

A REVIEW: MODIFICATION, BENEFICIAL PHYSIOLOGICAL EFFECTS AND APPLICATIONS OF SLOWLY DIGESTIBLE STARCH

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ABSTRACT

This review introduces basic information about slow digesting starch (SDS): chemical structure, modification, physiological effect and application. Generally, the structural feature of SDS is an optimal mix of semi crystalline and amorphous material. Theoretically, there are three groups of methods for obtaining slow-digesting starch: (a) using chemical agents, (b) using physical techniques, and (c) using enzymes. Chemical treatments were cross-linking, citric acid treatment and so on. Physical treatments were retrogradation, hydrothermal treatment etc. Furthermore, enzymatic treatments were debranching reactions, maltogenic α -amylase and transglucosidase reactions. Theoretically, starch was separated to three digestible fractions: (i) RDS, amount of glucose released after 20 min; (ii) SDS, amount of glucose released between 20 and 120 min hydrolysis; and (iii) RS, total starch minus amount of glucose released within 120 min hydrolysis. The potential health benefits of SDS are related to glucose metabolism. The SDS content of consumed foods is related to not only glucose metabolism and diabetes management but also the risk reduction of diabetes, cardiovascular diseases, colon cancer, and breast cancer. Finally, SDS can be used as an ingredient in the food matrix.

Keywords: diabetes; digestibility; physiological effect; slowly digestible starch; starch modification.

1. BACKGROUNDS

Starch, which is a major component in plant foods, is the main dietary source of carbohydrate in human nutrition [1]. This biological polymer is deposited in storage organs of our main starch crops such as corn, potato, rice, cassava, water yam, etc. Starch content ranges between 65 and 90% (based on dry matter) in roots of yam, sweet potato, and cassava, in potato tubers, and in maize grains. Starch of various sources varies in shape, size and composition. Various native starches, which have different functionalities, are already on the market [2].

Although glycemic homeostasis and gastrointestinal integrity and function are maintained by dietary carbohydrate, the diet high in carbohydrate reduces the likelihood of developing obesity and its co-morbid condition. In order to avoid obesity, diabetes and cardiovascular disease, the maintenance of energy balance is necessary. A key role in meeting the carbohydrate requirements in

human is 50–55% of energy intake [3]. For nutritional purposes, Englyst's procedure is one of popular measurements to analyze the starch digestion kinetic. According to the rate of glucose release and its absorption in the intestinal tract, starch has been classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) [4].

Native starch has many disadvantages for industrial applications or nutritional aspects. Therefore, the functionalities of starch can be modified by physical, chemical and enzymatic treatment [5]. There are many previous studies focusing on chemical modification of starch such as cross-linking and acylation. Nowadays, however, there is a growing interest in non-chemical treatments.

Physical modification of starch can be applied alone or with other treatment to reach the desired properties. Hydrothermal treatment (action of heat and moisture) is considered to be safer than chemical

treatment [6]. Based on different combinations of starch, water, and temperature, different hydrothermal treatments such as gelatinization, annealing, and heat-moisture treatment (Figure 1) can be applied. The gelatinization needs a certain minimum level of water content, and a temperature, higher than gelatinization temperature, has to be reached [7]. A temperature above glass transition temperature but below gelatinization temperature, a certain moisture content (<35 %), and a certain period of time are employed for heat-moisture treatment [5]. Normally, heat-moisture treatment was applied to granular starches in most of the previous papers without destroying their granular structure [6].

Enzymatic treatment is a third type of starch modification in which various enzymes are used depending upon different objectives. Generally, there are four common types of enzyme, which is useful for this treatment: (i) amylases that hydrolyze (1→4) α-D-glucosidic bonds, (ii) isoamylases that hydrolyze (1→6) α-D-glucosidic bonds, (iii) glucanotransferases that transfer (1→4) α-D-glucosidic bonds, and (d) branching enzymes [α-(1→4) α-(1→4) transferases] [8].

Both the formation of SDS and RS as functional foods and their structural studies

are attracting scientists. Chemical, physical and enzymatic treatments are applied for these purposes to various starch sources.

2. DEFINITION OF SLOWLY DIGESTIBLE STARCH

An *in vitro* method established by Englyst *et al.* [4] has been widely used to determine starch fractions: (i) RDS, amount of glucose released after 20 min; (ii) SDS, amount of glucose released between 20 and 120 min hydrolysis; and (iii) RS, total starch minus amount of glucose released within 120 min hydrolysis. High amount of RDS and SDS was found in A-type starch, which has the shorter double helices and interior crystallites. However, a high amount of RS was exhibited in B-type starch. Longer chains form stable helices, which are further stabilized by hydrogen bonds [1]. The digestibility correlates with amylopectin side-chain length; DP 8–12 and DP 16–26 positively and negatively correlate with α-amylase hydrolysis, respectively [9]. Based on specific structure and interactions of several factors, starch exhibits its slow digestibility. In most cases, B-type crystallites show a lower susceptibility to hydrolysis than A-type crystallites. Generally, the structural feature of SDS is an optimal mix of semi crystalline and amorphous material (Figure 1) [1].

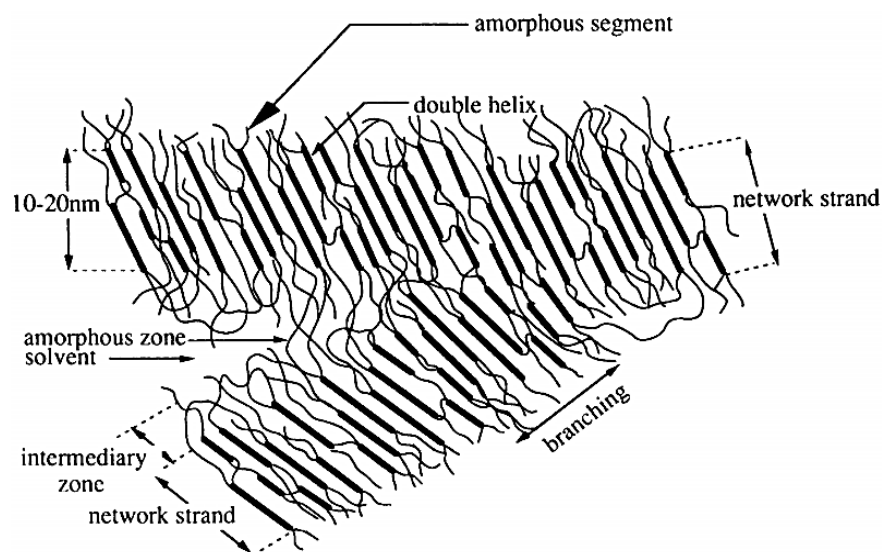


Figure 1. Structure of amylose gels as structural feature of recrystallized SDS [1, 10].

3. FORMATION OF SLOWLY DIGESTIBLE STARCH

Up to now, a few researches on SDS preparation have been conducted including physical treatment [11, 12, 13], chemical treatment [14], and enzymatic treatment [15, 16].

3.1. Chemical modifications

Woft *et al.* [17] reported the kinetics of digestion of chemically treated cooked waxy, dull waxy, common and high amylose starches. The cross-linking treatment caused insignificant changes in digestibility, whereas a reduction in the extent of hydrolysis was observed by oxidation and dextrinization treatment.

Shin *et al.* [18] investigated the optimum condition for SDS formation from rice starch by citric acid treatment determined using a response surface methodology. The fraction of SDS+RS reached the maximum of 54.1%, which was 28.1% higher than the control. Acid-treated SDS fractions increased by 8.9–14.2%. Furthermore, citric acid-treated starch showed decreases in wavelength of maximum absorbance, viscosity, and gel-forming ability, while showing increases in apparent amylose content, blue value,

dextrose equivalent, cold-water solubility and transmittance.

3.2. Physical modifications

Zhang *et al.* [19] investigated generation of slowly digestible starch using temperature-cycled retrogradation (4/25°C, 24 cycles). The maximum SDS content of 51.62% was obtained from waxy rice starch. The authors suggested that the temperature-cycled retrogradation is applicable to the preparation of slowly digestible starch in high yield from waxy rice starch. In addition, isothermal storage condition (4 or 25°C) caused higher in vitro glycemic indexes of slowly digestible starch products than temperature-cycled retrogradation did.

The formation and structural characteristics of slowly digestible non-pasted granular sweet potato starch were examined under hydrothermal treatment conditions [18]. The maximum SDS content was 31.0%, which was 15.4% higher than that of native starch without any further hydrothermal treatment. A negative correlation between temperature and relative crystallinity was observed. The non-pasted granular slowly digestible sweet potato starch consisted of very rigid amorphous regions and partially disrupted crystalline regions.

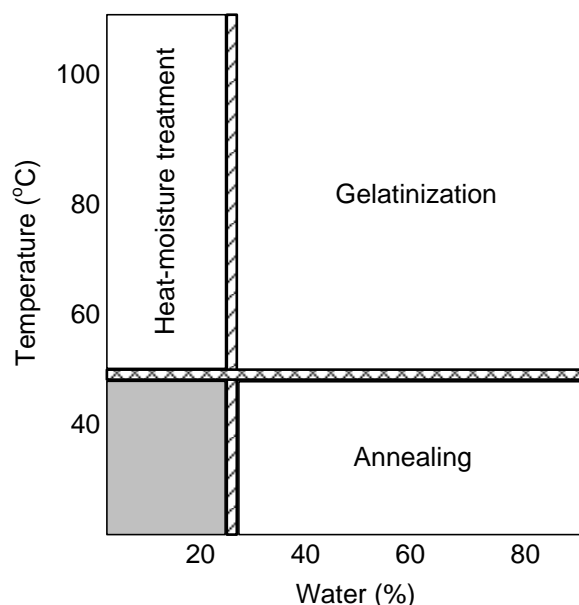


Figure 2. Different combinations of starch, water, and temperature affecting starch behavior [7]. (The borders between different areas are only approximate)

3.3. Enzymatic modifications

Partially debranched starch showed enhanced SDS content during storage at cold temperature, while the storage at higher temperature, where propagation and perfection of starch crystallites could occur, results in less digestible starch [12]. In fact, SDS fraction is composed of less perfect crystallites and amorphous components [18].

A previous study by [15] reported the partial shortening of amylopectin exterior chains and the length of amylose, which are caused by an increase in the branch density of starch, resulted in a decrease of digestion rate. The starches treated with β -amylase, β -amylase and transglucosidase, maltogenic α -amylase, and maltogenic α -amylase and transglucosidase showed reduced enzymatic digestion with an accompanying increase of SDS content. The mixture of B- and V-type X-ray diffraction patterns and a significant increase in α -1,6 bonds were observed in all enzyme-treated starches. Obviously, slow digestion property of starch was contributed by the increase in the starch branch density and the crystalline structure.

4. BENEFICIAL PHYSIOLOGICAL EFFECTS OF SLOWLY DIGESTIBLE STARCH

The potential health benefits of SDS are related to glucose metabolism. The metabolic effects of starch are linked to the rate of carbohydrate absorption after a meal. The glycemic index (GI) is commonly used to deal with these effects. It is defined as the incremental area under the blood glucose's response curve after intake of a standard amount of carbohydrate from a test food relative to a control food (glucose or white bread). Generally, the insulin response relates well to the glycemic response that is based on the rate of digestion of the food. The release of glucose by *in vitro* digestion over 3–5h reflects the blood glucose area *in vivo* [20].

Ultimate benefit of SDS is the control of blood glucose level. The SDS content of

consumed foods is related to glucose metabolism, diabetes management, mental performance, and satiety. SDS possesses a medium to low GI, and low GI diets are associated with decreased risk of diabetes, cardiovascular diseases, colon cancer, and breast cancer [20]. A significant reduction of potential risk factors for metabolic syndrome was reported by using SDS instead of RDS [21].

Foods rich in SAG (slowly available glucose) induce lower glycemic and insulinemic responses. In subjects with central obesity and some degree of insulin resistance, ingestion of SAG-rich meal lowered both the postprandial increase in insulinemia and the accumulation of circulating triacylglycerols and apo B-100 – or apo B-48–containing triacylglycerol-rich lipoproteins (TRL). In other words, the reduction of the glycemic and insulinemic responses, which decrease the postprandial accumulation of both hepatically and intestinally derived TRL, was found in foods high in SDS [22].

The decrease of gastric emptying and the improvement of the glycemic response of diabetes suggest beneficial effects of SDS on glucose homeostasis and energy regulation. The health benefits result from the consumption of a slowly digestible glycemic carbohydrate, inducing a sustained elevation of the incretin hormone of glucagon-like peptide-1 in the late postprandial phase (180–300 min) [23].

5. APPLICATIONS OF SLOWLY DIGESTIBLE STARCH

There are two different ways to attain a food product rich in SDS: (a) using an SDS ingredient, maintenance of its properties with the food matrix, and (b) formation of SDS during food processing. Because of low thermal stability of physically treated SDS, its use in the food industry is limited. However, protein or fiber in the food matrix protects SDS structure or forms a barrier to effective hydrolysis [1].

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