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A systematic comparative study on morphological, crystallinity, pasting, thermal and functional characteristics of starches resources utilized in China

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ABSTRACT

In this study, starches from diverse botanical sources (arrowroot, cassava, Chinese yam, fern root, kidney beans, lotus seed, taro, and water chestnut) were isolated and examined for morphological, pasting, thermal, and physico-chemical characteristics in order to distinguish their end use potential. Among isolated starches significant differences ($p < 0.05$) were observed in gelatinization temperatures, morphology, color, pasting, and functional properties. Amylose content of isolated starches varied between 17.12% and 35.62%. X-ray diffraction pattern of isolated starches displayed A-type (arrowroot, cassava, corn, and kidney bean), B-type (potato) and C-type (water chestnut, taro, Chinese yam, fern root, and lotus seed) crystalline pattern. The FT-IR spectra of isolated starches confirmed their carbohydrate nature. Furthermore, the current study affords information for the exploitation of isolated starches from the diverse botanical sources cultivated in China that would be convenient for commercial applications.

1. Introduction

Starch, a natural, renewable, and biodegradable polymer produced by variety of crops. Naturally, starch arises in the form of semi-crystalline granules comprising of linear amylose and highly branched amylopectin. It is an essential raw ingredient with a vast diverse applications in both food and non-food industries (Das, Jha, & Kumar, 2015; Sukhija, Singh, & Riar, 2016). Usually, starch has been broadly utilized in food industries to sustain the quality of stored food products. Till date starches from cereals, tubers and legumes have been widely studied due to the characteristic merits of easy availability, inertness, biodegradability, non-toxicity, fitting physicochemical properties (Das et al., 2015; Reddy, Kimi, & Haripriya, 2016). In addition, these characteristics, together, regulate the agro-industrial potential immense of starch. Predominantly, starch upsurges moisture retention and subsequently regulates aquatic movement in foodstuffs. Further, starches can used as chief raw ingredient like thickener, additive, gelling agent, stabilizer, binder and suspending agent in domestic and commercial applications (Kaur, Singh, Ezekiel, & Guraya, 2007; Sukhija et al., 2016).

Taro (*Colocasia esculenta*) is a starchy tuber crop and a member of *Araceae* family, is commonly dispersed in Asia, Africa, Middle America, and the Pacific Islands (Simsek & El, 2015). Predominantly, taro starch can be used as chief ingredient for production of noodles or bread, film making and encapsulation of flavors (Sukhija et al., 2016). Arrowroot (*Maranta arundinacea* L.), a member of *Marantaceae* family, is widely cultivated in India and China. The tuber of arrowroot contains high quantity of starch and also recommended as a dietary aid for gastro-intestinal disorders (Franklin et al., 2017). Cassava (*Manihot esculenta* Crantz), a member of *Euphorbiaceae*, is commonly cultivated in tropical regions of the World. Further, in cassava, starch is the primary carbohydrate and extensively used in commercial applications due to its exclusive thickening characteristics (Tan et al., 2017).

Water chestnut (*Trapa natans*), a member of *Trapaceae* family, is widely distributed in China, Africa and Northern America. It can be usually used as raw ingredient in making foods, which contains high quantity of starch and nutrients (Obiang-Obounou & Ryu, 2013). Chinese yam (*Dioscorea opposita*), a member of *Dioscoreaceae* family, is largely cultivated in China and has been treated as traditional Chinese medicine. It contains high quantity of starch, non-starch polysaccharides, cholesterol, choline, and allantoin (Wang et al., 2006). Lotus seed (*Nelunbo nucifera*) is a member of *Nymphaeaceae* family, is widely cultivated in China and Taiwan. It can be used as a traditional food and medicine, due to high content of amylose (~40%), which promotes the formation of resistance starch (Zhang, Zeng, Wang, Zeng, & Zheng, 2014). Kidney beans (*Phaseolus vulgaris* L.), a member of

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Phaseoleae family, is extensively cultivated in various regions of the world and also it contains high amount of carbohydrates, minerals and vitamins (Chung, Liu, Peter Pauls, Fan, & Yada, 2008).

In general, starch is mostly distributed in seeds and tubers of plants. Starches from diverse sources vary predominantly in their morphology and structure, as well as some of their quality characteristics (Kaur et al., 2007; Sukhija et al., 2016). Moreover, isolated starches are extremely flexible based upon the origin and discrepancy in terms of granule morphology, degree of crystallinity, quantity of amylose and amylopectin (Reddy, Luan, & Xu, 2017; Wang et al., 2006). Furthermore, these isolated starches are used in foods, pharmaceuticals and non-edible products. In view of the huge demand for this polymer in food and non-food industries, the research pays attention to other alternative sources which could fulfill commercial necessities. Till now, extensive research is performed on the structure, quality characteristics and applications of main stream starches such as corn, potato, and rice (Reddy et al., 2016; Singh, Singh, Kaur, Sodhi, & Gill, 2003). However, till now inadequate research performed on isolation, quality characteristics and applications of starches from non-main stream sources available in China. In addition, morphological, pasting, and thermal properties may help in knowing the domestic and industrial applications of isolated starches from these sources.

From this basis, the objective of this study was focused on isolation and characterization including morphological, gelatinization temperatures, degree of crystallinity, pasting, and functional characteristics of starches from underutilized and non-main stream sources available in China. Another main target was to compare the physico-chemical characteristics of isolated starches and frequently used commercial corn and potato starches for possible applications in domestic and commercial applications.

2. Materials and methods

2.1. Materials

The flours of fern root and water chestnut were procured from local market in Yunan and Shanghai, China, respectively. Raw materials such as taro flour, kidney bean flour and Chinese yam starch (CYS) was obtained from local market in Zhejiang, China. The lotus seed flour, potato starch (NPS), and corn starch (NCS) were collected from local market in Zhuhai, China. Starches of arrowroot (ARS) and cassava (CAS) were acquired from local market in Guangdong, China. All the chemicals and reagents utilized in this work are of analytical grade and were procured from Shanghai Yuanye Biological Technology Co. (Shanghai, China).

2.2. Starch isolation

Starches were separated from fern root, taro and water chestnut by partial modifications in the procedure described by Aboubakar, Njintang, Scher, and Mbofung (2008). Briefly, flour (10 g) was immersed in 100 mL distilled water for 12 h at room temperature and homogenized using a high speed laboratory blender (Philips HL 1632, India) for 2 min for preparation of slurry. The slurry was filtered through 100 and 200-mesh sieves and the filtrate was permitted to settle for 12 h. Further, the supernatant was removed and precipitate was washed twice with distilled water, followed by centrifugation at 3500 rpm for 15 min and then dried at 40 °C for 24 h in convention oven. Finally, the attained starch was ground and screened through 100-mesh sieve, and then stored in sealed and dried polyethylene bags till use.

The procedure of Reddy et al. (2017) with slight modifications was employed for starch extraction from kidney beans and lotus seeds. The seeds (100 g) were immersed in 500 mL of 0.3% sodium sulfite solution for 24 h at room temperature. The seeds were then blended for 5 min in a high speed laboratory blender (Philips HL 1632, India) and the slurry was sieved through 100 and 200-mesh sieves. The filtrate was mixed with distilled water (1:5 ratio) and permitted to stand for 12 h. Further, the precipitate was washed with distilled water, followed by centrifugation at 3500 rpm for 15 min and then dried at 40 °C for 24 h in an oven. Finally, the obtained starch was ground and screened through 100-mesh sieve, and then stored in sealed and dried polyethylene bags till use.

Other commercially obtained starches including potato, corn, cassava, Chinese yam and arrowroot starches were sieved through 100-mesh sieve, and then stored in sealed and dried polyethylene bags till use.

2.3. Amylose and moisture content

Starches were analyzed for amylose content following the procedure of Williams, Kuzina, and Hiynka (1970) with a standard amylose at 620 nm. Moisture content of starches were quantified using the gravimetric technique in a convention oven at 105 °C until constant weight (AOAC., 2016).

2.4. Color determination

Hunter Colorimeter (D-25, Hunter Lab Associates Inc.) was used for determination of color values of different starch isolates. The instrument was calibrated using Hunter lab color standards and the data were documented as $L*$ (lightness), $a*$ (redness and greenness) and $b*$ (yellowness and blueness) values.

2.5. Swelling power and solubility

Swelling power and solubility of starches were analyzed respectively, as per the procedure given by Lan, Li, Xie, and Wang (2015).

2.6. X-ray diffraction

The crystalline patterns of starches were performed using an X-ray diffractometer (XRD-7000, Shimadzu, Japan) using Cu Kα value of 1.54 radiation operated at 40 kV and 30 mA. The diffraction patterns of starches were obtained from a scanning range between 3° and 30° (2θ) at a scanning speed of 1.5°/min and a step size of 0.01°.

2.7. Thermal properties

The gelatinization of starches were studied using a differential scanning calorimeter (TA-Q20 DSC, Mettler-Toledo, Switzerland) according to a procedure at Reddy et al. (2017). Starch (3 mg, dry basis) and deionized water (7 μL) were weighed in a DSC pan, hermetically sealed and let it stand for 2 h at 4 °C. Samples were heated from 35 °C to 150 °C at the rate of 5 °C/min; and an empty DSC pan was used as reference.

2.8. Fourier transforms infrared spectroscopy

The infrared spectra of starches were obtained with a spectrometer (Bruker Optics Inc, USA) according to a procedure at Reddy et al. (2017). FT-IR samples were prepared by mixing starch with KBr and made into pellets before analysis. Calibration of the instrument was executed using KBr pellet as reference and spectrum were documented within the range of 4000 to 500 cm^{-1}.

2.9. Granule morphology

Starch granules morphology were observed by scanning electron microscope (SEM, S-3400N, Hitachi, Japan) according to a procedure at Reddy et al. (2017). Starch samples were directly applied on double sided sticky tape placed on a specimen holder and coated with carbon.