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Review

Structures, properties, and applications of lotus starches

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ABSTRACT

Lotus (*Nelumbo nucifera*) is an important aquatic crop in Asia. The rhizomes and seeds of lotus are popular food ingredients, and starch is their major component. The quality of lotus food products is much determined by the functional properties of the starch. This review summaries the chemical and physical structures, physicochemical properties, interactions with food ingredients, modifications, and food and non-food uses of starches from lotus rhizomes and seeds. The structure-property relationships of the starches are discussed. Compared with starches from other botanical sources, the lotus starches have some unique structures and properties. However, there is a lack of comparative studies on the applications of lotus starches and common starches. Future research directions on how to better understand and utilise lotus starches are suggested.

Contents

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1. Introduction

Lotus (*Nelumbo nucifera* Gaertn.) is an important freshwater aquatic plant within the family Nelumbonaceae (Fig. 1a). This family contains only one genus (*Nelumbo*) with two species (*N. nucifera* in Asia, Australia, Russia and *N. lutea* in eastern and southern North America) (Ming et al., 2013). Lotus is also commonly known as sacred lotus or Indian lotus, and the scientific synonyms previously included *Nelumbium speciosum*, *Nymphaea nelumbo*, and *Nymphaea stellata*. It should be noted *N. nucifera* is botanically different from the *Nymphaea* species (water lilies) (especially the blue lotus *Nymphaea caerulea*) of the family Nymphaeaceae, though they share a great similarity in the plant morphology and growing habits. The lotus seeds have exceptional longevity and had remained viable for as long as 1300 years in a Chinese location (Shen-Miller et al., 2002). The genome of lotus has been sequenced and provides a genetic basis for its further development as a sustainable crop (Ming et al., 2013).

Lotus has been cultivated in various parts of Asia such as China and India as an important food item for over 7000 years (Guo, 2009; Ming et al., 2013). The geographic regions for lotus cultivation range from tropic to temperate regions (Guo, 2009). In China, the cultivation area has reached over 0.2 million ha. Hubei province of Central China has been the largest grower of lotus, and the production quantity has reached 2 million tons (Guo, 2009). Lotus is also widely used as ornamental plant with great cultural and religious significance in Asia (Ming et al., 2013). The edible parts of lotus include the flowers, seeds, young leaves, and rhizomes (Fig. 1a–c). Various parts of lotus such as buds, flowers, leaves, seeds, and rhizomes have been used in traditional Asian medicine for diverse disorders. These medical disorders include cancer, hypertension, vomiting, depression, skin diseases, heart problems, diarrhea, and insomnia (Mukherjee, Mukherjee, Maji, Rai, & Heinrich, 2009; Zhang et al., 2015). Various bioactive components such as alkaloids, glycosides, flavonoids, triterpenoid, and vitamins have been identified in lotus products (Mukherjee et al., 2009). The most commonly used parts of lotus as food products are the rhizome and seed (Fig. 1b and c). The nutritional composition of raw rhizome and seed is presented in Table 1. They can be good sources of certain types of vitamins (e.g., niacin), minerals (e.g., K), and dietary fiber (Table 1). Various food products have been developed from the rhizome and seed, and are commercially available in Asian markets (Cai et al., 2008; Liu, Zhang, & Wang, 2010). They include herbal tea, porridge, juices and beverages, vinegar, flours, starch, puddings, canned foods, cakes, biscuits, noodles, battered rhizome slices, chips, and pickles (Cai et al., 2008; Liu et al., 2010). The flour of rhizome and seed is gluten free, and can be developed as a major ingredient for gluten-free food products to aid people with celiac disease. The major component of both rhizome and seed is starch, and may amount up to 70% of the dry weight (Zhang et al., 2015). Therefore, it is expected that the eating and nutritional quality of lotus food products is much determined by the starch quality. For example, starch content was highly correlated with relative firmness (positive correlation), initial freezing temperature and drip loss (negative correlations) of lotus rhizome upon freezing and thawing (Tu, Zhang, Xu, & Liu, 2015). The isolated lotus starches have different functional properties as compared with starches from other sources (Akuzawa & Kawabata, 2003), and the rhizome and seed starches are rather different in the structures and properties (Man et al., 2012). They may possess potential for certain food and non-food uses. There is a systematic lack of both fundamental and applied research on various aspects of lotus starches. This hinders the efficient development of lotus as a cash crop.

This review summarises the isolation, chemical composition, granular and chemical structures, physicochemical properties, nutritional quality, interactions with other food ingredients, modifications, and food and non-food applications of lotus rhizome and seed starches. Lotus starches are compared with other starches, and structure-property relationships of starch components are discussed. Future research directions on how to better understand and utilise these starches are suggested.

2. Isolation

The starch isolation of rhizomes is different from that of the seeds due to the different physical structure and composition (Guo et al., 2015a; Man et al., 2012; Suzuki et al., 1992). The rhizomes are peeled, cut into small pieces, and smashed with ice-cold water in a blender. The resulting slurry is screened through cheesecloth. The fibrous residue is further homogenized in a blender and squeezed to release the starch entrapped. The starch slurries are combined and filtered through sieves before centrifugation. The yellow layers on the top of the starch cake are manually scrapped off and discarded. The washing step is repeated several times to purify the starch before drying.

The dry lotus seeds are peeled before steeping overnight to soften the seeds. Dilute alkali was also used for the steeping of the seeds (Ito, Murase, Yamada, & Namiki, 1996). The steeped seeds are smashed with ice-cold water in a blender and isolated as for the rhizome starch isolation (Man et al., 2012). It may help to improve the isolation efficiency by removing the leaves (seed core as shown in Fig. 1b) in the inner part of the seeds.

3. Chemical composition

A great discrepancy in the chemical composition of lotus starches has been noted among diverse studies (Table 2). The difference in amylose content of lotus starches could be attributed to the differences in lotus genetics, growing conditions, and measuring and calculating methods (Gani, Gazanfar, et al., 2013; Gani, Masoodi, et al., 2013; Suzuki et al., 1992). Amylose contents of lotus rhizome starches of 3 Indian varieties ranged from 25 to 30% as measured by iodine-binding spectrophotometry-based method (Gani, Masoodi, et al., 2013). This diversity could be readily attributed to the plant genetics and growing conditions. Quantification method can greatly affect the amylose contents (Ito et al., 1996; Suzuki et al., 1992). For example, amylose contents of lotus rhizome starch were 18.5% and 21.7% as measured by iodine-binding-amperometry and gel-permeation chromatography of debranched starch based methods, respectively (Ito et al., 1996). Amylose contents of lotus rhizome starch were 15.9% as calculated