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Structural and functional properties of starches from Chinese chestnuts

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ABSTRACT

Structural and functional properties of starches isolated from four varieties of chestnuts grown in China were characterized in this study. The starch granules exhibited a variety of shapes, varying from round, croissant-like, irregular to triangular. The amylose content of four chestnut starches was about 21–22%. Average particle diameter of the four starches varied between 10.8 and 18.1 μm. The X-ray patterns of four chestnut starches were of C-type, with relative crystallinity ranging between 26 and 29%. Although there were only small differences between the starches in amylose content, they displayed significant variability in physicochemical and functional properties, such as swelling power, pasting characteristics, thermal and textural properties, freeze-thaw stability, and in susceptibility to *in vitro* attack by enzymes. Average particle diameter of four starch granules was negatively correlated with swelling power at 92.5 °C ($r = -0.956$, $p < 0.05$), and positively correlated with conclusion temperature in the DSC ($r = 0.988$, $p < 0.05$). Correlation between swelling power at 92.5 °C and conclusion temperature was also significant ($r = -0.973$, $p < 0.05$). This study provides sufficient information on properties of Chinese chestnut starches, which would be very helpful for their application in food and other industries.

1. Introduction

The chestnut (*Castanea mollissima* Bl.), belonging to the Fagaceae family, is one of the major nuts in China. It has a growing history of over 2000 years in China and makes great contribution to the national economy. The chestnut fruit is considered a high nutritional value food and has long been used as one of the Traditional Chinese Medicines for health care in China (Zhang, Chen, & Zhang, 2011). Chestnut fruit is also an important and popular food, which is consumed widely throughout Europe, America, and Asia (De Vasconcelos, Bennett, Rosa, & Ferreira-Cardoso, 2010). As one of the oldest edible fruits in northern hemisphere, chestnut was consumed as extensively as potato in the past (Ferreira-Cardoso, Sequeira, Torres-Pereira, Rodrigues, & Gomes, 1999). Although chestnuts are mainly consumed freshly after roasting, boiling or stir-frying with syrup, some processed chestnut products need to be reheated before eating. There is increasing evidence showing that the consumption of chestnuts has become more and more important for human nutrition due to the health benefits provided by the presence of bioactive components, including lectin, cysteine proteinase inhibitor and quercetin (Blomhoff, Carlsen, Andersen, & Jacobs, 2006). The chemical composition of chestnuts boasts the highest content in polymeric carbohydrates, considerable levels of vitamins, fibres, and acceptable content in lipids and adequate minerals (Borges, Carvalho, Correia, & Silva, 2007; Miguelez, Bernárdez, & Queijeiro, 2004). Recently, chestnut has received much more attention, as can be seen from the increasing publications. On one hand, chestnut presents a large potential for commercial use since it is a good source of starch. On the other hand, the consumption of chestnut has been shown to have many nutritional benefits.

Starch is the main storage carbohydrate of higher plants and the main source of energy in human diets. It is also a cheap raw material with distinct physiochemical properties that are very important for its application in food and non-food industries. Native starch is highly variable between and within plant species. This variability is evident in granular structure and functional properties (Wang, Sharp, & Copeland, 2011). The functional properties of starch granules include swelling power, starch solubility, gelatinization, retrogradation, syneresis, and rheological behaviour, which are generally determined by the multiple characteristics of starch structure.

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Table 1
Chemical composition of chestnut fruits.

Varieties	Total starch content (%)[a]	Protein (%)[a]	Lipid (%)[a]	Ash (%)[a]
Banhong	44.8 ± 0.8b	9.5 ± 0.3a	2.1 ± 0.1a	1.9 ± 0.1a
Yanlong	42.4 ± 1.0b	8.9 ± 0.4 ab	2.3 ± 0.2a	2.0 ± 0.2a
Yankui	50.8 ± 1.7a	7.7 ± 0.3c	2.3 ± 0.1a	2.2 ± 0.2a
Zaofeng	53.8 ± 1.6a	8.5 ± 0.2bc	2.4 ± 0.2a	2.3 ± 0.1a

Values are means ± SD. Means with the same letters in a column do not differ significantly ($p < 0.05$).
[a] Dry weight basis.

Starch is the main constituent of chestnut fruit. The starch content in chestnut fruit ranges from 38 to 80% (Borges, Gonçalves, Carvalho, Correia, & Silva, 2008; Miguelez et al., 2004). Although the structural and functional properties of chestnut starches have been studied (Correia & Beirão-da-Costa, 2010; Correia, Cruz-Lopes, & Beirão-da-Costa, 2012; Cruz, Abraão, Lemos, & Nunes, 2013; Yang, Jiang, Prasad, Gu, & Jiang, 2010; Yoo, Lee, Kim, & Shin, 2012; Zhang et al., 2011), there have been few comparative studies on the properties of starches from Chinese chestnut varieties. To extend the application of chestnut, the knowledge on the functional properties of chestnut starch, including its susceptibility to the enzymatic digestion, is extremely important. As a result, one aim of the present study was to characterize the structural and functional properties of starches from four Chinese chestnut varieties and to analyze the relationships between these properties. Another important aim was to compare the functional properties of chestnut starches and commonly used corn starches for the potential utilization of chestnut starch in food and other industries.

2. Materials and methods

2.1. Samples

Four Chinese chestnut varieties (Banhong, Zaofeng, Yanlong, Yankui) were obtained from chestnut storage and processing center of Hebei province, China. Yanlong is an advanced line from the breeding program of Hebei Normal University of Science and Technology. It was identified by Committee of Forestry Varieties of Hebei Province in 2009, and had Plant Breeders' Rights Application Number (S-SV-CM-003-2009). The chestnuts were grown and harvested at Yanshan Mountain in 2012 season. The harvested fruits were collected and stored at 4 °C.

2.2. Starch extraction

Starch was isolated according to the method of Wang et al. (2011) with modifications as follows. The chestnuts (700 g) were rinsed, peeled and homogenized in a kitchen blender with 1.5 L distilled water for 1–2 min at maximum speed. The starch slurry was passed through a 140 mesh filtrating cloth. The resulting starch suspension was allowed to settle overnight at 4 °C. The supernatant was decanted, and the brownish grey layer on top of the white starch sediment was removed. The starch pellet was dispersed in 500 ml of 0.15% NaOH and settled for 2 h at 4 °C. The supernatant was decanted, the sedimented starch was resuspended in 500 ml of deionized water, and the pH was adjusted to 6.5 with 0.1 M HCl. The starch suspension was allowed to sediment and the supernatant was discarded. The sedimented starch was washed several times with distilled water until the densely deposited white starch was obtained, and then freeze dried in a Freeze Dryer (LGJ-10 freeze drier, Four-Ring Science Instrument Plant Beijing Co. Lts, Beijing, China) at −50 °C.

2.3. Determination of the chemical composition of chestnuts and isolated starches

Total and damaged starch content were determined using Megazyme Total Starch and Starch Damage Assay Kits (Megazyme International Ireland Ltd. Bray Co., Wicklow, Ireland), respectively. The analyses were performed according to the instructions supplied with the kits. Amylose content was determined by iodine binding method according to Williams, Kuzina, and Hlynka (1970). Nitrogen, lipid and ash content were determined according to AOAC official procedures (methods 954.01, 920.39 and 923.03) (AOAC, 1997). Protein content was obtained by multiplying the nitrogen content by 6.25. Moisture content was determined by oven drying of the starch at 105 °C until constant weight (925.40 AOAC method) (AOAC, 2000).

2.4. Morphology of starch

Chestnut starch was imaged using the SU-1510 Scanning Electron Microscope (Hitachi Company, Japan). Starch samples were mounted on a specimen holder using a double-sided carbon adhesive tape and sputter-coated with gold. An accelerating voltage of 5 kV was used during scanning.

2.5. Particle size distribution

Particle size distribution of starch granules was measured using Laser Diffraction Particle Size Analyzer LA-920 (Horiba Instruments Ltd., Japan) according to the instructions supplied with the instrument. The starch was evenly dispersed in ethanol with magnetic agitation to attain a transmittance of 80%.

2.6. X-ray diffraction

X-ray diffraction analysis was performed using a D/max-2500vk/pc X-ray diffractometer (Rigaku Corporation, Tokyo, Japan) operating at 40 V and 30 mA. Starches were equilibrated over a saturated potassium chloride (KCl) solution at room temperature for one week before analysis (Wang, Yu, Zhu, Yu, & Jin, 2009). The intensity was measured from 3 to 40° as a function of 2θ and at a scanning speed of 1°/min and a step size of 0.02°. The degree of crystallinity was determined quantitatively following the method reported previously (Ribotta, Cuffini, León, & Añón, 2004). The crystallinity of starch was calculated as a ratio of the crystalline

Table 2
Chemical composition of chestnut starches.

Varieties	Moisture (%)	Protein (%)[a]	Lipid (%)[a]	Ash (%)[a]	Amylose (%)	Damage starch (%)	Mean particle size (μm)
Banhong	5.52 ± 0.24a	0.20 ± 0.04a	0.79 ± 0.08a	0.07 ± 0.02a	21.16 ± 0.38a	3.63 ± 0.21b	12.68 ± 0.05b
Yanlong	5.23 ± 0.36a	0.10 ± 0.03a	0.62 ± 0.04a	0.10 ± 0.03a	21.80 ± 0.18a	4.94 ± 0.28a	10.76 ± 0.03c
Yankui	5.70 ± 0.11a	0.13 ± 0.05a	0.73 ± 0.06a	0.14 ± 0.05a	22.27 ± 0.25a	3.25 ± 0.25c	12.52 ± 0.06b
Zaofeng	5.93 ± 0.3 a	0.15 ± 0.06a	0.65 ± 0.05a	0.09 ± 0.02a	21.67 ± 0.15a	2.22 ± 0.10d	18.10 ± 0.25a

Values are means ± SD. Means with the same letters in a column do not differ significantly ($p < 0.05$).
[a] Dry weight basis.