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Physico-chemical, morphological, thermal, cooking and textural properties of chalky and translucent rice kernels

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Abstract

Studies were undertaken to compare physico-chemical, morphological, thermal, cooking and textural properties of chalky and translucent kernels separated from three rice cultivars. Physico-chemical properties, such as 1000 kernel weight, bulk density, kernel hardness, length-breath (L/B) ratio and amylose content, were determined. The morphological properties of chalky and translucent kernels were studied using scanning electron microscopy while the thermal properties were determined by differential scanning calorimetery. The chalky kernels separated from different cultivars showed higher 1000 kernel weight and bulk density but lower kernel hardness and amylose content than their counterpart translucent kernels. Microscopic analysis revealed that the cells, as well as amyloplast, were loosely packed in the chalky kernels. Chalky grains showed higher transition temperatures, enthalpy of gelatinization, peak height index and gelatinization range than the translucent grains. The cooking and textural properties of chalky and translucent kernels differed significantly. The chalky kernels from different varieties showed lower values for cooking (cooking time, water uptake, L/B ratio and elongation ratio) and textural parameters (packability, cohesiveness, chewiness, hardness) than the translucent kernels.

Keywords: Rice; Translucent; Chalky; Amylose; Cooking; Thermal; Textural profile analysis; Microstructure

1. Introduction

Rice (*Oryza sativa* L.) is one of the leading food crops of the world and is the staple food of over approximately one-half of the world's population. Rice production in India has witnessed a spectacular increase in the recent past and is approximately one-third of the total rice production of the world. The paddy rice production of India was 58.99 million tonnes in 1985–1986 that rose to 88.55 million tonnes in 1999–2000. The rice produced in different parts of India varies significantly in composition and cooking quality. Genetic and environmental factors are mainly responsible for variation in composition and cooking quality of rice. For example, the variation in amylose content in rice varieties has been described by a single nucleotide polymorphism in an allele of the waxy gene encoding the granule-bound starch synthase (GBSS) enzyme by Ayres, McClung, Larkin, Bligh, Jones, and Park (1997). This polymorphism has been observed to be temperature-dependent by Larkin and Park (1999). The higher environment temperature decreased amylose content in endosperm of non-waxy rice (Asaoka, Okuno, & Fuwa, 1985). The adverse environmental conditions, at the time of ripening of kernels, resulted in development of fissured, immature, diseased and chalky kernels (Bhat, Deosthale, Roy, Vijayraghvan, & Tulpule, 1982; Singh, Sekhon, & Kaur, 1990). Chalkiness in rice has been reported to be a vital characteristic and to develop as a result of prevailing weather conditions during the growth period. Tashiro and Ebata (1975) and Tashiro and Wardlaw (1991) have shown that high temperature during specific stages of grain development tends to increase the occurrence of chalky grains in rice. Lisle, Martin, and Fitzgerald (2000) reported that chalkiness commonly occurs in rice when high temperatures are experienced during grain development. Chalkiness reduces grain resistance

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to forces applied during the milling process, causing a decrease in head rice recovery. The presence of chalky kernels adversely affects consumer acceptability and, usually, rice containing more than 2% chalky kernels is rejected in most world markets.

The objective of present study was to compare the physico-chemical, cooking, thermal and textural properties of translucent and chalky grains separated from different rice varieties.

2. Materials and methods

2.1. Physical properties

The 1000-kernels from each sample were counted randomly in triplicate and weighed separately to determine 1000 kernel weight. Grain hardness was determined as force required to break a kernel using the Instron Universal Testing Machine (model-4464, Instron, Buckinghamshire, England) at a cross head speed of 50 mm/min. For determination of bulk density, a 250-ml cylinder was tared and 50 g of sample gently added and volume measured. Bulk density of translucent and chalky kernels was calculated as mass per unit volume. L/B was determined by dividing the length with breadth of 10 kernels.

2.2. Chemical properties

Amylose was determined using method of Williams, Kuzina, and Hlynka (1970).

2.3. Scanning electron microscopy (SEM)

Scanning electron micrographs were obtained with a scanning electron microscope (Jeol JSM-6100, Jeol Ltd., Tokyo, Japan). Translucent and chalky grain flour was suspended in ethanol to obtain a 1% suspension. One drop of flour–ethanol solution was applied on an aluminium stub, and the flour was coated with gold-palladium (60:40). An accelerating potential of 10kV was used during micrography.

2.4. Differential scanning calorimetry (DSC)

Chalky kernels from all the varieties were ground to pass through a no. 100 (BSS) sieve and thermal properties were determined using a DSC-821^{e} (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. The DSC analyser was calibrated using indium and an empty aluminium pan was used as reference. Rice flour (3.5 mg, dwb) was weighed into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of a Hamilton microsyringe to achieve a flour–water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the DSC. Sample pans were heated at a rate of 10 °C/min from 20 to 100 °C. Onset temperature (T_c), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were calculated automatically. Because the peaks were symmetrical, the gelatinization range (R) was computed as (T_c–T_o), as described by Vasanthan and Bhatty (1996). Enthalpies were calculated on a rice flour dry basis. The peak height index (PHI) was calculated by the ratio $\Delta H/(T_p - T_o)$, as described by Krueger, Walker, Knutson, and Inglett (1987).

2.5. Cooking quality

Both chalky and translucent kernels from different varieties were cooked for the minimum cooking time, as described by Batcher, Helmintoller, and Dawson (1956). The head rice (2 g) was taken in a test tube from each sample and cooked in 20 ml distilled water at 90 °C in a water bath. The minimum cooking time was determined by removing a few kernels at different time intervals during cooking and pressing between two glass plates until no white core was left. Water absorption of cooked rice was determined by the increase in weight of rice after cooking to optimum cooking time. Solid loss in gruel was determined by drying an aliquot of cooking water in a Petri dish at 70 °C in an oven until completely dry. Elongation ratio was determined by dividing the cumulative length of 10 cooked kernels by length of 10 uncooked raw kernels.

2.6. Back extrusion test

A stainless steel cylinder with cylindrical plunger, having diameter 40 mm and annulus gap of 2.5 mm, was used to conduct the back extrusion test. Cooked rice samples (60 g) were placed inside the test cylinder and then pressed with 150 g weight for 30 s before conducting the test. An Instron Universal Testing Machine (model-4464, Instron, Buckinghamshire, England) was used with 500 N load cell at a crosshead speed of 100 mm/min to perform the test. A force–distance curve was obtained from the test and the following textural parameters were determined (Fig. 1):

1. Hardness = average slope of the initial linear portion of the curve (N/mm).
2. Cohesiveness = force require to initiate shear and extrusion (N).
3. Chewiness = area under the curve (Nmm).
4. Packability = distance travelled by the plunger before an average linear slope is reached (mm).
5. Maximum force = maximum force observed during extrusion (N).

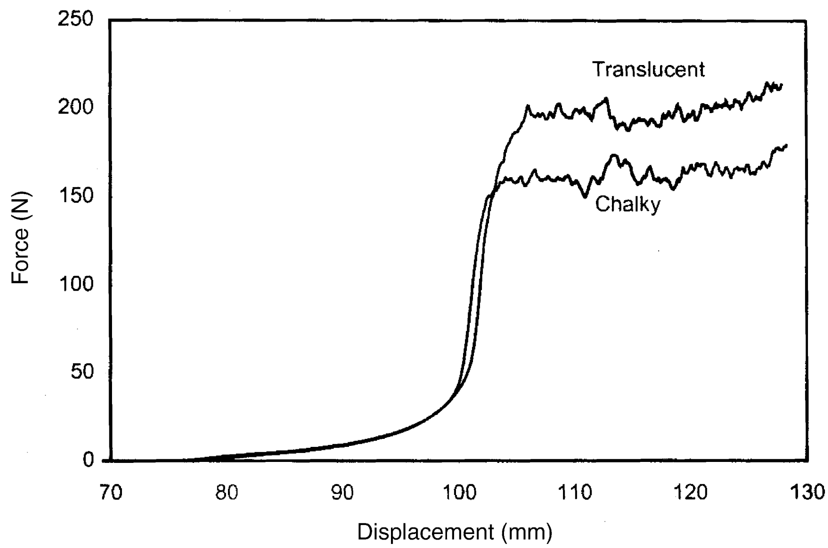

Fig. 1. Typical force–distance curve of translucent and chalky cooked rice grains obtained from back extrusion test.

2.7. Statistical anaylysis

The data reported in Tables 1–4 are averages of triplicate observations. The data were subjected to statistical analysis using Minitab Statistical Software (Minitab Inc., USA).

3. Results and discussion

3.1. Physico–chemical properties

The 1000-kernel weight of translucent grains was significantly lower than chalky grains obtained from different rice varieties. PR-106 translucent grains showed a 1000-kernel weight of 16.30 g against 19.33 g and 17.40 g, respectively, for IR-8 and Basmati-370. Chalky grains of PR-106, IR-8 and Basmati-370 showed 1000-kernel weights of 16.55, 23.42 and 18.71 g, respectively. Bulk density of translucent grains was lower than that of chalky grains obtained from different rice varieties. The length-breadth (L/B) ratio of chalky grains, from different rice varieties, was lower than their counterpart translucent grains; however, the differences were significant only in the IR-8 variety. Amylose content in different rice varieties varied from 8.5 to 11.7%, and highest amylose content in PR-106 and lowest in Basmati-370 were observed. The translucent rice kernels from different varieties showed significantly higher amylose content than their counterpart chalky kernels. Sandhya Rani and Bhattacharya (1989) also observed a lower amylose content in chalky kernels of rice.

3.2. SEM

Microstructure of grain from different rice varieties differed significantly. A comparison between grains from different rice varieties showed Basmati-370 had a smaller granule size than PR-106 and IR-8 grains. Microscopic analysis also revealed a significant variation in the microstructure of translucent and chalky rice grains (Fig. 2). However, the differences between chalky and translucent grains of PR-106 and IR-8 varieties were more prominent. The cells and amyloplasts were

Table 1
Physico-chemical properties of chalky and translucent grains from different rice cultivars[a]

Cultivar	Type	1000-Kernel weight (g)	Bulk density (g/cm^3)	L/B ratio	Grain hardness (kg)	Amylose content (%)
PR-106	Translucent	16.30a	0.880e	3.8bc	9.4e	11.7e
	Chalky	16.55a	0.885e	3.4b	4.1a	7.6b
IR-8	Translucent	19.33d	0.850c	3.2b	8.8d	10.7d
	Chalky	23.42e	0.865d	2.5a	6.6b	7.0b
Basmati-370	Translucent	17.40b	0.810a	3.9c	11.5f	8.5c
	Chalky	18.71c	0.824a	3.9c	7.9c	5.5a

[a] Values with similar letters (a–f) in column do not differ significantly ($P < 0.05$).

Table 2
Differential scanning calorimetry (DSC) thermal properties of chalky and translucent grains from different rice cultivars[a]

Cultivar	Type	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	PHI	*R*
PR-106	Translucent	62.7a	68.2a	74.5a	3.81c	0.684b	11.9c
	Chalky	63.1a	68.4a	74.9b	4.24d	0.791c	11.9c
IR-8	Translucent	63.7b	68.9b	72.3c	2.42a	0.461a	8.7a
	Chalky	64.0b	69.1b	74.6d	3.19b	0.623b	10.6b
Basmati-370	Translucent	68.1c	74.2c	81.8e	5.16e	0.846d	13.7d
	Chalky	68.7d	74.3c	84.8f	6.16f	1.075e	16.2e

T_o = onset temperature, T_p = peak temperature, R = gelatinization range (T_c–T_o); ΔH_{gel} = enthalpy of gelatinization (dwb, based on starch weight), PHI = peak height index $\Delta H_{gel}/(T_p - T_o)$.
[a] Values with similar letters (a–f) in column do not differ significantly ($P < 0.05$).

Table 3
Cooking properties of chalky and translucent grains from different rice cultivars[a]

Cultivar	Type	Cooking time (min)	Water uptake (%)	Elongation ratio	Gruel solid losses (%)
PR-106	Translucent	20.5b	4.3c	7.0d	1.9ab
	Chalky	18.5a	3.6ab	10.0e	1.7a
IR-8	Translucent	25.3d	3.6ab	5.5b	1.8ab
	Chalky	23.0c	3.4a	9.5e	1.7a
Basmati-370	Translucent	33.0f	4.0bc	4.5a	2.0b
	Chalky	30.5e	3.9bc	6.0c	2.0b

[a] Values with similar letters (a–f) in column do not differ significantly ($P < 0.05$).

Table 4
Textural properties of cooked chalky and translucent grains form different rice cultivars[a]

Cultivar	Type	Packability (mm)	Cohesiveness (N)	Maximum force (N)	Hardness (N/mm)	Chewiness (Nmm)
PR-106	Translucent	16.0c	37b	78b	20.6c	1724b
	Chalky	10.5a	20a	52a	5.0a	885a
IR-8	Translucent	13.5b	72c	136d	25.8d	3080c
	Chalky	11.5a	25a	97c	18.7b	1745b
Basmati-370	Translucent	23.0d	140d	210f	60.1e	4943e
	Chalky	22.0d	135d	180e	58.2e	4737d

[a] Values with similar letters (a–f) in column do not differ significantly ($P < 0.05$).

observed to be tightly packed in the translucent grains from different varieties. Chalky grains showed the presence of single rather than compound amyloplasts, air spaces and some disordered granular structure.

3.3. Thermal properties

Chalky kernels showed higher T_c and ΔH than translucent grains in all varieties. T_o and T_p of chalky and translucent grains did not differ significantly. IR-8 and Basmati-370 rice showed significantly lower *PHI* and R than PR-106. The lower ΔH and T_c of translucent grains than chalky reflected loss of double helical structure at lower temperatures in the former type. The higher transition temperatures of chalky kernels than their translucent counterparts may be attributed to the presence of lower amylose and higher amylopectin contents. Because amylopectin has been reported to play a major role in starch crystallinity, the amylose lowers the melting point of crystalline regions and the energy for starting gelatinization (Flipse, Keetels, Jacobson, & Visser, 1996). Therefore the chalky kernels with lower amylose contents might have less amorphous region and more crystalline region, increasing gelatinization temperature and endothermic enthalpy (Sasaki, Yasui, & Matsuki, 2000; Sodhi & Singh, 2003). Similar results

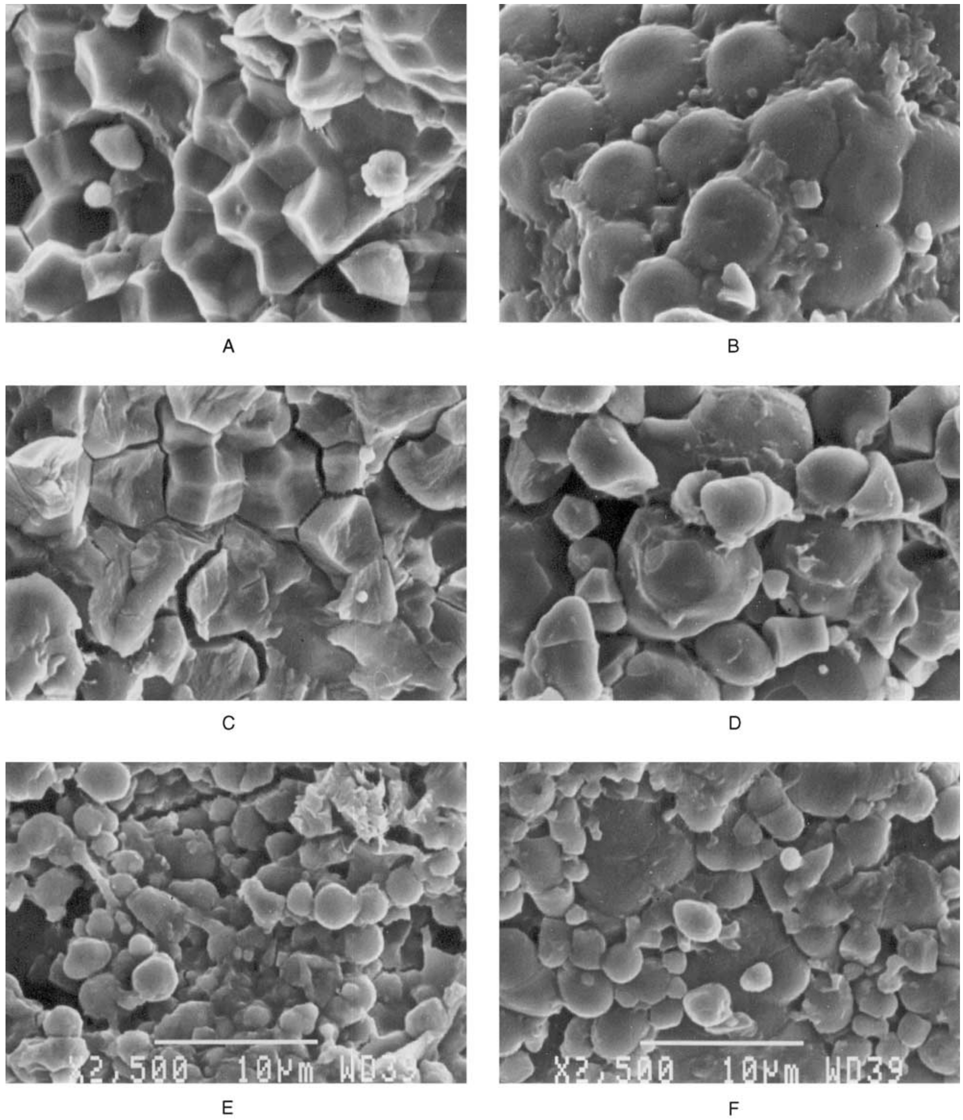

Fig. 2. Scanning electron micrograms of translucent and chalky grains from different rice varieties (PR-106, A = Translucent, B = Chalky; IR-8, A = Translucent, B = Chalky; Basmati-370, A = Translucent, B = Chalky).

have been reported for rice by Nakazawa, Noguchi and Takahashi (1984) and corn starch by Krueger et al. (1987). Translucent and chalky grains of Basmati-370 showed significantly higher T_o, T_p and T_c than those from PR-106 and IR-8 varieties. The higher T_o, T_p, T_c and ΔH for Basmati-370 rice may be due to a lower amylose content as well as the small and compact nature of starch granules (Sodhi & Singh, 2003). Differences in thermal properties among the different rice varieties, due to difference in protein and lipid contents, cannot be ruled out (Biliaderis, Page, Slade, & Sireet, 1985; Marshall, Normand, & Goynes, 1990)

3.4. Cooking characteristics

Chalky grains from different varieties showed a lower cooking time and water uptake ratio than their counterpart translucent grains. The cooking times for translucent rice grains from PR-106, IR-8 and Basmati-370 were 20.5, 25.5 and 33 min, respectively, against 18.5, 23 and 30.5 min, respectively for chalky rice grains from these varieties. Among the varieties, Basmati-370 showed the highest cooking time, followed by IR-8 and PR-106 rice. L/B and elongation ratio were observed to be highest in Basmati-370 and lowest in IR-8 cooked rice. The presence of air spaces and single granule, rather than compound amyloplast, as well as disorganised cellular structure, offers the opportunity for fast diffusion of water in the chalky grains during cooking and causes a decrease in cooking time (Lisle et al., 2000). The translucent grains showed greater L/B and elongation ratio than their chalky rice counterparts after cooking. The differences in cooking properties in rice varieties and between translucent and chalky grains may be due to differences in their amylose contents and granular structures. The long amylopectin chains may crystallize with an amylose molecule, which might extend through adjacent 'clusters', thereby contributing to double helices in several crystallites and which could result in a lower degree of swelling, a reduction in the leaching of solids and a harder texture rice (Ong & Blanshard, 1995). Chrastil (1990) reported cooking times from 15–25 min for fresh short and long grains of milled rice from different North American varieties.

3.5. Textural properties

Among the various rice varieties, Basmati-370 cooked grains showed highest packability, cohesiveness, chewiness, maximum force and hardness values. Packability of PR-106 was higher than that of IR-8 cooked rice. The textural analysis revealed that translucent cooked grains had higher packability, cohesiveness, chewiness, maximum force and hardness values than chalky cooked grains. The translucent rice kernels of Basmati-370, IR-8 and PR-106 showed hardness values of 58.22, 25.82 and 20.63 N/mm, respectively. The difference in textural properties of translucent and chalky grains was predominant in IR-8 and PR-106 varieties. IR-8 translucent kernels showed cohesiveness, chewiness and hardness values of 72.5 N, 3081 Nmm, and 25.82 N/mm, respectively, against the values of 25 N, 1745 Nmm and 18.71 N/mm for chalky kernels.

The difference in textural properties between varieties and translucent and chalky kernels may be attributed to differences in the amylose content, ratio of long/short chain amylopectin chains and granular structure. The highest value of hardness in Basmati-370 rice may be attributed to the presence of smallest size starch granules. Sowbhagya, Ramesh, and Bhattacharya (1987) observed positive correlation between amylose content and firmness of cooked rice. Juliano, Villareal, Perez, Villareal, and Hizukuri (1987) and Reddy, Ali, and Battacharya (1993) reported the rice with higher amylose content and long chain amylopectin tended to have a hard texture, while rice with a lower amylose content and short chain amylopectin tended to have a softer texture. The longer amylopectin chains and higher amylose content could provide a favourable milieu for inter or intra molecular interactions of starch with other components, such as protein or lipids (Ong & Blanshard, 1995). On the other hand, high concentrations of short amylopectin chains in chalky kernels may inhibit interaction.

In summary, the physicochemical, thermal and cooking properties of chalky grains differed significantly from those of translucent grains mainly due to lower amylose content, presence of air spaces and some disordered granular structure.

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