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Physicochemical and functional characteristics of lentil starch

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ABSTRACT

The physicochemical properties of lentil starch were measured and linked up with its functional properties and compared with those of corn and potato starches. The amylose content of lentil starch was the highest among these starches. The crystallinity and gelatinization enthalpy of lentil starch were the lowest among these starches. The high amylose: amylopectin ratio in lentil starch resulted into low crystallinity and gelatinization enthalpy. Gelatinization and pasting temperatures of lentil starch were in between those of corn and potato starches. Lentil starch gels showed the highest storage modulus, gel strength and pasting viscosity than corn and potato starch gels. Peleg's model was able to predict the stress relaxation data of these starches well ($R^2 > 0.98$). The elastic modulus of lentil starch gel was less frequency dependent and higher in magnitude at high temperature (60 °C) than at lower temperature (10 °C). Lentil starch is suitable where higher gel strengthened pasting viscosity are desired.

1. Introduction

Lentil (*Lens culinaris*, M.) is one of the most important crops belonging to leguminaseae family. Lentil seeds contain about 69% carbohydrates and most of which is present in the form of starch (Adsule & Kadam, 1989; Jood, Bishnoi, & Sharma, 1998). The starch in lentils is mainly distributed in the cotyledons dispersed in protein matrix and exists in granular form. According to FAO Statistics (2010) total world production of lentil was 4.58 million metric tonnes. Lentils are shipped after primary processing, therefore, there is a great deal of opportunity to develop value added products. Hence, greater understanding of physicochemical characteristics of lentil starch, which is the major constituent, is essential in providing sound scientific basis for new product development.

Starches are ubiquitous macromolecules synthesized by plants and have wide application in both food and non-food products (Lillford & Morrison, 1997). In food, starch is used as the major ingredient as well as a minor ingredient imparting some specific functions (Jane, 1997). Some of these functions include thickening, coating, gelling, adhesion, and encapsulation. When starch is heated in the excess of water, at a characteristic temperature range it swells irreversibly and undergoes order-to-disorder phase transition (Cook & Gidley, 1992). This phenomenon is known as gelatinization and the characteristic temperature range at which this transition occurs is called gelatinization temperature. Gelatinization temperature is unique and characteristic to the starch source. Important functional properties of starch such as pasting and gelation are derived once the starch is gelatinized. The gelatinization results into swelling of starch granules, loss of crystallinity, uncoiling and dissociation of double helices (crystal melting) and finally disruption of the starch granules (Biliaderis, Grant, & Vose, 1979; Donovan, 1979; Parker & Ring, 2001). At high concentration, starch forms a three dimensional gel network, retards phase separation and provides basic structure to food products such as bread, cakes and puddings.

Starch is comprised of amylose and amylopectin, however, the size, shape and the composition (amylose to amylopectin ratio) of starch vary with botanical origin. Differences in starch physicochemical characteristics have significant impact on their functional properties, affecting their suitability for specific and targeted use. Based on the requirement of food products, starch from different sources possessing different physicochemical characteristics have to be selected to meet the specific processing needs. For example, high amylose starch is preferred for fried food coating batter due to its film forming properties that provides crispy texture in deep fried products (Jane, 1997). High amylose starch is also known to have excellent film forming properties (Fu, Wang, Li, Wei, & Adhikari, 2011). Amylose content of lentil starch is high and ranges from 29 to 45.5% (Hoover & Sosulski, 1991).

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Starch granules are semi-crystalline in nature consisting of ordered and disordered regions. The double helices formed by short amylopectin chains are involved in the formation of the crystallites in starch granules while disordered or amorphous regions are believed to be made up of amylose (Bogracheva, Wang, Wang, & Hedley, 2002). The amylose-to-amylopectin ratio has great impact on the structure–function property of starch (Tester, 1997).

Pasting and gel formation are the two most important functional properties of starch. The understanding of these functional characteristics is essential in food processing operations involving starch. The understanding of the rheological properties helps in the selection of ingredients to suit the end product requirements. Corn and potato starches have been extensively investigated, readily available and commonly used in food processing (Silverio, Fredriksson, Andersson, Eliasson, & Aman, 2000). Similar studies on lentil starch are very limited and there is a lack of information on the structure–function relationship of this starch.

The limited publications on lentil starch mainly deal with chemical composition, granule morphology, molecular weight, crystallinity and gelatinization properties (Biliaderis et al., 1979; Bhatty & Slinkard, 1979; Hoover & Ratnayake, 2002). Most of the functional properties covered in these publications are based on RVA or Barbender methods (Hoover & Manuel, 1995; Kaur, Sandhu, & Lim, 2010). Study on small amplitude oscillation rheological properties in lentil starch are quite limited (Ahmed & Auras, 2011). Some publications also reported the chemical and physical modification of lentil starches (Chung, Liu, & Hoover, 2009; Hoover & Manuel, 1995; Hoover & Sosulski, 1986) to increase resistance towards mechanical shearing, acid hydrolysis, high temperatures and/or enzyme hydrolysis. These works mostly deal with the correlation of physicochemical properties with in vitro digestibility of starch. The use of chemically modified starch is not popular with consumers and is restricted by legislation (Lillford & Morrison, 1997). There is a lack of systematic study linking the physicochemical properties with functional and rheological properties of lentil starch. Thus the purpose of this work was to measure the physicochemical properties of lentil starch (composition, crystallinity, gelatinization behaviour) and relate these measurements with functional properties such as swelling, pasting and gelation. Relatively well studied starches such as corn and potato starch are used for comparison.

2. Materials and methods

2.1. Raw materials

The lentil starch was isolated from Aldinga cultivar of lentil (Section 2.2). The lentil seeds were provided by Department of Primary Industries, Horsham, Australia. Corn starch and potato starch were purchased from Ajax Chemicals, NSW, Australia.

2.2. Isolation and purification of starch

Starch was isolated by wet method. Dehulled lentils were pulverized into lentil flour using a disc mill with 0.5 mm aperture. Lentil flour was suspended in water (1:10, w/v) and pH of the suspension was adjusted to 8.0 with 1 M NaOH/HCl and mixed using a magnetic stirrer at ambient condition (20 ± 2 °C) to solubilize the protein and thus facilitate the separation of starch. The mixture was allowed to settle for 2–3 h and supernatant was removed by centrifuging at 17,500 *g* in a centrifuge (Sorvall SS34) for 15 min. The starch was washed by resuspending in distilled water for 3–4 times and the supernatant was decanted off. Finally, starch dispersion was sieved through series of US standard sieve sizes of 120, 170 and 325. Purified starch was then dried in a custom-built air dryer (Adhikari, Howes, Shrestha, Tsai, & Bhandari, 2006) at 35 °C for 24 h and the dried starch sample was kept in a sealed container at 4 °C until further use.

2.3. Physicochemical properties of starch

2.3.1. Proximate composition

Starch samples were analysed for their moisture (Method No. 925.1), crude protein (N × 6.25) (Method No. 920.87) and ash content (Method No. 923.03) following the standard method of analysis (AOAC, 2005).

2.3.2. Amylose content

Amylose content of the isolated lentil starch along with the corn and potato starch was determined by using amylose/amylopectin kit from Megazyme (Wicklow, Ireland). This method uses the specific binding of Concanavalin A to non-reducing end groups of amylopectin and thus precipitates this fraction of the starch.

2.3.3. Starch morphology

Starch morphology of the lentil starch along with the corn and potato starch was studied by scanning electron microscope (SEM) (JEOL, JSM 6300 SEM, Japan). For SEM, very thin layer of starch powder was directly applied to double-sided adhesive tape on an aluminium stub and was coated with gold. An accelerating potential of 15 kV was used during micrography during image acquisition.

2.3.4. Light microscopy

Birefringence of native and heated (lentil, corn and potato) starch suspensions were observed under polarized and non-polarized light with a microscope fitted with a digital camera (Canon EOS 60D, Canon Ltd.). The images were recorded at 100× magnification for all starch samples.

2.3.5. Fourier transform infrared spectroscopy (FTIR)

Infrared spectra of dry starch powder and starch suspension in water and thermally treated starch suspensions (90 °C, 10 min) were recorded on a Nicolet 6700-FTIR (ThermoScientific, Waltham, MA, USA) equipped with a thermoelectrically cooled deuterated triglycine sulphate (DTGS). The iTR attenuated total reflectance (ATR) sampling accessory was used in these tests. Each specimen was applied on to the face of diamond crystals of the sample accessory. IR spectra were collected in the range of 4000–625 cm^{-1} at a resolution of 4 cm^{-1}. For each sample, 50 scans were carried out and averaged. Raw spectra were baseline corrected and deconvoluted by using Omnic software (Thermo Scientific).

2.3.6. X-ray diffraction (XRD)

X-ray diffraction (XRD) traces of the lentil starch granules were measured using a Siemens (D501, Siemens, Karlsruhe, Germany) diffractometer with CuKα < 1 radiation. Diffractograms were recorded between 5° and 35° (2θ) at a rate of 1.20°/min (2θ) and with a step size of 0.05° (2θ). Crystallinity of the starch was determined following the method of Nara and Komiya (1983). With this method, crystallinity is calculated by dividing the area under the crystalline peaks by the total area under the diffractogram. Background fitting and areas were measured by using Traces (version 6.0) software program.

2.3.7. Granule particle size

The particle size distribution of the starch samples was measured using a Malvern laser diffraction particle size analyser (Mastersizer 2000™, Malvern Instrument, USA). Water was used as a dispersing medium for all the powders. The refractive index values used for water and starch were 1.33 and 1.41 respectively. The