assuming drying and storage functions.

The milling tests carried out on rice grain did not show any significant difference between two treatments.

Marked differences in pasting properties came into view. There was a significant disparity in pasting curves obtained from two aerations treatments. A higher peak value was observed for corn with chilled aeration. On the other hand, rice subjected to chilled treatment had a lower peak viscosity. All the pasting characteristics differed significantly between the two treatments. Technological importance can hence be derived from these data and the particular type of aeration be proposed based on the intended use of the grain.

The samples of milled rice subjected to the two drying treatments showed a significant difference in terms of cooking time and gruel solid loss. This indicates another possible avenue for further research. The cooking characteristics may have considerable impact on grain demand and price as consumers often link cooking properties with quality.

The germination test provided a strong evidence to draw conclusions. A significant difference was observed in the % germination of grains. A strong argument could be put forward for the use of chilled air aeration to produce seeds for agricultural use. Vigour tests for seeds of other crops may be worthwhile conducting in order to further evaluate the process.

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