Food Chemistry 229 (2017) 329–340

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Review

Structures, properties, modifications, and uses of oat starch

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ARTICLE INFO

Article history:
Received 14 September 2016
Received in revised form 4 February 2017
Accepted 13 February 2017
Available online 16 February 2017

Keywords:
Oat starch
Structure
Property
Modification
Application

ABSTRACT

There has been increasing interest to utilise oats and their components to formulate healthy food products. Starch is the major component of oat kernels and may account up to 60% of the dry weight. Starch properties may greatly determine the product quality. As a by-product of oat processing and fractionation, the starch may also be utilised for food and non-food applications. This mini-review updates the recent advances in the isolation, chemical and granular structures, physicochemical properties, chemical and physical modifications, and food and non-food uses of oat starch.

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http://dx.doi.org/10.1016/j.foodchem.2017.02.064
0308-8146/

1. Introduction

Oats (*Avena* spp.) belong to the grass family Poaceae and are mostly cultivated in cool climate. The most common species of oats is *A. sativa*, while others with agricultural/local significance include *A. nuda* (naked oats), *A. strigose*, *A. byzantina*, and *A. abyssinica* (Zwer, 2016). The world production of oats reached over 22 million tonnes in 2014. The major producers are Russia, Canada, Poland, Australia, Finland, and USA (FAOSTAT, 2016).

Starch is the major component of oats and may amount up to 60% of the dry weight (Doehlert, Simsek, Thavarajah, Thavarajah, & Ohm, 2013). Whole grain oats contain a range of bioactive components (Rasane, Jha, Sabikhi, Kumar, & Unnikrishnan, 2015; Zwer, 2016). The protein content of oats ranges from ~9 to 15% with a higher lysine concentration than wheat and maize. The content of β-glucans as dietary fiber ranges from ~2 to 8%. The lipid content of oats is ~3–11% which is higher than that of most other cereals. The majority of oat lipids are unsaturated fatty acids. Oats contain vitamin E with α-tocotrienol and α-tocopherol being the major forms (up to 90%). Other minor vitamins of oats include thiamine, riboflavin, and niacin. Whole grain oats are a good source of polyphenols. The major phenolic acids are ferulic, *p*-coumaric, caffeic, vanillic acids, and hydroxybenzoic acid and their derivatives. Small amounts of flavonoids, including glycosylvitexin, apigenin, tricin, isovitexin, and vitexin, are also present in oats. Avenanthramides, as phenolic alkaloids, are present in oats, being unique among cereals and pseudocereals (Rasane et al., 2015; Zwer, 2016). Due to the presence of the above-mentioned chemical constituents such as β-glucans, oats possess a range of health effects such as cholesterol-lowering and anticancer properties (Rasane et al., 2015; Zwer, 2016).

Oats have been commonly used as livestock feed. They are suitable as feed for dairy and beef cattle, horses, and sheep. They have also been gaining importance as human foods in light of the above-mentioned bioactive components and health effects (Rasane et al., 2015; Zwer, 2016). Oats have been processed and formulated into a range of food products such as bread, biscuits and cookies, breakfast cereals, granola bars and cereals, infant foods, non-dairy milk, and yoghurt (Rasane et al., 2015; Zwer, 2016). Since starch can be the major component of these products, the properties of starch may be critical to their eating and nutritional quality. For example, the total starch content of oats is positively linked with slippery and less uniformed sensation of oatmeal (Lapveteläinen et al., 2001). Furthermore, there has been increasing interest in the unitization of oat components such as bran and β-glucans as dietary fiber for healthy food formulation. Starch becomes a by-product after the extraction and fractionation of oats (Gangopadhyay, Hossain, Rai, & Brunton, 2015). Oat starch can be used in a range of products such as fat replacers, cardboard and brown paper products, coating agents for tablet formulation, and cosmetic and cleanser products (Autio & Eliasson, 2009; Zwer, 2016). Therefore, understanding the composition, properties and structures of the starch could provide a basis to better utilise oat starch for human benefits, and to develop oats as a sustainable crop.

Previous reviews of oat starch focused on the literatures from roughly two decades ago (Autio & Eliasson, 2009; Sayar & White, 2011; Zhou, Robards, Glennie-Holmes, & Helliwell, 1998). Since then, there has been great advance in oat starch research due to assessing more genetic resources and the conceptual breakthroughs. The present mini-review focuses on the recent advance in our understanding in the isolation, composition, structures, properties, modifications, and uses of oat starch. The readers are strongly encouraged to refer to the previous reviews (Autio & Eliasson, 2009; Sayar & White, 2011; Zhou et al., 1998) to gain the background information of oat starch, and to better understand the present updates.

2. Isolation

Autio and Eliasson (2009) reviewed the starch isolation from oat kernels on both industrial and laboratory scales. In the laboratory, oat flour is soaked in a solution containing NaOH (0.1-0.01 M) before centrifugation and filtration for starch purification. Sometimes, protease may be added to facilitate the starch isolation process. In industry, oat groats are dry-milled and soaked in a cellulase and hemicellulase-containing solution. This process produces protein and fiber fractions beside starch (Autio & Eliasson, 2009).

Al-Hakkak and Al-Hakkak (2007) reported a novel gluten-based starch isolation method. Briefly, wheat gluten was added to the oat flour in a ratio of 18% (w/w, gluten/flour). Salt (3%) was also added to facilitate the isolation process. Upon hydration, wheat gluten network forms through kneading. Oat protein also involves in the network through protein-protein interactions. The dough is proved for 1 h before washing. The starch fraction is then separated by bolt cloth before recovering by centrifugation. The starch yield was 60% of the flour weight and was 84.6% of the theoretical total starch content in the flour. The starch purity was also high with the protein and fat contents being less than 0.3%. Pentosans and β-glucans were not detected in the isolated oat starch. No chemicals were involved in the process which is also compatible with industrial wheat starch manufacturing. This non-destructive gluten-based starch isolation can be extended to include a range of other plant sources such as barley and rye, chickpeas and lentils, and amaranth (Al-Hakkak & Al-Hakkak, 2007). The isolation method has been a US patent (Al-Hakkak, 2006). This method, however, remains to be better develop to simultaneously isolate other oat components such as protein and β-glucans which may possess higher market values than the starch.

3. Composition

Previous reports showed that the total starch content of oats of various genotypes could amount up to 60% of the dry weight (Zhou

Table 1
Amylose contents of oat starch.

Genotype No.	Amylose content (%)	Amylose quantification method	References
1 (*A. strigose*)	0	Gel-permeation chromatography (Sepharose CL 2B) of whole starch	Verhoeven et al. (2004)
1 a	36–38 (apparent amylose content), 30 (absolute amylose content) b	Iodine-binding potentiometry-based method	Stevenson et al. (2007)
1	27.1	Gel-permeation chromatography (Sepharose CL 6B) of debranched starch	Bertoft et al. (2008)
1	22.7 (Con A), 20.5 (HPSEC)	Concanavalin A (Con A)-based precipitation, high-performance size-exclusion chromatography (HPSEC) of whole starch	Simsek et al. (2013)
3 c	12–22%	Iodine-binding spectrophotometer-based method	Zheng et al. (2015)

All the genotypes are of *A. sativa* except for being noted; No., number; (a) 3 milling fractions differing in size: 300–850 μm, 150–300 μm, and <150 μm; (b) absolute amylose content derived from the difference in iodine affinity between starch and amylopectin; (c) developing endosperms of 3 varieties from 15 to 33 days after anthesis.