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Physicochemical properties of starches from diverse rice cultivars varying in apparent amylose content and gelatinisation temperature combinations

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ABSTRACT

The physicochemical properties of starches isolated from 14 rice cultivars produced in China were investigated. These rice starches showed a non-random combination of AAC and GT. Rice starches showed a typical A-type diffraction pattern with the degree of crystallinity ranging from 32.3% (a high AAC rice) to 45.5% (a waxy rice). AAC was significantly correlated with the pasting, thermal and textural properties. The positive correlations were found with PV, HPV, CPV, SB and HD ($p < 0.05$), while the negative corrections were found with SP, ADH, COH, T_o, T_p, T_c and ΔH ($p < 0.05$). However, AAC had no correlations with BD, P_{Time} and percentage of retrogradation ($R\%$). The degree of crystallinity and GT had a positive correlation with the retrogradation properties. It could be concluded that although AAC was the major factor affecting the physicochemical properties of rice starch, the retrogradation property of rice starch was mainly determined by the degree of crystallinity and GT.

1. Introduction

Rice is the principal staple food for half of the world's population. Improvement of rice grain quality has long been the main target for rice breeding programs in most countries due to the improvement of the living standards. Four aspects for grain quality, i.e. milling, appearance, nutrition, cooking/eating qualities have been routinely evaluated with the eating and cooking quality being the most important trait affecting consumer acceptability of rice (Bao, 2012). Starch is one of main components in rice grain so that its physicochemical parameters such as apparent amylose content (AAC), gelatinisation temperature (GT), gel consistency, and rapid visco-analyser (RVA) pasting viscosity have been set up to routinely predict the cooking and eating quality.

Rice starch is mainly composed of linear amylose and highly branched amylopectin. The apparent amylose content (AAC) in waxy rice is lower than 2%, whereas common rice has an AAC ranging from very low (5–12%), low (12–20%), intermediate (20–25%) to high (25–33%) (Bao, Shen, Sun, & Corke, 2006; Chávez-Murillo, Méndez-Montealvo, Wang, & Bello-Pérez, 2012; Sodhi & Singh, 2003; Wani et al., 2012). The gelatinisation temperature (GT) determined by differential scanning calorimeter (DSC) reflects the ease or difficulty to cook the rice (Bao, Sun, & Corke, 2007). GT is related to the chain-length distribution of amylopectin (Bao, Xiao, Hiratsuka, Sun, & Umemoto, 2009; Noda, Nishiba, Sato, & Suda, 2003). The GT in different rice cultivars can be classified as low, intermediate and high (Juliano & Perez, 1984).

The genetic diversity in starch physicochemical properties among diverse germplasm has been well documented (Bao et al., 2006; Mir & Bosco, 2014; Singh, Kaur, Sodhi, & Sekhon, 2005; Sodhi & Singh, 2003; Yu, Ma, Menager, & Sun, 2012). It is interesting to note that the combination of AAC and GT for a given rice is not random. For example, high-AAC rice usually has intermediate or low-GT; low-AAC rice or waxy rice usually has high or low-GT (Juliano, 1998; Juliano & Villareal, 1993). In contrast, it is difficult to find the combinations of high-AAC and high-GT, or low-AAC and intermediate-GT rice (Juliano,

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Abbreviations: AAC, apparent amylose content; ADH, adhesiveness; BD, breakdown; COH, cohesiveness; CPV, cold paste viscosity; DSC, differential scanning calorimeter; GT, gelatinisation temperature; HD, hardness; HPV, hot paste viscosity; P_{Time}, peak time; P_{Temp}, pasting temperature; PV, peak viscosity; RVA, rapid visco-analyser; $R\%$, percentage of retrogradation; SB, setback; SP, swelling power; T_o, onset temperature; T_c, conclusion temperature; T_p, peak temperature; WSI, water solubility index; ΔH, enthalpy of gelatinisation; $\Delta H_{(r)}$, enthalpy of retrogradation.

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1998; Juliano & Villareal, 1993). From a systematically survey on the physicochemical properties of Chinese rice germplasm, we have found many combinations of AAC and GT (Bao et al., 2006, 2007). However, the starch characteristics of these rice varying in AAC and GT combinations have not been reported.

The functional properties of starches are of great importance to recognize the extensive utilisation of starches in both food and non-food industries (Wang et al., 2010). AAC was reportedly the major factor influencing the physicochemical properties of rice starch (Sodhi & Singh, 2003). In general, rice starches with higher amylose content display higher pasting temperature, lower peak viscosity and higher setback viscosity, whereas those with lower amylose content have less tendency to retrogradation and higher swelling power (Jane et al., 1999; Sodhi & Singh, 2003). The swelling behaviour of cereal starch is primarily a property of its amylopectin content, but amylose acts as both a diluent and an inhibitor of swelling (Kaur, Panesar, Bera, & Kumari, 2014; Wang et al., 2010). Although these studies have revealed the factors affecting functional properties of rice starch, the results may be varied because few rice cultivars with a small diversity in their starch properties were used in these studies. If a diverse set of rice cultivars that represent all the AAC-GT combinations are studied, the factors that may affect the functional properties of starch need to be determined.

In this study, fourteen rice cultivars with variations in AAC and GT combinations were selected to examine their physicochemical and functional properties, and to determine which were the main factors affecting various functional properties. Such information may not only contribute to understanding the major factors affecting starch functional properties, but also help identify uses for these starches in food and other industries.

2. Materials and methods

2.1. Materials

Fourteen paddy cultivars including three waxy (Youzaonuo, Xiangnuo and Lishuinuo), five low-AAC (Zhefu504, 93-11, Zhonghua11, Ce482 and Xiushui11), two intermediate-AAC (IR64 and Lemont) and four high-AAC (Jiayu293, Zhenshan B, Long B and Zaiyeqing 8) were employed in this study (Table 1). All samples were dehulled using a husker (Model FC2K-Y, Yamamoto Co. Ltd., Yamagata-ken, Japan), and milled to white rice using a Satake Rice Machine (Satake Corporation, Japan).

2.2. Starch isolation

Starch was extracted by using the alkaline steeping method performed according to Takeda, Takeda, Mizukami, and Hanashiro (1999) with minor modification. Briefly, milled rice grain samples were immersed in 0.25% NaOH solution and placed at room temperature for 24 h; the grain samples were blended for about 3 min (HR2168, Philips, Netherland), then the blended slurry was stepwise filtrated through 100 (149 μm), 400 (37 μm) mesh sieves. The filtrate was washed by MilliQ water and centrifuged at 3000×g for 15 min. The supernatant and top yellow protein layer were discarded. The lower starch layer was resuspended in MilliQ water and neutralised by acid chloride solution, and then centrifuged as above; this procedure was repeated twice more. The isolated starch was dried in oven at 40 °C and ground to pass through a mesh 70 (212 μm) sieve.

2.3. Amylose and moisture determination

Apparent amylose content (AAC) of isolated rice starch was analysed by using the iodine reagent method. 10 ml of 0.5 mol/L KOH was added to 20 mg starch sample (dry weight based), the suspension was mixed thoroughly by vortex. The dispersed sample was then transferred to a 100 ml volumetric flask and 5 ml of 1 mol/L HCl was added, followed by 0.5 ml of iodine reagent. The solution was diluted to 100 ml and the absorbance was measured at 620 nm on a spectrophotometer after 20 min. The determination of AAC was calculated according to a standard curve developed using different ratios of amylose and amylopectin blends.

Moisture content was determined using a MJ33 Moisture Analyzer (Mettler-Toledo, Switzerland).

2.4. X-ray diffraction and scanning electron microscopy (SEM)

X-ray diffraction pattern measurements of rice starch were analysed by employing Siemens D5005 X-ray diffractometer (Bruker AXS, Karlsruhe, Germany) equipped with Cu-Kα (1.54 Å) radiation. The accelerating voltage and current of 30 kV and 30 mA, respectively, in combination with scan rate of 1°/min were used. The diffractograms were recorded in a 2θ ranged from 3° to 35° with sampling width of 0.02°. The crystalline peaks were determined according to a previous publication (Lopez-Rubio, Flanagan, Gilbert, & Gidley, 2008), and the crystalline and amorphous areas were calculated following the method of Hayakawa, Tanaka, Nakamura, Endo, and Hoshino (1997). Crystallinity was calculated as follows:

Table 1
Amylose content, crystalline and swelling properties (85 °C) of rice starches.

Class[1]	Code	Cultivar	AAC (%)	Moisture (%)	Crystallinity (%)	SP (g/g)	WSI (%)
Waxy	BP011	Youzaonuo	0.8^{h}	8.9^{bcd}	45.5^{a}	39.9^{a}	15.3^{j}
	BP597	Lishuinuo	0.1^{h}	10.5^{a}	36.8^{ef}	ND	ND
	BP601	Xiangnuo	0.1^{h}	8.9^{bcd}	42.9^{b}	31.5^{b}	31.8^{d}
Low	BP005	Zhefu 504	14.6^{g}	8.4^{de}	41.0^{c}	23.2^{e}	17.4^{h}
	BP025	Ce 482	18.3^{e}	8.5^{cde}	36.0^{ef}	21.9^{f}	23.8^{f}
	BP033	93-11	17.3^{f}	8.3^{e}	34.2^{gh}	23.8^{d}	16.0^{i}
	BP050	Xiushui 11	17.8^{ef}	8.8$^{b\text{–}e}$	34.7^{fg}	27.5^{c}	17.7^{h}
	BP605	Zhonghua 11	17.4^{f}	9.3^{b}	37.3^{de}	19.6^{g}	25.3^{e}
Intermediate	BP015	Lemont	21.6^{d}	10.1^{a}	38.0^{de}	19.2^{gh}	9.5^{l}
	BP047	IR64	21.0^{d}	8.6^{cde}	38.3^{de}	27.5^{c}	17.7^{h}
High	BP003	Jiayu 293	24.9^{c}	9.0^{bc}	42.0^{bc}	16.2^{i}	19.3^{g}
	BP028	Zhenshan B	27.7^{b}	8.8$^{b\text{–}e}$	37.9^{de}	7.0^{l}	77.0^{b}
	BP578	Zaiyeqing 8	28.7^{a}	9.0^{bc}	39.2^{cd}	9.7^{j}	58.4^{c}
	BP628	Long B	28.1^{ab}	10.0^{a}	32.3^{h}	8.7^{k}	88.2^{a}

Values in the same column with the same letters do not differ significantly ($p < 0.05$). ND, not detected.

[1] The class was assigned according to the apparent amylose content.