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Physical properties of *Amaranthus* starch

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ABSTRACT

Physicochemical and functional properties of starches isolated from fifteen grain amaranth cultivars (*Amaranthus* spp.) produced in China were analysed in this study. Amaranth starches had low but diverse amylose contents, ranging from 4.7% to 12.5%. Wide variation was also found in physicochemical properties, such as swelling power, water solubility index, pasting, thermal and textural properties. Amylose content was significantly correlated with functional properties, including pasting, thermal and textural properties and appeared to be the important determinant for these properties. Correlations among pasting, thermal and textural parameters were also significant. Principal component analysis using 17 variables extracted four principal components that explained 88% of the total variance. The first component represented amylose content, pasting and gel textural properties and explained 59% of the total variance, while the second component represented the thermal properties and accounted for an additional 14.5% of the total variance.

1. Introduction

Grain amaranth is receiving more and more attention as a grain crop not only due to its resistance to abiotic and biotic stresses, but also due to its high biomass production and high nutritional value. Since the 1980s grain amaranth has been grown commercially in the United States with fairly good success (Baker & Rayas-Duarte, 1998), and almost at the same time this crop was introduced into China from the US by the Chinese Academy of Agricultural Sciences, although vegetable types had been planted in China for centuries (Wu & Corke, 1999). A number of locally adapted amaranth cultivars have been obtained in China through selection and cultivation for two decades.

Starch constitutes the main component of amaranth grain and plays an important role in its food applications, such as for food thickeners for soups, fat replacers, gravies and sauces, and in breakfast cereals, muffins, cookies, snacks, pastas and health food. Other current and potential commercial uses of amaranth starch are in cosmetics, biodegradable films, paper coatings and laundry starch (Choi, Kim, & Shin, 2004). The starch properties of amaranth have been characterised in many studies (e.g. Baker & Rayas-Duarte, 1998; Choi et al., 2004; Hoover, Sinnott, & Perera, 1998; Marcone, 2001; Radosavljevic, Jane, & Johnson, 1998; Uriyapongson & Rayas-Duarte, 1994; Wu, Yue, Sun, & Corke, 1995). Amaranth starch granules are small with diameters of 0.5–2 μm (Hoover et al., 1998; Marcone, 2001). Amaranth starch displays an A-type X-ray pattern (Choi et al., 2004; Hoover et al., 1998; Qian & Kuhn, 1999). Its amylose content is low, ranging from 3–8% depending on different genotypes (Choi et al., 2004; Hoover et al., 1998; Marcone, 2001; Qian & Kuhn, 1999; Uriyapongson & Rayas-Duarte, 1994). However, these studies cover relatively few cultivars, which cannot represent the whole variation among amaranth genotypes. Thus, it is difficult to gain an adequate understanding of the functional properties of amaranth starches and their relationships. Preliminary screening of starch properties from a larger number of genotypes was conducted (Wu & Corke, 1999).

In the present study, 15 cultivars were selected representing different amaranth species to further characterise their physicochemical and functional properties. The objectives of this study are: (i) to determine the physicochemical and functional properties, i.e. amylose contents, swelling, pasting, thermal and textural properties; (ii) to analyse the relationships among and between these properties and (iii) to analyse the variances among these properties by principal component analysis. The study should help to widen the application of amaranth starches.

2. Materials and methods

2.1. Materials

Amaranth seeds of 15 cultivars representing four species were harvested from China (Table 1). All seed samples were dried in the oven at 40 °C for 48 h and ground into flour using a blender (BL530, Kenwood, Japan) to pass through a 500 μm sieve.

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Table 1
Background information, moisture, granule size, amylose content and swelling properties of starches from different amaranth cultivars in China

Cultivars	Species	Origin	Moisture (%)	Average granule size (μm)	Amylose (%)	SP[a] (g/g)	WSI[b] (%)
K350	*Amaranthus cruentus* L.	US	13.0	1.32	11.4 a	13.9 bc	16.1 c
R159	*Amaranthus cruentus* L.	US	11.9	1.25	8.7 b	20.0 a	78.7 b
D88-1	*Amaranthus cruentus* L.	US	11.8	1.24	5.5 cd	15.5 b	85.4 ab
V69	*Amaranthus cruentus* L.	China	11.7	1.28	12.5 a	12.9 cd	29.0 c
Japan19	*Amaranthus cruentus* L.	Japan	12.0	1.12	8.6 b	11.4 de	83.8 ab
M7	*Amaranthus cruentus* L.	Mexico	11.6	1.26	5.8 cd	10.0 e	95.3 a
Cr064	*Amaranthus cruentus* L.	Mexico	11.4	1.26	5.2 cd	9.5 e	92.1 a
Cr049	*Amaranthus cruentus* L.	Mexico	11.7	1.19	6.0 cd	10.5 de	89.6 ab
K112	*Amaranthus cruentus* L.	Mexico	12.1	1.21	5.7 cd	11.9 de	86.9 ab
R104	*Amaranthus cruentus* L.	Mexico	11.6	1.15	5.0 cd	9.1 e	90.7 ab
5293	*Amaranthus cruentus* L.	Mexico	12.1	1.32	4.7 d	13.7 c	92.7 a
Tibet Yellow	*Amaranthus paniculatus* L.	China	12.1	1.16	8.9 b	10.0 e	78.0 b
NO1	*Amaranthus hypochondriacus* L.	US	12.4	1.09	5.8 cd	13.1 cd	91.0 ab
NO2	*Amaranthus hypochondriacus* L.	Mexico	12.6	1.05	5.4 cd	12.3 cd	90.6 ab
NO3	*Amaranthus hybridus* L.	Pakistan	13.9	1.21	6.1 c	10.5 de	85.1 ab

Values in the same column with the same letters do not differ significantly ($P < 0.05$).
[a] Swelling power at 85 °C.
[b] Water solubility index at 85 °C.

2.2. Starch isolation

Starch extraction, was performed according to the method described by Choi et al. (2004) with some modifications. Briefly, the flour sample was immersed in 0.25% aqueous NaOH solution and kept at 5 °C for 24 h. Before stepwise filtration through 60 (250 μm), 100 (149 μm), 270 (53 μm) and 400 (37 μm) mesh sieves, the slurry was blended for about 3 min (BL530, Kenwood, Japan). Double deionised water was used to wash the slurry until no white starch was washed out. The filtrate was then centrifuged at 3000 *g* for 25 min. The supernatant was discarded, and the top yellow protein layer was also removed. The lower starch layer was resuspended in double deionised water, and centrifuged as above, and this procedure was repeated twice more. The isolated starch was dried in an oven at 40 °C and ground to pass through a mesh 70 (212 μm) sieve.

2.3. Amylose, moisture and scanning electron microscopy (SEM)

Amylose content (AC), was analysed using an Amylose/Amylopectin Assay Kit (Megazyme, Ireland) based on concanavalin A (Con A) method. Moisture content, was determined by using LJ16 Moisture Analyser (Mettler-Toledo, Switzerland). Starch granule morphology was obtained by an environmental scanning electron microscope (ESEM, Philips XL-3, The Netherlands).

2.4. Swelling power and water solubility index

Swelling power and water solubility index were determined according to the method of Li and Yeh (2001) with some modifications. Starch (100 mg, dry weight basis) was weighed directly into a screw-cap test tube, and 10 mL distilled water was added. The capped tubes were then placed on a vortex mixer for 10 s and incubated in 55 °C, 65 °C, 75 °C, 85 °C, 95 °C water bath for 30 min with frequent mixing by vortex at 2 min intervals. The tubes were then cooled to room temperature in an iced water bath and centrifuged at 2000 *g* for 30 min, and the supernatant was removed with suction. The cloudy solid layer was considered as supernatant, only the material adhered to the wall of the tube was thought as sediment and weighed (W_s). The supernatant was dried to constant weight (W_1) in a forced-air oven at 100 °C. The water solubility index (WSI) and swelling power (SP) were calculated as follows:

$$\mathrm{WSI} = W_1/0.1 \times 100\%, \quad \mathrm{SP} = W_s/[0.1(100\% - \mathrm{WSI})](\mathrm{g/g}).$$

2.5. Pasting properties

Pasting properties of starch were determined using a Rapid Visco Analyser (RVA, Model 3D, Newport Scientific, Warriewood, Australia) with Thermocline for Windows software (Version 2.0). Starch (3 g, 14% moisture basis) was mixed with 25 g double deionised water in the RVA sample canister. A programmed heating and cooling cycle was used where the samples were held at 50 °C for 1 min, heated to 95 °C in 7.5 min, held at 95 °C for 5 min before cooling to 50 °C in 7.5 min and holding at 50 °C for 2 min. The peak viscosity (PV), hot paste viscosity (holding; HPV), cool paste viscosity (CPV) and their derivative parameters breakdown (BD = PV−HPV), setback (SB = CPV−PV) and peak time (P_{Time}) were recorded (Bao, Kong, Xie, & Xu, 2004). The viscosities are presented in Rapid Visco Units (RVU).

2.6. Thermal properties

Thermal properties were analysed using a Differential Scanning Calorimeter 2920 (TA Instruments, New Castle, DE, USA) according Xu, Xie, Kong, and Bao (2004) with some modifications. Starch (2.0 mg, db) was weighed into an aluminium pan and 6 μl distilled water was added. The pan was hermetically sealed and equilibrated at room temperature for 1 h, then heated at the rate of 10 °C/min from 30 to 120 °C with an empty sealed pan as a reference. Parameters such as onset (T_0), peak (T_p), conclusion (T_c) temperature, width at half peak height ($\Delta T_{1/2}$) and enthalpy (ΔH) of gelatinisation were determined by Universal Analysis software version 2.5H.

2.7. Textural properties

The starch gel formed in the canister after RVA analysis was kept in the RVA canister, sealed with Parafilm™ and kept at 4 °C for 24 h (Bao et al., 2004). Textural properties were analysed using a TA-XT2*i* Texture Analyser (Stable Micro Systems Ltd., Surrey, England) equipped with Texture Expert software (version 1.2), Each starch gel sample in the canister was pressed to a distance of 15 mm (trigger force = 0.05 N) with a cylinder probe 20 mm in diameter at the speed of 0.5 mm/s during two replicated runs, the pre-speed and post-speed were both set at 1.0 mm/s and the acquisition rate was 4.00 pps. Hardness (HD, g), adhesiveness (ADH, g·s) and cohesiveness (COH) were calculated from the profiles by using the Texture Expert software.