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Review

Buckwheat starch: Structures, properties, and applications

Fan Zhu

School of Chemical Sciences, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

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ABSTRACT

Background: There is increasing interest in utilization of buckwheat for healthy food applications. Common buckwheat (*Fagopyrum esculentum*) and tartary buckwheat (*Fagopyrum tataricum*) are cultivated in Asia, Europe, and Americas for various food formulation and production. Starch, the major component of the seeds, may account over 70% of the dry weight. Therefore, it is expected that, to a large extent, the quality of starch determines the quality of buckwheat food products. Furthermore, Buckwheat starch has great potential for various food and non-food uses due to the unique structural and functional features.

Scope and approach: This review summarises the current knowledge of chemical composition, chemical structure of amylose and amylopectin, physical structure of granules, physicochemical properties, enzyme susceptibility, modifications, and uses of buckwheat starch. Suggestions on how to better understand and utilise the starch are provided.

Key findings and conclusions: Amylose contents of buckwheat starch ranged from 20 to 28%. Starch granules are most polygonal with size ranging from ~2 to 15 μm and an average diameter of ~6–7 μm. The polymorph is A-type. The amount of extra-long unit chains of amylopectin (DP > 100) is higher than that of cereal amylopectins. Low glycaemic index of buckwheat food products could be attributed to the non-starch components. Buckwheat starch has been used as fat replacer, ingredient for extruded products, nanocomposite material, and fermentation substrate for alcoholic beverage. It may be concluded that buckwheat starch can be a unique source of specialty starch for innovative food and non-food applications.

1. Introduction

Buckwheat belongs to the genus *Fagopyrum* of the family Polygonaceae (Cai, Corke, & Li, 2004). The most cultivated species include *Fagopyrum esculentum* known as common buckwheat and tartary buckwheat (*Fagopyrum tataricum*). Tartary buckwheat is also known as bitter buckwheat due to the bitter taste and high amount of flavonoids present in the kernels. A much less cultivated species with great local significance in Asia is *Fagopyrum dibotrys* (synonyms *Fagopyrum acutatum* and *Fagopyrum cymosum*) which is known as golden or tall buckwheat (Liu, Li, Zhu, Li, & Shui, 2006a). Buckwheat has great ecological adaptability. It can grow well in marginal lands with harsh climatic and soil conditions. In particular, tartary buckwheat can grow at high altitudes even with low precipitation and low temperature (Cai et al., 2004). Historically, buckwheat was a popular food crop in Europe and Asia. The production declined greatly in the 20th century. This is due to the introduction of nitrogen fertilizer and the competition of other crops such as wheat (Ahmed et al., 2014). In recent years, buckwheat is becoming popular due to its various "re-discovered" health benefits and as a potential functional food source (Ahmed et al., 2014). Statistics of Food and Agriculture Organization of the United Nations (FAO) showed that, during the last two decades, the world production of buckwheat decreased gradually towards 2010 before a slow increase from 2011 onwards (Fig. 1). The world production quantity of buckwheat reached 2,347,558 tonnes in 2013, and the top five producers were Russia, China, Ukraine, France, and Poland (Supplementary Table 1). In terms of yield, the top 5 countries in 2013 were France (34,786 H g/Ha), Czech (24,000 H g/Ha), Bhutan (23,608 H g/Ha), Croatia (20,526 H g/Ha), and Bosnia and Herzegovina (15,434 H g/Ha) (FAOSTAT, 2015).

Buckwheat is becoming a research focus in recent years most due to the healing and preventative roles in diverse diseases (Ahmed et al., 2014; Cai et al., 2004; Guo et al., 2013; Li & Zhang, 2001). The proximate composition of major nutrients of

E-mail address: fzhu5@yahoo.com.

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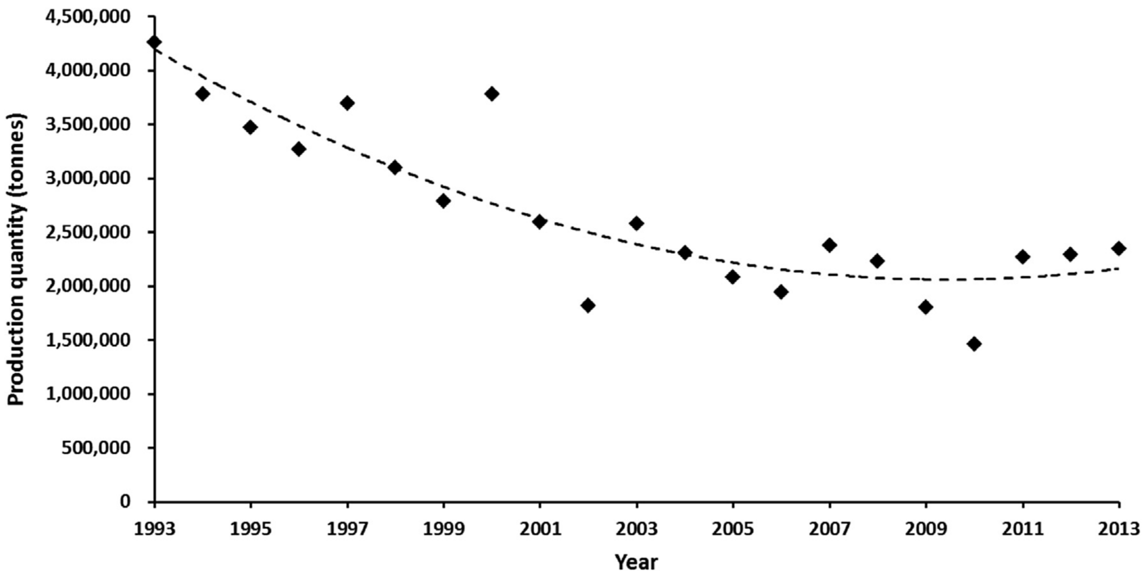

Fig. 1. World production of buckwheat from 1993 to 2013 (FAOSTAT, 2015). Solid black points represent the actual production quantity. Dashed line represents the general trend of production quantity through the 20 years. Data may include official, semi-official, or estimated data.

buckwheat seeds/flour/groats falls within the ranges of the common cereals and pseudocereals (Supplementary Table 2). Compared with cereals and other pseudocereals, buckwheat appears rather unique in the composition of some functional nutrients. Buckwheat protein is balanced in the amino acid composition (relatively high lysine content). Buckwheat is relatively high in dietary fibre content. Minor important nutrients include polyunsaturated essential fatty acids (i.e. linoleic acid), minerals such as Mg and K, vitamins (B, C, and E), D-chiro-inositol, fagopyritols, and flavonoids (e.g., rutin and quercetin) (Li & Zhang, 2001; Wijngaard & Arendt, 2006). The presence of tannins, phytic acid, and protease inhibitors lowers the enzyme susceptibility and digestion of starch (Wijngaard & Arendt, 2006). The above-mentioned factors render buckwheat various health benefits. These include hypocholesterolemic activity, suppression of body fat accumulation, antioxidant and free radical scavenging activities, anti-hypertension, anti-inflammation, reducing the occurrence of colon cancer, and so on (Ahmed et al., 2014; Li & Zhang, 2001; Wijngaard & Arendt, 2006). In particular, buckwheat can be a major ingredient of gluten-free food products for people with celiac diseases (Giménez-Bastida, Piskuła, & Zieliński, 2015). Various food products have been developed from buckwheat in the light of the above-mentioned health benefits. These include vinegar, beer and whisky, bread and steamed bread, breakfast cereals, porridge and soup, noodles and pasta, pancakes, biscuits and cookies, and tea (Cai et al., 2004; Hatcher, You, Dexter, Campbell, & Izydorczyk, 2008; Li & Zhang, 2001; Zhang, Gao, Gao, Yin, & Xi, 2011). The majority of these buckwheat products are commercially available in niche markets with limited size.

Starch is the major component of buckwheat seeds, and may amount up to over 70% of the dry weight (Ikeda, Kishida, Kreft, & Yasumoto, 1997). The properties and structures of starch are critical for the quality of buckwheat food products (Hatcher et al., 2008; Ikeda et al., 1997). For example, starch and amylose contents were highly correlated to the springiness of heated buckwheat dough, probably due to gelling capacity of amylose and starch (Ikeda et al., 1997). Understanding the structure and functionality of starch provides a basis for the quality of buckwheat products, and help commercialize them to a larger scale. Since the pioneering work on buckwheat starch by Hurusawa and Miyashita (1963, 1964a, 1964b, 1965, 1966) from Japan, a great progress has been made worldwide. This review aims to summarise the present knowledge of composition, structures, properties, modifications, and uses of buckwheat starch, and to provide future research directions.

2. Isolation

The content of starch in buckwheat flour may amount up to 80% of the dry weight (Hong, Ikeda, Kreft, & Yasumoto, 1996; Ikeda et al., 1997). Wet-milling process has been used to isolate buckwheat starch (Zheng, Sosulski, & Tyler, 1998). Basically, dehulled buckwheat groats are steeped overnight in aqueous solution that may contain small amount of chemicals such as $NaHSO_3$ (0.2%). The hydrated groats are milled in a high-speed blender (e.g., Waring blender), and the resulting slurry is screened and washed with water to remove the fibrous materials (Zheng et al., 1998). Alternatively, groats are dry-milled into flour, and the resulting flour is steeped in aqueous solution that may contain alkaline at a low concentration. The steeped slurry is further milled in a blender before passing through mesh. The resulting slurry is centrifuged, and the protein layer on the top of the sediment is removed. The starch cake is re-suspended in water. The washing step is repeated to further remove the protein and other impurity before drying (Li, Lin, & Corke, 1997). The steeping/washing process may involve alkaline solution (e.g., 0.1% NaOH) to facilitate the separation of other components from starch (Acquistucci & Fornal, 1997; Christa, Soral-Śmietana, & Lewandowicz, 2009; Soral-Śmietana, Fornal, & Fornal, 1984a; Zheng et al., 1998). It should be noted that differences in isolation method and experimental conditions may result in differences in starch composition and properties.

3. Chemical composition

Great diversity in the chemical composition of starches from both common and tartary buckwheat has been observed (Table 1). Amylose content of buckwheat starches, a major attribute, varied greatly among different studies. This could be attributed to the buckwheat genetics and growing conditions (Gao et al., 2016; Gregori & Kreft, 2012), as well as the measuring method (Yoshimoto et al., 2004). The genetic and environmental variations