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Review

Chemistry, structure, functionality and applications of rice starch

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ABSTRACT

Starch represents one of the major agricultural products in the world and is used in a wide range of food and non-food applications. It is the main component of rice grains, influencing their physical and cooking properties. Over the last few decades, considerable research has been carried out on starch from various sources, which has greatly helped in understanding its properties. This paper provides an overview of the composition and structure of rice starch and the influence of components other than amylose and amylopectin, such as lipids and proteins, on its physicochemical properties. Research on characterisation of the functional properties of rice starch is reviewed in particular. Furthermore, the applications of rice starch and enhancement of its functionality through chemical or physical means are discussed.

Contents

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for about 3.5 billion people worldwide (Muthayya et al., 2014). With a global annual production estimated at about 480 million metric tons (milled rice basis), an average yield of 4.4 metric tons per hectare, and a harvested area of about 160 million hectares, rice represents one of the leading food crops in the world (USDA, 2015). It is also estimated to yield more food energy per hectare than any other cereal, when the actual extraction rates (i.e., the fraction of each grain utilised as food) are taken into account (Childs, 2004). Rice constitutes an important source of carbohydrates, mainly starch, that is predominantly present in the endosperm cells of mature brown rice, accounting for approximately 90% of the dry weight of milled rice (Juliano, 1985). Physical and cooking properties of rice depend on starch and its interactions with other constituents of the rice endosperm, i.e., lipids, proteins and water (Fitzgerald, 2004).

Starch is the most common storage carbohydrate in plants and is one of the most important agricultural products to man. Annual starch production from cereals, which constitute the major sources of starch for human use, is approximately 2 billion tonnes. While, in developed countries, starch accounts for at least 35% of daily calorific intake, in many areas, especially Africa and the Far East, it can provide as much as 80% of daily calorific intake and this may be from only one source such as rice (Burrell, 2003).

Although starch is widely consumed in the native form (i.e., as cereal grains and potatoes), it is also being increasingly utilised in foods (e.g., baby foods, bakery products, confectionery, ice cream,

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List of abbreviations

CL	average chain length
CLSM	confocal laser scanning microscopy
DP_n	number-average degree of polymerization
DP_w	weight-average degree of polymerization
DSC	differential scanning calorimetry
FFA	free fatty acids
GBSS	granule-bound starch synthase
HPSEC-MALLS-RI	high-performance size-exclusion chromatography equipped with multi-angle laser-light scattering and refractive index detectors
LPL	lysophospholipids
M_n	number-average molecular mass
MW	molecular weight
M_w	weight-average molecular mass
SEM	scanning electron microscopy
SGAPs	starch granule-associated proteins
T_c	conclusion gelatinisation temperature
T_g	glass transition temperature
T_o	onset gelatinisation temperature
T_p	peak gelatinisation temperature
ΔH	gelatinisation enthalpy

meat products, sauces, snack foods, soft drinks, soups) and serves as a substrate for the production of starch hydrolysis products such as maltodextrins and glucose syrups (Copeland et al., 2009). The unique properties of starch are also exploited in non-food applications, including agrochemicals, adhesives, cosmetics, detergents, medical, oil drilling, paper and cardboard, pharmaceuticals, plastics and textiles (Ellis et al., 1998).

2. Composition and structure of starch

Starch is a polymeric mixture of two types of α-glucans, i.e., amylose and amylopectin (Fig. 1), and is deposited in plants in the form of granules, the size and shape of which differ among species. The diameter of the granules ranges from less than 1 μm to more than 100 μm, whereas shape can be angular, oval, round, spherical or irregular (Lindeboom et al., 2004). Individual starch granules in rice are the smallest among cereal grains, with diameters of approximately 3–8 μm each; they are angular in shape, and are clustered as compound granules. Rice starch compound granules have diameters of up to 150 μm, are polyhedral in shape, and contain several (20–60) individual granules (Bao and Bergman, 2004; Fitzgerald, 2004). Amylose and amylopectin account for approximately 98–99% of the dry weight of starch granules, and the ratio of the two polysaccharides varies depending on the botanical origin of the starch. A number of authors have thoroughly described the structure and properties of amylose and amylopectin (Banks and Greenwood, 1975; Blanshard, 1987; Buléon et al., 1998; Donald, 2004; French, 1972; Whistler and Daniel, 1984; Zobel and Stephen, 1996).

Amylose is considered to be an essentially linear polymer of α-1,4-linked glucose molecules, although experimental evidence has confirmed that some branching occurs on the amylose chains (Curá et al., 1995; Gunning et al., 2002; Hizukuri et al., 1981; Juliano, 1998; Takeda and Hizukuri, 1987). Takeda et al. (1986) reported that amylose purified from rice starch has weight-average degree of polymerization (DP_w) and number-average degree of polymerization (DP_n) values of 2750–3320 and 980–1110, respectively, and average chain length (CL) of 250–370. High-performance size-exclusion chromatography equipped with multi-angle laser-light scattering and refractive index detectors (HPSEC-MALLS-RI) has shown isoamylase-debranched amylose of six rice cultivars to have weight-average molecular mass (M_w) and number-average molecular mass (M_n) of $5.1–6.9 \times 10^5$ and $1.4–1.8 \times 10^5$ g/mol, respectively, and DP_w and DP_n of 2569–4273 and 847–1118, respectively (Chen and Bergman, 2007). Amylose content varies greatly among rice varieties; waxy (glutinous) rice starch has an apparent amylose content of 0.8–1.3%, whereas non-waxy rice starch contains 8–37% amylose. The amylose content of milled rice may be classified as waxy, 1–2%; low, 7–20%; intermediate, 20–25% and high, >25% (Juliano, 1985).

Amylopectin has a highly branched structure, consisting of α-1,4-linked glucose molecules and about 5–6% α-1,6-linkages at the branch points (Hoover, 2001). The M_w of amylopectin from several botanical sources has been reported to range from 7.0×10^7 to 5.7×10^9 g/mol, as determined by HPSEC-MALLS-RI, with non-waxy and waxy rice amylopectin having M_w of 2.7×10^9 and 5.7×10^9 g/mol, respectively (Yoo and Jane, 2002). The DP_n of

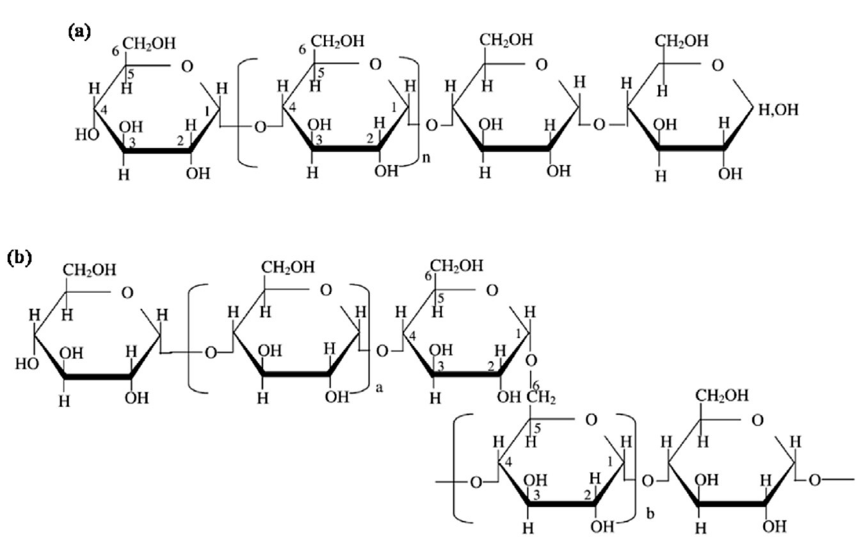

Fig. 1. Structure of (a) amylose and (b) amylopectin (adapted from Tester et al., 2004).