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Differences in cooking and eating properties between chalky and translucent parts in rice grains

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Abstract

Differences in cooking and eating properties between chalky and translucent parts of rice grains were investigated in samples from six *indica* rice varieties with different palatabilities. A differential scanning calorimeter (DSC), rapid visco analyzer (RVA) and texture analyzer were employed for determining physicochemical parameters, which were used as indirect indicators of cooking and eating quality. The results showed that the chalky part in milled rice had a dramatically higher transition temperature (T_o, T_p, T_c) and ΔH than the translucent part and the difference was much larger than that among varieties. Meanwhile, the chalky part had lower GC, SP and higher hardness than the translucent part, while there were slight or little differences in RVA properties and AC between the two parts. It may be suggested that the higher transition temperature and ΔH associated with higher chalky occurrence are major cause of deteriorated cooking quality due to increased energy requirement for gelatinization, in addition to the adverse effect of chalk occurrence on the visual appearance of rice.

Keywords: Rice; Chalk; Differential scanning calorimeter; Rapid visco analyzer; Texture; Gelatinization

1. Introduction

Rice is the most important cereal crop with about 40% of total grain production in China. In the past two decades there was a marked improvement in yield; however, little progress was made in quality improvement, especially for *indica* rice, which is widely planted in southern China. The higher chalk occurrence and poor palatability in *indica* rice make it unsatisfactory for human consumption (Shi, Zhu, Zhang, & Chen, 1997). However, *indica* rice is predominantly planted as an early-season crop in areas of southern China, with high yield stability and lower cost in production, compared with the late-season rice (Hu, Zhai, Tang, & Wan, 2002). It is quite imperative to improve the quality of early-season *indica* rice.

It has been well-documented that high chalk occurrence in early-season *indica* is mainly attributable to adverse climatic conditions during grain filling and high temperature is considered as the most important factor (Asaoka, Okuno, & Fuwa, 1985; Yawinder, Nagi, Sidhu, & Sekden, 1986). High temperature at the filling stage accelerates filling rate, resulting in short filling duration (Umemoto, Nakamura, & Ishikura, 1995; Yoshida & Hara, 1977) and loosely-packed starch granules and higher chalky occurrence in rice grains (Tashiro & Wardlaw, 1991; Tashiro, 1980). It has been reported that high temperature at the filling stage diminished cooking and eating properties of rice (Cruz, Kumar, Rajendra, Kaushik, & Khush, 1989; Shi et al., 1997; Taira, 1999). Accordingly, it is generally considered that high chalky occurrence is directly related to inferior cooking and eating qualities. However, such a conclusion appears to be still short of strong support. In all reports up to date, comparisons were made on grain samples with different chalky occurrence, formed under different developmental conditions or due to different grain position in a panicle. Cooking and eating qualities are greatly affected by environment and grain position (Cheng, Zhang, Zhao, Yao, & Xu, 2003; Lisle, Martin,

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& Fitzgerald, 2000). Therefore, more detailed studies are required to clarify the association between chalky occurrence and cooking and eating qualities.

The objective methods for evaluating cooking and eating properties of rice quality were physicochemical measurement and instrument tests (Tan & Corke, 2002). Rapid visco analyzer (RVA), differential scanning calorimetry (DSC) and texture analysis have commonly been used in determining the physicochemical parameters of rice flour and starch, so that the relationships between these parameters and cooking and eating properties can be established (Chen, Lu, & Li, 1999; Han & Hamaker, 2001; Hizukuri, 1985; Lu, Chen, & Li, 1997). In this paper, we compared differences in thermal properties, RVA and texture characteristics between chalky and translucent parts by using six early-season *indica* rice varieties, aiming at determining if chalky occurrence affects inherently cooking and eating quality. In order to eliminate the possible effect of temperature and position of grains in a panicle on cooking quality, the comparison was made on separated chalky and translucent parts from the same grains.

2. Materials and methods

2.1. Sampling

Six *indica* rice varieties, with different palatabilities, were used in the study: Zhou 903 and Jiazao 935 (the high palatability cultivars), Zhe 733 and Jia 293 (the moderate palatability cultivars), Zhefu 802 and Guanglu'ai 4 (the low palatability cultivars). These cultivars were planted at the experiment farm of Huajiachi campus, Zhejiang University in 2002, and the field management followed local practice. At maturity, rice grains were randomly harvested, dried and stored at room temperature for 3 months, maintaining about 13.5% of moisture, and then dehulled and milled. Each milled grain was separated into chalky and translucent parts by using an anatomic knife. In order to obtain well-defined chalky and translucent samples, only the clear fraction of chalky or translucent endosperm was sampled and analyzed. All samples were ground in a Tecator cyclone (Udy, Fort Collins, Corp., USA) to pass a 0.5 mm screen.

2.2. Analytical methods

2.2.1. Thermal properties

Thermal properties were determined with a differential scanning calorimeter (DSC, Model DSC-7, Perkin–Elmer, Norwalk, CT, USA) equipped with an intra-cooling °C system. Rice flour (2.5 mg) was allowed to equilibrate for 1 h prior to analysis. The samples were weighed directly into DSC pans and distilled water was added to obtain a flour-to-water ratio of 1:2 (w/w). Then the pans were hermetically sealed and equilibrated for 2 h at room temperature before heating in the DSC. The measurements were carried out at a heating rate of 10 °C/min from 40 to 110 °C. The instrument was calibrated by using indium and an empty pan as reference. The onset temperature of gelatinization (T_o), peak temperature of gelatinization (T_p) and conclusion temperature of gelatinization (T_c) were determined from DSC thermograms, as described by the method of Fujita, Morita, and Fujiyama (1993). The enthalpy (ΔH) was estimated by integrating the area between the thermogram and a base line under the peak and was expressed in terms of Joules per unit weight of dry starch (J/g), which was obtained by data processing software supplied with the DSC-7 instruction. Duplicate measurements were performed for each sample.

2.2.2. RVA characteristics

Pasting properties were measured with a Rapid Visco Analyzer model 3-D RVA (Newport Scientific, Sydney, Australia). Rice flour (3 g each sample) was weighed directly into the aluminium RVA canister and 25 ml of distilled water were added and mixed with the rice flour. The RVA test profile was adopted from the method of Chen et al. (1999). The sample was held at 50 °C for 1 min, heated to 95 °C at a rate of 12 °C/min (i.e. in 3.75 min), held at 95 °C for 2.5 min, cooled to 50 °C at a rate of 12 °C/min and held at 50 °C for 2.5 min. The rotating speed of the paddle was kept at 160 rpm throughout the run except that the paddle speed was 960 rpm at the first 10 s. All measurements were twice replicated.

2.2.3. Texture of RVA gel

Texture analysis of RVA gels was conducted according to Bhattacharya, Zee, and Corke (1999). The flour slurry, formed in the canister after the RVA cycle, was kept at room temperature (23–25 °C) overnight and allowed to gel. The canister was sealed with paraffin wrap to prevent moisture loss during the storage period. The gel formed in the can was used directly for texture analysis with a TA.XT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK), equipped with a texture expert software programme. A standard two-cycle programme was used to compress the gels for a distance of 10 mm at a crosshead speed of 30 mm/min, using a 7-mm cylindrical probe with a flat end. From the force–time curves obtained, textural parameters of hardness, cohesiveness and springiness were computed , using the software supplied with the instrument. Each measurement involved four replications. Chewiness, representing the amount of energy needed to disintegrate the rice, was calculated from hardness, cohesiveness and springiness (i.e. hardness × cohesiveness × springiness).

2.2.4. Swelling properties

Swelling power (SP) was determined, in duplicate, according to the method of Sasaki and Matsuki (1998). 0.5 g of flour sample was mixed with 15 ml water in a centrifuge tube with cap and heated at 75–85 °C for 30 min. The heated sample was cooled rapidly to room temperature in an ice water bath and centrifuged at 5000 rpm for 20 min. The supernatant was carefully removed and the swollen starch sediment was weighed. SP was the ratio of wet sediment to the initial flour weight.

2.2.5. Amylose content and gel consistency

Amylose content was measured according to the method of Juliano (1985), and gel consistency was determined by the method of Cagampang, Perez, and Juliano (1973). Triplicate measurements were performed for each sample.

2.3. Data analysis

The statistical analysis was performed using single factor ANOVA for all data (SAS, 1985). Significant difference was evaluated based on $P < 0.05$.

3. Results and discussion

3.1. Difference in DSC properties

A significant difference was found in the DSC parameters between chalky and translucent parts, with the chalky part showing higher transition temperature (T_o, T_p, T_c) and ΔH, although the extent of difference depended on variety, ranging from 0.9 to 8.6 °C in T_p and from 1.1 to 3.4 J/g in ΔH, respectively (Table 1). High transition temperature (T_o, T_p, T_c) and ΔH have been proved undesirable in terms of cooking quality of rice due to the increased temperature and energy requirement for gelatinization (Fujita et al., 1993; Normand & Marshall, 1989). Hence, the current results proved the assumption that the chalky occurrence had an adverse effect on cooking quality of rice. Moreover, it was noticed that the difference in ΔH was greater between chalky and translucent parts than among cultivars, indicating that the chalky occurrence diminishes cooking quality of rice and inferior cooking of early-season *indica* rice is, to some extent, attributed to its high chalky occurrence.

There was also a remarkable difference in the peak position and /or height of DSC curves between chalky and translucent parts, suggesting that chalky occurrence in rice grains affect distinctly thermal parameters (Fig. 1), which may be reflected by starch crystalline perfection (Cooke & Gidley, 1992; Myers, Morell, James, & Ball S, 2000). Starch gelatinization involves the melting of double helices and a loss of crystallinity (Imberty, Buleon, Tran, & Perez, 1991). High gelatinization might be attributed to the closely-packed crystalline structure within starch granules (Tang, Ando, Watanabe, Takeda, & Mitsunaga, 2001). Therefore, it may be assumed that the interior structure of a single starch granule might be more rigid in chalky parts than in translucent part, which accounts for the greater energy requirement in the gelatinization for the grains with higher chalky occurrence, although a loosely-packed structure, smaller granule and larger air space among starch granules were observed in chalky grains (Singh, Sodhi, Kaur, & Saxenda, 2003; Tashiro & Wardlaw, 1991).

3.2. Difference in starch swelling properties and amylose content

Chalky parts had significant lower gel consistency (GC) than translucent parts for all cultivars but Zhefu 802, indicating inherent association between chalk occurrence and gel consistency. However, there was no distinct difference in AC between chalky and

Table 1
Difference in DSC properties between chalky and translucent parts

Cultivars	Types	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
Zhou 903	Chalky	66.5 ± 0.09a	74.3 ± 0.07a	87.1 ± 0.07a	10.6 ± 0.03a
	Translucent	60.8 ± 0.12b	65.5 ± 0.11b	82.6 ± 0.09b	8.1 ± 0.06b
Jiazao 935	Chalky	70.5 ± 0.07c	77.6 ± 0.05c	88.6 ± 0.08c	11.4 ± 0.02c
	Translucent	68.9 ± 0.16d	74.9 ± 0.14d	86.7 ± 0.12d	7.9 ± 0.04d
Zhe 733	Chalky	71.5 ± 0.08e	75.4 ± 0.07e	86.9 ± 0.09e	11.2 ± 0.07e
	Translucent	68.3 ± 0.06f	74.5 ± 0.05f	86.4 ± 0.08e	10.1 ± 0.06f
Jia 293	Chalky	73.1 ± 0.14g	78.4 ± 0.12g	86.7 ± 0.11f	9.8 ± 0.08g
	Translucent	67.6 ± 0.06h	72.3 ± 0.07h	79.8 ± 0.05g	7.6 ± 0.03h
Zhefu 802	Chalky	68.7 ± 0.12i	74.2 ± 0.11i	86.1 ± 0.09h	10.5 ± 0.07i
	Translucent	64.5 ± 0.08j	72.6 ± 0.07j	84.1 ± 0.11i	9.0 ± 0.05j
Guanglu'ai 4	Chalky	66.4 ± 0.07k	73.3 ± 0.11k	92.0 ± 0.07j	11.2 ± 0.05k
	Translucent	63.6 ± 0.0121	70.6 ± 0.091	83.9 ± 0.13k	9.5 ± 0.041

T_o = Onset temperature, T_p = Peak temperature, T_c = Conclusion temperature, R = Gelatinization range (T_o). Values with different letters in a column represent significant difference ($P < 0.05$).

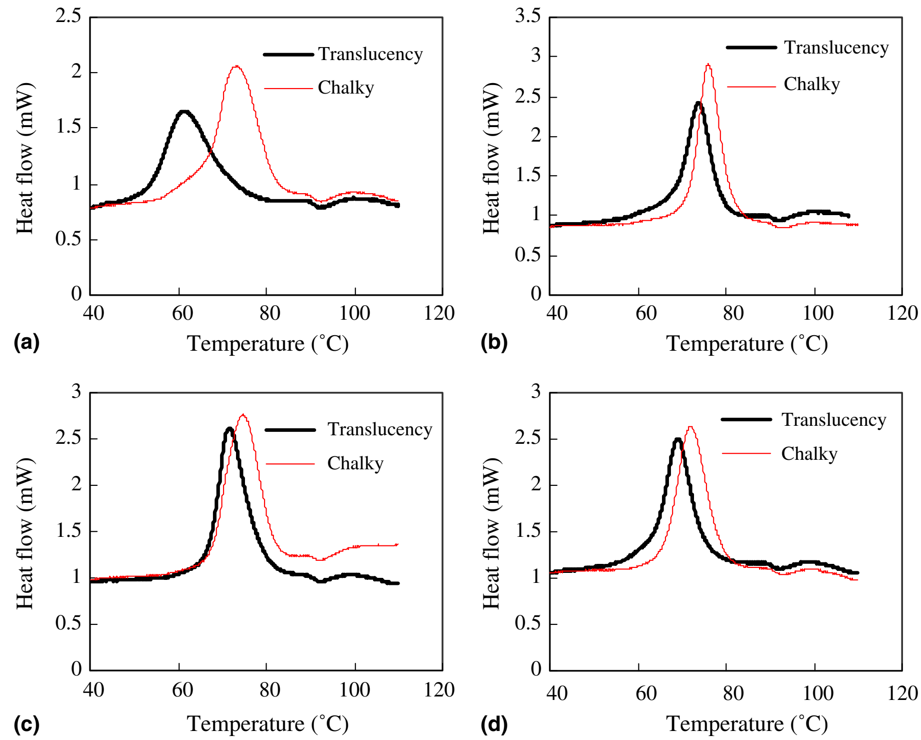

Fig. 1. DSC profiles of chalky and translucent parts for 4 rice varieties: a, Zhou 903; b, Jiazao 935; c, Zhe 733; d, Zhefu 802.

translucent parts, suggesting that AC is not inherently related to chalk occurrence. The present results are not agreement with previous reports by Lisle et al. (2000) and Singh et al. (2003), who revealed that chalky grains kernels had lower AC than translucent grains. The disagreement of our finding with others could be attributed to experimental differences. In the previous reports, the analysis was made the whole kernels with different chalky occurrence, which were taken from different plants exposed to contrasting temperatures or due to different positions in a panicle. It is reported that rice grains at lower position in a panicle are higher in chalky occurrence and lower in AC content (Matsumoto & Yoshida, 1994). Meanwhile, high temperature increases chalky occurrence and reduces AC content (Asaoka et al., 1985). Thus, the association between AC content and chalky occurrence might be confounded by the effect of environment (development condition) or grain position. In this study, we compared chalky and translucent parts of the same kernels, thus the interference of environment or grain position should be eliminated.

Swelling power (SP) is reported as a ratio of swollen starch wet sediment to the initial flour weight. SP in six rice varieties ranged from 10.2% to 14.6%, with Zhou 903 and Jiazao 935 being relatively higher (Table 2).

Table 2
Difference in GC, AC and SP between chalky and translucent parts

Cultivars	Types	GC (mm)	AC (%)	SP (g/g)
Zhou 903	Chalky	50.5 ± 5.8a	14.5 ± 0.5a	13.1 ± 0.3a
	Translucent	67.9 ± 2.3b	16.7 ± 0.3b	14.6 ± 0.5b
Jiazao 935	Chalky	40.4 ± 3.4c	15.6 ± 0.4c	12.4 ± 0.3c
	Translucent	56.5 ± 2.6d	15.1 ± 0.3c	13.8 ± 0.6d
Zhe 733	Chalky	45.7 ± 3.8e	23.6 ± 0.5d	11.9 ± 0.7e
	Translucent	60.6 ± 4.1f	23.8 ± 0.7d	12.3 ± 0.4e
Jia 293	Chalky	43.2 ± 4.0g	23.5 ± 0.3e	10.0 ± 0.5f
	Translucent	59.3 ± 3.2h	21.9 ± 0.6f	11.7 ± 0.3g
Zhefu 802	Chalky	37.6 ± 6.7i	23.8 ± 0.5g	10.9 ± 0.5h
	Translucent	43.7 ± 5.3i	24.7 ± 0.4h	10.6 ± 0.6h
Guanglu'ai 4	Chalky	35.5 ± 3.7j	24.5 ± 0.2i	11.4 ± 0.6i
	Translucent	41.8 ± 4.6j	24.0 ± 0.4i	11.6 ± 0.3i

GC = Gel consistency, AC = Amylose content, SP = Swelling power. Values with different letters in a column represent significant difference ($P < 0.05$).

Bhattacharya et al. (1999) reported that high AC restricted the swelling capacity of starch granules, and as a result reduced the amount of starch exudates leaching into the solution. The present results were consistent with those of Chen et al. (1999). However, no consistent difference was found in AC between chalky and translucent parts in six varieties, implying that some other factors are probably related to SP of starch granules, besides AC. It may be seen, from Table 2, that the chalky part has a slightly lower SP than the translucent part, although the difference was not significant for *cvs* Zhe 733 and Zhefu 802. Because the swelling behaviour of cereal starch is primarily related to insoluble amylose and/or longer chain amylopectin (Jane & Chen, 1992) and the rigidity of the starch granule is inversely proportional to the SP (Vasanthan & Bhatty, 1996), the

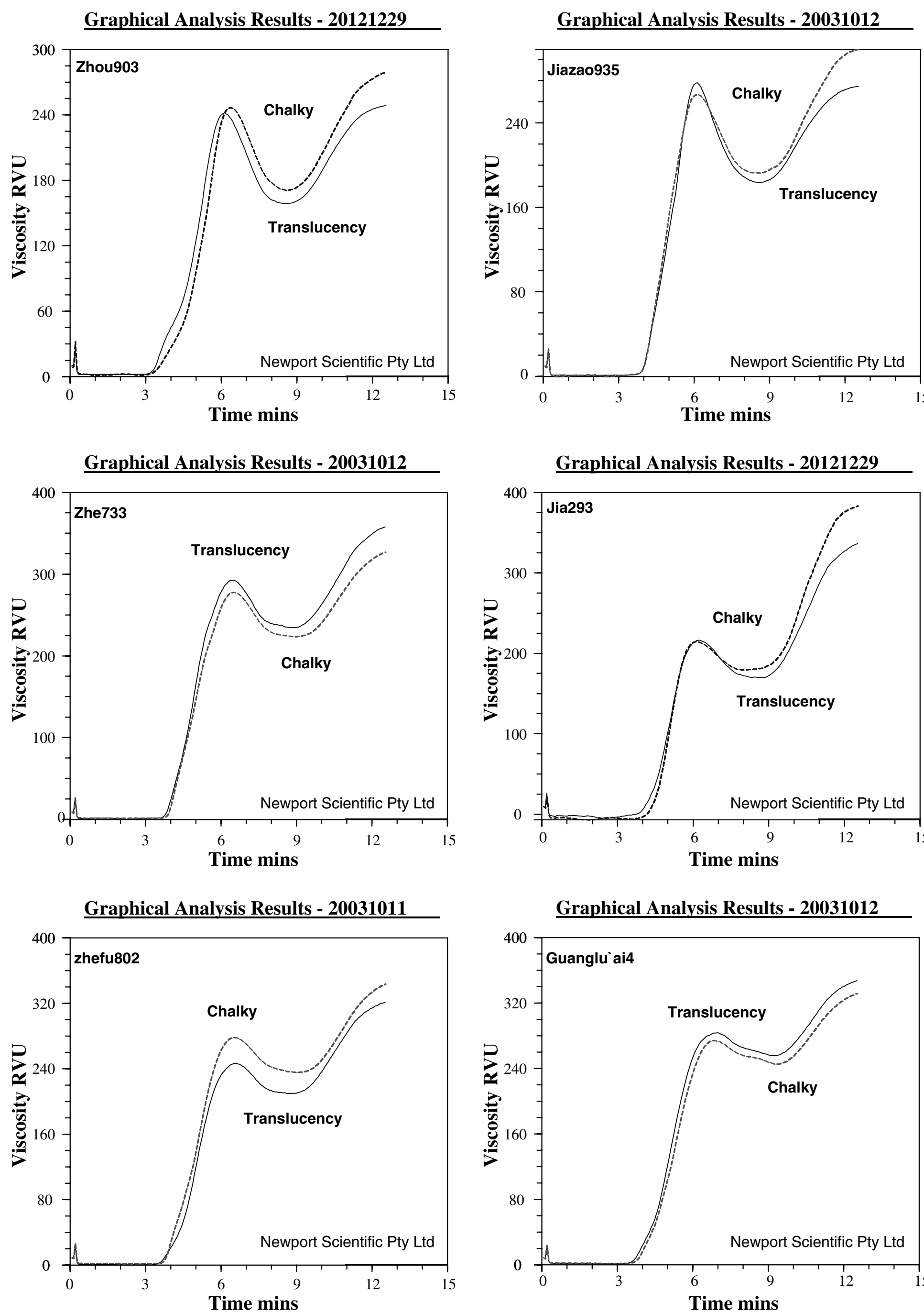

Fig. 2. Viscosity curves of chalky and translucent parts in rice grains.

lower SP in the chalky part reflects the more rigid granular structure.

3.3. Difference in RVA characteristics

The RVA profile was generally used as one of the indirect indicators for eating quality in rice sensory evaluation (Champagne et al., 1999; Reddy, Subramanian, & Zakiuddin, 1994). It can be seen from Fig. 2 that the chalky part had basically the same RVA profile as the translucent part, although there was a slight difference in the peak of RVA viscosity. On the other hand, a wide variation could be found among six rice varieties in the RVA profile (Fig. 3). It was demonstrated that rice palatability was more dependent on shape of RVA profiles than on absolute value of RVA viscosity (Shu, Wu, Xia, Gao, & McClung, 1998), the rice varieties with superior quality generally had higher paste breakdown and lower paste consistence than those with inferior quality (Han & Hamaker, 2001; Jane & Chen, 1992). The present results reveal that chalky occurrence is not closely related to RVA properties. Therefore it may be assumed that chalky occurrence has little impact on palatability, but the assumption is still to be confirmed by sensory testing.

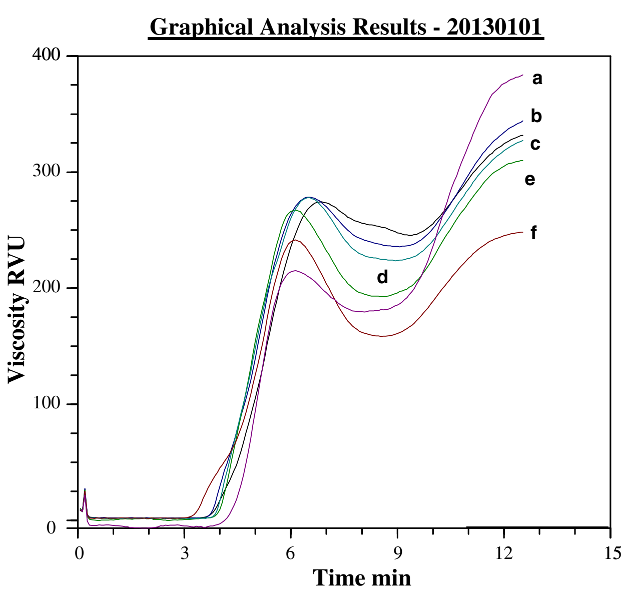

Fig. 3. Viscosity curves of chalky parts for six rice varieties: a, Jia 293; b, Zhefu 802; c, Guanglu'ai 4; d, Zhe 733; e, Jiazao 935; f, Zhou 903.

3.4. Difference in textural properties of RVA gels

Hardness, cohesiveness and springiness may reflect the performance of flour gels in compress-endurance, stickiness and elasticity. These traits were evaluated in texture analysis to achieve a deep insight of sensory properties of rice (Ong & Blanshard, 1995; Sowbhagya, Ramesh, & Bhattacharya, 1987). Meanwhile, chewiness, which is a comprehensive index of hardness, cohesiveness and springiness (hardness × cohesiveness × springiness) was also calculated (Table 3). A distinct difference was found in textural properties of RVA gels among the six rice cultivars, with Zhou 903 and Jiazao 935 having lower hardness and chewiness than other varieties. Comparatively, there was a smaller variation in elasticity among all samples. The results were agreement with a previous report by Bhattacharya et al. (1999), who indicated that rice with higher amylose content and longer chain amylopectin tended to have a harder texture, while rice with a lower amylose content and shorter chain amylopectin tended to have a softer texture. Moreover, the chalky part generally had somewhat higher hardness and chewiness than the translucent part, although the difference was not significant for some varieties. It may be suggested that chalky occurrence changed, to some extent, the textural properties of rice grain and the poor texture in the chalky part was mainly caused by its relatively high hardness and chewiness.

Table 3
Difference in textural parameters between chalky and translucent parts

Cultivars	Types	Hardness (g)	Cohesiveness (g)	Springiness (mm)	Chewiness (g × mm)
Zhou 903	Chalky	11.5 ± 0.3a	0.72 ± 0.04a	0.83 ± 0.01a	6.9 ± 0.1a
	Translucent	11.2 ± 0.4a	0.66 ± 0.05b	0.85 ± 0.02a	6.3 ± 0.2b
Jiazao 935	Chalky	10.1 ± 0.2b	0.67 ± 0.01c	0.86 ± 0.01b	5.8 ± 0.2c
	Translucent	9.6 ± 0.5b	0.68 ± 0.04c	0.86 ± 0.03b	5.6 ± 0.3c
Zhe 733	Chalky	17.5 ± 0.3c	0.54 ± 0.03d	0.87 ± 0.02c	8.2 ± 0.2d
	Translucent	16.9 ± 0.2d	0.53 ± 0.05d	0.86 ± 0.01c	7.8 ± 0.4d
Jia 293	Chalky	22.7 ± 0.1e	0.55 ± 0.02e	0.87 ± 0.01d	10.8 ± 0.2e
	Translucent	20.3 ± 0.3f	0.51 ± 0.07e	0.91 ± 0.02e	9.5 ± 0.3f
Zhefu 802	Chalky	23.1 ± 0.4g	0.57 ± 0.02g	0.89 ± 0.03f	12.0 ± 0.3g
	Translucent	22.8 ± 0.2g	0.61 ± 0.01g	0.89 ± 0.02f	12.3 ± 0.2g
Guanglu'ai 4	Chalky	25.1 ± 0.2h	0.51 ± 0.02h	0.92 ± 0.03g	11.9 ± 0.1h
	Translucent	24.9 ± 0.5h	0.52 ± 0.03h	0.90 ± 0.02g	11.7 ± 0.3h

Values with different letters in a column represent significant difference ($P < 0.05$).

4. Conclusion

The present results demonstrate that chalky occurrence distinctly lowers cooking quality of rice. Chalky rice had higher transition temperature and ΔH, which caused more energy requirement for gelatinization and can be considered the major factors resulting in the lower cooking quality, in addition to inferior visual appearance quality. Moreover, the chalky occurrence tended to give a hard texture, lower GC, SP and higher hardness. However, there was no distinct difference in the RVA properties and AC between chalky and translucent parts, indicating that chalky occurrence has less impact on rice palatability than on cooking properties as measured by DSC.

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