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Rheological, textural, and enzymatic hydrolysis properties of chickpea starch from a Chinese cultivar

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ABSTRACT

The rheological, textural, and enzymatic hydrolysis properties of starch isolated from the seed of a Chinese chickpea cultivar were compared with corn. The chickpea starch peak, final, breakdown, and setback viscosities (2631 ± 5, 1532 ± 3, 1346 ± 2, and 247 ± 0 cP, respectively) suggest a higher stability and consistency than corn. During gelatinization, the starch granules irreversibly lost their integrity and formed a continuous amorphous structure. The gel strength increased during storage for 24 h then slowly increased until 168 h. The chickpea starch gel became firmer owing to its high amylose content. During heating, storage modulus (G′) and loss modulus (G″) of starch suspension increased rapidly above 60 °C but reduced on further heating. During cooling, G′ decreased rapidly from 95 to 75 °C then increased slowly until 25 °C, with no change in G″. The hydrolysis rate of chickpea starch was lower than that of corn starch, indicating its higher resistance to α-amylase digestibility during retrogradation.

1. Introduction

Starch is one of the most abundant carbohydrates in the biosphere and the principal energy reserve in plants. Storage starch is deposited in the storage organs of cereal grains, roots, tubers, and legumes, such as wheat, corn, oat, rice, potato, tapioca, and mung bean. It serves as the most important energy-providing material (55–75%) not only for human nutrition but also for animal feed (Blennow & Eliasson, 2004; Osorio-Dıaz et al., 2002). Traditionally, starch has been widely used to maintain the quality of stored food products (Abegunde, Mu, Chen, & Deng, 2013); it improves moisture retention and consequently controls water mobility in food products. It can also be used as an alternative coating for delivering active sensitive ingredients in the food and pharmaceutical industries (Ye et al., 2014). As a biodegradable polymer, it also has huge potential as a versatile renewable resource for various material applications (BeMiller & Whistler, 2009). In the higher plants, starch is stored as two discrete types of semi-crystalline granules: the mainly linear amylose and the highly branched amylopectin. Amylose, a linear fraction, is linked by α-(1 → 4) bonds with a few long-chain branches and has a moderate molecular weight (approximately 10^6 Da); amylopectin, a highly branched fraction is linked by α-(1 → 4) and α-(1 → 6) linkages and has a high molecular weight (approximately 10^8 Da) (BeMiller & Whistler, 2009; Gallant, Bouchet, & Baldwin, 1997). Different starches exhibit various textural structures and physicochemical, rheological, and digestive properties that are specific to each particular plant even though starch of different botanical origins has identical structural units, or even if the starches have the same botanical origin. Starch manufacturing is often carried out at relatively high temperatures where rheological parameters have a direct influence on their diverse textural and nutritional properties and hence the applications of the starch-based products (Ma, Chang, Yu, & Wang, 2008; Ramis et al., 2004; Wang et al., 2012). A wide range of native starches with highly different functionalities are required to satisfy the needs of the market (BeMiller & Whistler, 2009; Li et al., 2014; Miao et al., 2014). Finding new sources of starch, specifically targeted to have a particular structure and functionalities would help to satisfy these needs.

Chickpea (*Cicer arietinum* L.), a legume of the family Fabaceae, sub-family Faboideae, is one of the earliest cultivated legumes originating in the Middle East 7500 years ago (Chavan, Kadam, Salunkhe, & Beuchat, 1987; El-Adawy, 2002; Lineback & Ke, 1975). Because of its high resistance to drought and barren growing conditions, chickpeas are now widely cultivated in Asia, the Mediterranean Basin, Australia, and North America (Hoover, Hughes, Chung, & Liu, 2010; Hughes et al., 2009). On average, chickpeas contain 63% carbohydrate, 22% protein, 8% crude fiber, 4.5% fat, and

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2.7% ash (Chavan et al., 1987). It is an important source of high-quality protein and therefore an alternative to meat as well as a source of minerals, vitamins, and many other important nutrients. Most of its carbohydrate is contributed by starch (37.5–50.8%) (Miao, Zhang, & Jiang, 2009). Therefore, chickpea starch is considered commercially important for many processed foods and its use in food systems is primarily governed by its gelatinization, gelation, and pasting properties. However, relatively few studies on the rheological and enzymatic hydrolysis properties of chickpea starch have been reported, which have a great influence on processing techniques and applications (Polesi & Sarmento, 2011). Recent studies have focused only on the isolation and characteristics of chickpea starch (De Almeida Costa, Da Silva Queiroz-Monici, Pissini Machado Reis, & De Oliveira, 2006; Lertphanich et al., 2013; Miao et al., 2009; Singh, Sandhu, & Kaur, 2004; Yañez-Farias, Moreno-Valencia, Falcón-Villa, & Barrón-Hoyos, 1997). Therefore, the objective of the present study is to determine the pasting and gelling behavior, rheological properties, and enzymatic hydrolysis *in vitro* of chickpea starch from a Chinese cultivar. The results could be useful for a better understanding of its biochemical and functional characteristics for potential applications in a variety of processed foods.

2. Materials and methods

2.1. Materials

Dry chickpea (*Desi*) seeds were purchased from Taixing Jitai Agri-Product Co. Ltd. (Taixing, China).The corn starch was given by Wuxi Thaihua Starch Co. Ltd. (Wuxi, China). The chemicals were purchased from Shanghai Experimental Reagent Co. Ltd (Shanghai, China). Protease from *Aspergillus sojae*, α-amylase type VI-B (Cat. No. P-1625, activity 3 × USP/g) from porcine pancreas, potato amylose and amylopectin were purchased from Sigma Chemical Co (St. Louis, MO, USA). Amyloglucosidase (EC 3.2.1.3., 3300 U/mL) from *Aspergillus niger* was obtained from Novozymes (Tianjin, China), respectively. The specific activity for *A. sojae* protease was specified as 0.4 unit/mg solid (1 unit hydrolyzes casein to produce the color equivalent of 1 mmol tyrosine/min at pH 7 and 37 °C using the Folin-Ciocalteu reagent).

2.2. Starch isolation

The chickpea starch was extracted from dry chickpea seeds using the wet milling procedure of Miao et al. (2009). The dried chickpea starch granules were stored in a closed container for further analysis. The amylose content was determined by using the iodine binding colorimetric method (Jiang, Miao, Ye, Jiang, & Zhang, 2014). Potato amylose and amylopectin were used as standard samples for establishing the standard curves. The iodine affinity of starches was determined using a UV/visible Spectrophotometer (UV-2102PC, Unico Instrument Co., Ltd., Shanghai, China). The amylose content of chickpea and corn starch were 32.8% and 25.6%, respectively.

2.3. Light microscopy

Diluted starch samples (1 g in 25 mL of water) were heated on a hot plate for 5 min in a glass Petri dish. After reaching the experimentally specified temperature (95 °C), the sample was immediately viewed under an XP-201 light microscope (Shanghai Caikon Optical Instruments factory, Shanghai, China) at a magnification of 400×.

2.4. Paste behavior

The paste behavior of the chickpea starch was determined using a RVA-3D Rapid Visco Analyzer (RVA) (Newport Scientific Pvt. Ltd., Warriewood, Australia). An 8% (dry basis) starch slurry with a final weight of 28 g was used. Obtaining the profile involved equilibrating the slurry for 1 min at 50 °C, then increasing the temperature to 95 °C at a rate of 5 °C/min. The temperature was held at 95 °C for 7 min, reduced to 50 °C at a rate of 6 °C/min, then held at 50 °C for 4.5 min. The changes in viscosity during this sequence were recorded, noting the peak, final, breakdown and setback viscosities, the peak temperature, and the time values.

2.5. Gel behavior

The starch pastes prepared in the RVA were poured into small aluminum canisters and stored at 4 °C for 3, 6, 12, 24, 72, and 168 h to cause gelation as described by Wang, White, and Pollak (1992). The gel strength (texture) of the starch paste was measured at five different locations on each sample using a TA-XT2i texture analyzer (Stable Micro Systems, Godalming, Surrey, UK). The gel was compressed at a speed of 1.0 mm/s to a distance of 6.0 mm using a P5 cylinder probe with the chart recorder speed at 25.00 pps.

2.6. Rheological properties

The dynamic oscillatory rheological testing was performed using an AR1000 rheometer (TA Instrument Ltd., New Castle, DE, USA) with a 2-cm-diameter parallel-plate geometry and a Peltier device. The starch suspension (20% w/w) was placed between plastic cone and plate and sealed with silicon oil to minimize evaporation during the measurements. The gap used was 2 mm. A temperature sweep was performed from 25 to 95 °C and from 95 to 25 °C at a rate of 5 °C/min with a frequency of 1 Hz and 1% strain. Initial strain sweeps showed that 1% strain was within the linear viscoelastic range for the tested samples. The storage modulus (G′), loss modulus (G″), and tan (delta) values of the starch suspension were recorded as functions of temperature.

2.7. Enzymatic hydrolysis in vitro

In vitro starch hydrolysis was performed to determine the resistance to α-amylase according to the method of Goñi, Garcia-Diz, Mañas, and Saura-Calixto (1996)with minor modifications. Starch samples (100 mg) were weighed into 50-mL centrifuge tubes, with 10 mL of deionized water. The starch hydrolysis was performed in two ways: in the first experiment, the samples were heated in a boiling water bath for 30 min, and measured immediately at30, 60, 90, 120, 150, and 180 min. In the second experiment, the gelatinized starches were stored in a refrigerator at 4 °C for 24 h to cause adequate retrogradation. To avoid any loss of sample material, the enzymatic hydrolysis was determined on the next day in the same sample tubes as used for gelatinization and each sample was analyzed in triplicate. The hydrolysis rate of the starch was expressed as a percentage of the total starch hydrolyzed at different times.

3. Results and discussion

3.1. Light microscopic images

Fig. 1 shows the images of native and gelatinized chickpea starches obtained using optical microscopy. Starch granules do not dissolve in cold water but when heated together with enough water (Wei et al., 2011), the granules disintegrate, absorb water, and