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Physicochemical properties of quinoa starch

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ABSTRACT

Physicochemical properties of quinoa starches isolated from 26 commercial samples from a wide range of collection were studied. Swelling power (SP), water solubility index (WSI), amylose leaching (AML), enzyme susceptibility, pasting, thermal and textural properties were analyzed. Apparent amylose contents (AAM) ranged from 7.7 to 25.7%. Great variations in the diverse physicochemical properties were observed. Correlation analysis showed that AAM was the most significant factor related to AML, WSI, and pasting parameters. Correlations among diverse physicochemical parameters were analyzed. Principal component analysis using twenty three variables were used to visualize the difference among samples. Six principal components were extracted which could explain 88.8% of the total difference. The wide variations in physicochemical properties could contribute to innovative utilization of quinoa starch for food and non-food applications.

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a pseudocereal originated from the Andes of South America, and has been cultivated there since 3000–4000 years ago. Quinoa has a high tolerance to abiotic stresses such as soil salinity, acidity, drought, flooding, and frost. It has been introduced to other parts of the world such as United States, China, Europe, Canada, and India (Abugoch, 2009; Bazile, Fuentes, & Mujica, 2013; Bhargava, Shukla, & Ohri, 2006). There is a great diversity in the properties and quality of quinoa products due to the wide geographic distribution and genetic resources. The colors of quinoa seeds are rather various, include white, yellow, red, black, and so on (Bhargava et al., 2006; Ruiz et al., 2014; Vega-Gálvez et al., 2010). During the last two decades, quinoa has experienced a renaissance due to its attractive nutritional features (Repo-Carrasco, Espinoza, & Jacobsen, 2003; Valencia-Chamorro, 2003; Wang & Zhu, 2015). The seeds rich in starch can be used to produce diverse food products such as rice replacement, infant food, flakes, pancakes, bread, and puffed grains (Valencia-Chamorro, 2003; Wang, Opassathavorn, & Zhu, 2015; Wang & Zhu, 2015). In particular, quinoa is rarely allergenic to people with celiac diseases due to the absence of gluten-type protein.

Starch is the major component of quinoa seeds, making up approximately 53.5–69.2% of the dry matter (Mundigler, 1998; Steffolani, León, & Pérez, 2013; Wright, Huber, Fairbanks, & Huber, 2002). The starch granules are usually located in the perisperm of the seed, and are present as simple units or as spherical aggregates (Lorenz, 1990; Ruales & Nair, 1994). Previous studies showed that quinoa starch (QS) granules are small (1–3 μm in diameter) (Lorenz, 1990). The amylose content ranged from 4 to 25% (Inouchi et al., 1999; Lindeboom, 2005; Praznik et al., 1999; Qian & Kuhn, 1999; Tang, Watanabe, & Mitsunaga, 2002; Watanabe, Lai, Tang, & Mitsunaga, 2007). Amylopectin of QS had a particular large number of short chains and a small number of long chains (Inouchi et al., 1999). The low amylose content and unique amylopectin structure are influential to the functional properties of starch. QS gelatinizes at relatively low temperatures as compared to amaranth, normal and waxy maize starches (Kong, Bao, & Corke, 2009; Sandhu & Singh, 2007; Singh, Inouchi, & Nishinari, 2006), and exhibits lower pasting temperature and peak viscosity than both normal and waxy maize starches (Lindeboom, Chang, Falk, & Tyler, 2005). QS also showed excellent freeze-thaw stability (Ahamed, Singhal, Kulkarni, & Pal, 1998; Lindeboom et al., 2005).

Most of the previous studies on physicochemical properties of QS analyzed rather limited number of samples, or focused on the comparison among QS (only 1 or 2 samples) and starches from other botanical sources (Linsberger-Martin, Lukasch, & Berghofer, 2012; Nascimento et al., 2014; Steffolani et al., 2013; Wright et al., 2002). Lindeboom et al. (2005) analyzed QS from 8 quinoa lines cultivated in Canada, and investigated the correlations between amylose content and various physicochemical properties. Systematic documentation of physicochemical properties of QS from a

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worldwide collection is still to be conducted. Besides, the relationships among the physicochemical properties of QS have been little studied. This greatly hinders diverse applications of QS as a novel starch resource. Furthermore, the quality of quinoa products such as cooking and eating properties can be much determined by the properties of starch (Wang & Zhu, 2015; Wu, Morris, & Murphy, 2014). Understanding starch properties would greatly support the application and commercialization of this crop on a larger scale. Thus, a survey of diverse starches isolated from commercial quinoa seeds can promote understanding the variations in the quality of commercial food products. The aims of this study were to characterize the physicochemical properties of 26 QS from a range of suppliers and geographic areas, and to investigate the relationships among these properties.

2. Materials and methods

2.1. Materials

Twenty-six types of commercial quinoa seeds were collected from different countries and suppliers with a range of geographic origins (Table 1). Porcine pancreatic α-amylase (PPA, 1821 units/mg protein) and maize amylopectin were purchased from Sigma–Aldrich Chemical, Co. (Auckland, New Zealand). GELOSE 50 and normal maize starches were from Ingredion ANZ Pty Ltd. (Auckland, New Zealand). GELOSE 50 is a type of maize starch with an apparent amylose content of 50%. All other chemicals and reagents were purchased from ECP Ltd. (Auckland, New Zealand), except for dimethyl sulfoxide (DMSO), sulfuric acid, and phenol from Avantor Performance Materials Inc. (PA, USA), Scharlau (Barcelona, Spain), and Sigma–Aldrich Chemie GmbH (Deisenhofen, Germany), respectively.

2.2. Quinoa starch extraction

QS was extracted using the procedure of Annor, Marcone, Bertoft, and Seetharaman (2014) with some modifications. Quinoa seeds were frozen by liquid nitrogen for 2 min before milling into flour with a coffee bean grinder for 1 min. Quinoa flour (100 g) was stirred with 1 L of sodium borate buffer (12.5 mM, pH 10, containing 0.5% sodium dodecyl sulfate (SDS) [w/v] and 0.5% $Na_2S_2O_5$ [w/v]) for 30 min to remove the proteins and lipids. The residue was recovered by centrifugation at 3000 × *g* for 10 min. The above removing procedure was repeated. The residue was washed with deionized water (1 L) and recovered by centrifugation at 3000 × *g* for 10 min. The residue was subsequently suspended in distilled water and stirred overnight to further release the protein from the starch granules. Afterwards the starch slurry was passed through four layers of cheesecloth and then through a 140 μm nylon mesh. The slurry was centrifuged, and the brown layer that formed on the top of the starch layer was scraped off with a spatula and discarded. This step was repeated six times to remove the brown particles and SDS. The resulting starch fraction was dried in an air-forced oven at 35 °C for 48 h, ground to powder, and sealed in air tight plastic container.

2.3. Moisture content

Moisture content (MC, %) was determined using an air-force oven according to the approved AACCI methods 44-40.01 (AACCI, 2000) with slight modifications. Aluminum pans were dried at 125 °C to constant weight and kept in a desiccator at room temperature. Starch samples (200 mg) were accurately weighed into the aluminum pans and dried at 120 °C until constant weight. MC refers to the percentage of loss in sample weight.

2.4. Apparent amylose content

Apparent amylose content (AAM) was determined according to an iodine binding-based method (Schoch, 1964) with some modifications. KI (0.1079 g) and I_2 (0.0315 g) were dissolved in 100 mL deionized water and stored in dark at 4 °C. A series of mixtures of GELOSE 50 and maize amylopectin were prepared for calibration. The AAM of GELOSE 50 and maize amylopectin were treated as 50% and 0%, respectively. Sample (20 mg) was weighed into a Kimax tube fitted with a Teflon-faced rubber liner. A reagent blank was prepared in the same way without adding starch. 90% DMSO (8 mL) was added and mixed vigorously for 2 min using a vortex mixer. The tubes were then heated at 85 °C in a water bath with intermittent mixing for 30 min. All the tubes were then allowed to cool at room temperature before diluting to 25 mL with deionized water. The diluted sample (3 mL) was mixed vigorously with deionized water (40 mL) and iodine solution (1 mL) in a 50 mL volumetric flask. The absorbance of the sample was measured at 600 nm after 15 min of incubation. AAM was calculated using regression equation.

2.5. Amylose leaching

Amylose leaching (AML) was analyzed according to Gunaratne and Hoover (2002) with some modifications. Starch (20 mg, db) was dispersed in water (10 mL) and heated at 55 °C, 65 °C, 75 °C, 85 °C, and 95 °C, respectively for 30 min with shaking every 1 min to suspend the slurry. The tubes were then cooled to room temperature and centrifuged (3000 × *g*, 30 min). The supernatant (1 mL) was withdrawn and AAM determined as in Section 2.4. AML was expressed as percentage of amylose leached from starch.

2.6. Swelling power and water solubility index

Swelling power (SP, g/g) and water solubility index (WSI, %) were determined using a method modified from Tsai, Li, and Lii (1997). Briefly, sample (0.15 g, db) was weighed into a centrifuge tube with coated screw cap, and 10 mL deionized water was added. The tubes were then heated at 55 °C, 65 °C, 75 °C, 85 °C, and 95 °C, respectively, with frequent shaking by vortex for 1 h before cooling in ice water bath and centrifugation (3000 × *g*, 30 min). The supernatant was poured out in an aluminum pan. The remaining solid fraction was weighed (W_s). The supernatant was dried to a constant weight (W_1) at 100 °C. The WSI and SP were calculated as follows:

$$\mathrm{WSI} = \left(\frac{W_1}{W_0}\right) \times 100\%$$

$$\mathrm{SP\,(g/g)} = \frac{W_s}{W_0 \times (1 - \mathrm{WSI})}$$

2.7. Pasting analysis

Pasting properties of starch were determined according to a previous description (Li, Lin, & Corke, 1997) using an MCR 301 Rheometer (Anton Paar, GmbH, Ostfildern, Austria) equipped with a starch cell. Starch (2.0 g, db) was mixed with 20 mL deionized water. A programmed cycle (27 min) was used where the samples were held at 50 °C for 5 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 pasting temperature (PT), peak temperature (PKT), peak viscosity (PV), hot paste viscosity (HPV), cool paste viscosity (CPV), and the derivative parameters breakdown (BD = PV − HPV), setback (SB = CPV − HPV), stability ratio (SR = 100 × HPV/PV), and setback