Latest Development Of Slowly Digestible Starch And Resistant Starch

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***Abstract*—Recently, slowly digestible starch and resistant starch and starch have drawn considerable attention due to their demonstrated and putative positive impacts on health and functional properties. Resistant starch and slowly digestible starch positively influences the functioning of the digestive tract, microbial flora, the blood cholesterol level, the glycemic index and assists in the control of diabetes. Among their desirable physicochemical properties are their swelling capacity, viscosity, gel formation and water-binding capacity, which make them useful in a variety of foods. This has resulted in the development of different methods for their preparation processing and purification, hence a comprehensive review of methodologies for preparation of resistant starches and slow digestible starches and their physicochemical properties is warranted. This review on latest development of functional starches includes particularly their classification starch according to rate and extent of digestion, physicochemical properties, and preparation methods and developed processing methods. Their applications, physiological and health benefits are also discussed. This review will provide more knowledge which will help for more researches, applications and nutritional purposes of those starches.**

Keywords—Development, Slowly digestible, resistant starch

I. INTRODUCTION

As the main carbohydrate source in human nutrition starch plays a major role in supplying metabolic energy, which enables the body to perform a multitude of functions [1, 2]. In human nutrition, starch is classified as rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS), according to the rate and extent of digestion[3]. Rapidly digestible starch (RDS) refers to the starch fraction that causes an increase in blood glucose level immediately after ingestion [4, 5]. Whereas SDS is an intermediate starch fraction between RDS and RS, which is digested slowly through the entire small intestine to provide sustained glucose release with a low initial glycemia and a subsequent slow and prolonged release of glucose[6] . Moreover, resistant starch (RS) is the fraction of the starch that cannot be digested in the small intestine and is partially fermented in the large intestine[6] to produce short-chain fatty acids and other products [1, 2, 5, 7, 8] such as acetic acid, propionic acid and butyric acid and gases in the large bowel[9]. Thus, resistant starch prevents diabetes, contribute to energy balance and health benefits to the colon [10]. Consequently, starch ingredients with high levels of slow digestible starch and resistant starch were reported to improve the nutritional function of foods [11].

Recently ,the increasing consciousness of the consumers that food may promote human health and well-being has encouraged many food developers and researchers to functionalize products beyond its mere nutritional value[12]. Several qualitative researches has been conducted on production of functional starches by modification of starches by physical, chemical and enzymatic processes [13, 14] . Those includes production of resistant starch from rice by dual autoclaving-retrogradation treatment[15], enzymatic modification of corn starch with 4-α glucanotransferase[1] , foot yams by heat-moisture-treated (HMT) starch [11, 16, 17] , enzymatic debranching in legume flours[18], from acid-modified amylotype starches[5] and type 4 resistant starch from acetylated indica rice by chemical modification [7] .

However, the latest development of slowly digestible and resistant starches has not previously been systematically reviewed. The aim of this review is to overview the latest developments of slowly digestible and resistant starch. This review summarizes the current knowledge regarding classification starch according to rate and extent of digestion, physicochemical properties of slowly digestible and resistant starch, their preparation and processing methods. Their applications and physiological and health effects are also discussed.

II. CLASSIFICATION OF STARCH ACCORDING TO RATE AND EXTENT OF DIGESTION

A. Rapidly digestible starch

Rapidly digestible starch (RDS) is rapidly digested and absorbed in the human small intestine, leading to a rapid elevation of blood glucose[6]. Rapidly digestible starch (RDS) is digested in vitro within 20 min[15]. The gelatinized normal maize starch had lower resistant starch and higher rapidly digestible starch compared to the gelatinized high-amylose maize starches[19]. According to different studies, when rapidly digested carbohydrates and refined sugars are included in diets, blood glucose levels increase, enhancing the risk of insulin intolerance and resulting in detrimental health effects[20]. Therefore RDS is associated with increased blood glucose and insulin level; which is linked with coronary heart disease, diabetes and the aging process [10].

A study on rice starch digestibility and amylopectin fine structure parameters showed that cultivars with the highest proportion of long chains had the lowest rapidly digestible starch (RDS)[21]. The RDS content was 28.1, 38.6, 41.5, and 57.5% in long grain, Arborio, Calrose, and glutinous rice, respectively, which was inversely related to amylose content [22]. The Zae49 and Zae50 gelatinized starches revealed lower rapid digestible starch and higher resistant starch than the other high-amylose maize gelatinized starches[19]. The rapid digestible starch(RDS) fraction in raw banana flour (total starch content 75%) was reported to be 3% compared to 15% slow digestible starch and 57% of resistant starch [23].

B. Slowly digestible starch

Slowly digestible starch (SDS) is digested between 20 and 120 min[15]. It is digested completely in the small intestine at a lower rate as compared to rapidly digestible starch (RDS) [4, 11]. This results in a slow and prolonged release of glucose into the bloodstream ; which is associated with low glycemic index [4] , reduced risk of diabetes as well as cardiovascular diseases[6]. The slow glucose released by slowly digestible starch may cause effect on mental alertness and activity level [23]. For native starch, normal maize starch had significantly higher rapidly digestible starch and slow digestible starch and lower resistant starch than the high-amylose maize starches[19] .

C. Resistant starch

Resistant starch (RS) cannot be digested in the small intestine, it is fermented in the large intestine into short-chain fatty acids [6]. It resist to hydrolysis of in vitro treatment of pullulanase α-amylase and not absorbed in small intestine [7]. Moreover, resistant starch is the starch portion that is fermented in the colon as dietary fiber[2], which may be linked to better colonic health[1]. Compared with traditional insoluble fibers, RS has many advantageous features; it has a natural white color, a bland flavor and has a better appearance and texture[26] .There are four types of resistant starch : physically inaccessible starch locked within the cell walls (RS_1), ungelatinized native granular starch with type B crystallinity (RS_2), retrograded starch (RS_3), and chemically modified starch due to cross-linking with chemical reagents (RS_4) [4-6, 15].

Among these types, the RS2 has granular form and resistant to enzyme digestion [12, 28]. Whereas , RS3 has been shown to improve glucose tolerance , lower plasma cholesterol and blood lipids [5]. The amount of resistant starch in foods depends on the type and amount of starch (crystal and granular structure, amylose: amylopectin ratio, the chain length of amylose, and linearization of amylopectin), as well as the processing, cooking, and storage conditions of food (heat and moisture conditions)[4]. Starch with high amylose content has a high resistance to digestion and provides many health benefits for humans [29]. The table I summarizes types of resistant starch, their description and their sources. The RS1 and RS2 are slowly but almost completely digested with appropriate pre-processing of foods, but RS3 totally resists to digestion [5]. Unripe banana is very rich in indigestible carbohydrates (up to 60–80% dm), which is composed of cellulose, hemicelluloses, lignin, starch, dietary fibre, and resistant starch (RS2)[25].

TABLE I. TYPES OF RESISTANT STARCH

Types of resistant starch	**Description and sources**		
	Description	**Sources**	**References**
Type I resistant starch	Physically inaccessible starch	Coarsely ground or whole-kernel grains ,seeds ,leg umes	[5, 24]
Type II resistant starch	Granular starch with the B- or C-polymorph	High-amylose maize starch, Non-gelatinized sources, such native potato Raw banana starch, native potato starch.	[19, 25]
Type III resistant starch	Retrograded starch	Cooked and cooked starchy foods after cooling, e.g., in breads, corn flakes, or potatoes, foot yams	[16, 26, 27].
Type IV resistant starch	Chemically modified starches	Cross linked starch hydroxypropyl starch and acetyl succinate starch e.g., acetylated indica rice	[7, 11, 24]

III. PHYSICOCHEMICAL PROPERTIES OF SLOWLY DIGESTIBLE STARCH AND RESISTANT STARCH

A. General physicochemical properties of slowly digestible starch and resistant starch

Physicochemical properties of starch vary with botanical source, reaction specifications, type of substituent group and degree of substitution[30]. Recently, many researchers have been conducted on physicochemical, functional[21, 22], thermal, morphological , rheological properties of starches [31]. Resistant starch is characterized by a smaller molecular structure with a length of 20–25 glucose residues , linear polysaccharides that are connected by hydrogen bonding[2]. The major physical–chemical and functional properties of starch are gelatinization, retrogradation, solubility, water absorption power, syneresis and their rheological behaviour in pastes and gels[32]. Gelatinization and retrogradation are important to food texture and digestibility[21] . The properties of starch granules are greatly influenced by the amount of amylose in the starch granules [13]. In addition ,the main variation in the composition of rice starch caused by the relative proportions of the two fractions in the starch granules and this, together with the chain length distribution and the frequency and spacing of branch points within the amylopectin molecule , has a profound influence on the physicochemical properties of starch[33] . The avocado seed starch had a slightly lower gelatinization temperature (65.7◦C) than maize starch (66.32◦C) despite their differing amylose contents[34]. It has been revealed that the organic acids affect physicochemical and functional properties of native and some modified starches [35].

B. Properties of resistant starch

1) Thermal properties

Recently , it has been shown that the thermal properties of starch granules from different botanical sources with normal and no amylose content are highly influenced by the structure of the amylopectin component[21]. For normal starch, the gelatinization temperature decreases with an increase in amylose content[29]. Reduction in gelatinized temperatures had advantages of reducing the energy cost during the manufacture of products where these modified starches are used as thickening agent at low temperatures [13]. Furthermore, the high-amylose starch usually has B- or C-type crystallinity, the B-type crystallinity needs higher gelatinization temperature than A-type crystallinity [29]. Retrograded starch forms a strong hydrogen bond between the molecules and completes a cement structure in amorphous regions[36]. For retrograded starch, the amyloses and the long branch-chains of amylopectin and the intermediate component can form double helices (retrogradation) to increase the resistance to digestion after gelatinization[19]. In addition, there is the positive correlations between the length of the internal chain segments between the smallest branched units in amylopectin and the onset temperature of gelatinization of the granules and that the enthalpy of gelatinization correlates with the length of the external chains [21].

It has been revealed that for high-amylose maize starches, the retrogradation of gelatinized starch decreased the rapidly digestive starch and increased the RS[19].

The study on effect of heat-treatment on the acetyl content and RS content of acetylated rice reported the change in RS4 content but no change in acetyl content and the greatest increase in the RS_4 was found at 120 °C [7, 35]. Heat-processed foods could contain sufficient amounts of resistant starch that is able to survive prolonged incubation with α-amylase and other amylolytic enzymes [7]. Furthermore, RS3 totally resists to digestion and has shown thermal stability properties in most normal cooking operations and enables its use as an ingredient in a wide variety of conventional foods [5, 37].

2) Rheological properties of resistant starch

Starch is a natural polymer, principal storage polysaccharide of higher plants and composed with glucose polymers of amylose and amylopectin [13, 29]. Both amylopectin–amylopectin interactions and amylose–amylopectin interactions play imperative role in gel properties changes during long-term storage [21]. A study demonstrated that dual autoclaving-retrogradation treatment can cause reorganization of the amylose and amylopectin chains of starch which decrease in breakdown viscosity of treated rice starches, indicates their resistance to shear thinning during cooking[15]. Acetic acid caused lower viscosity and production of less cohesive and softer gels with higher degree of syneresis during storage[35]. The catechin was found to reduce setback viscosity of the gelatinized wheat starch and starches stored for 48 h [36]. The longer chains of amylopectin play a key role in gel formation due to the fact that gels containing amylopectin with longer average branch length were stronger than those containing shorter average branch length [21].

However, native starch lacks some functional aspects and it is prone to syneresis during cold storage and cannot withstand high shear and pH[30]. Minor change in starch molecular conformation and starch structure could result in changes in rheological properties of starch[38]. Starch granules can absorb water, swell, and impart viscosity when heated[39].

The lesser enzyme treated starch had an appreciable viscosity found at low shear and the viscosity decreased with an increase of reaction time with 4 –α-GT during starch processing[1]. The viscosity has been reported to be inversely related to the digestibility of the treated starches[1]. For starches with a unimodal size distribution such as maize and potato, the amylose content and pasting viscosity increase and the gelatinization temperature and hydrolysis degree decrease with increasing granule size[29].

3) In vitro starch digestibility properties of resistant starch

Digestibility of raw native starches has been attributed to the interplay of many factors, such as starch source, granule size, amylose to amylopectin ratio, extent of molecular association between starch components, the type and degree of crystallinity, amylose chain length, amylopectin fine structures, and presence of amylose–lipid complexes [23]. The 4- α-Glucanotransferase (4 -α-GT) treated starch samples showed an increase in slow digestion property compared to the control starch sample[1]. The decreased hydrolysis rate of resistant starch in the in vitro starch digestibility assay was associated to more short amylose which reduce the ability of starch to be digested by enzymes [2]. Although resistant starch is not digested in the small intestine, it may be fermented into short chain fatty acids (SCFA) and gases by the microflora in the large bowel [6]. Short chain fatty acids (SCFA) , particularly butyrate have been implicated in promoting good colonic health and preventing the incidence of colon-rectal cancer[40].

The cooked normal corn starch (control sample) had 80.08% of rapid digestible starch, 9.40% of slowly digestible starch and 10.52% of resistant starch while the 4- α-Glucanotransferase (4- α-GT) treated starch also had greater resistant starch in range of 11.08–21.34% than the control sample [1] . The reduction in transition temperature range of treated starch samples is a marker of expanded homogeneity with perfection of crystallites and this increased resistance of starch against digestion[15]. In addition, the long branch-chains of amylopectin and the intermediate component, which form the more stable B-type double helical structure, are more resistant to digestion than the short branch-chains forming the A-type double helical structure[19]. Moreover, partial 4-α -GT treatment of normal corn starch reduced starch digestibility, which was related to the amylose, molecular weight, chain length and viscosity[1].

The dual modified treated starch (DMT) possess resistant enzymatic properties[2]. It has been reported that acetylated starch, hydroxypropyl starch and crosslinked starch reduced the extent of enzyme-catalyzed hydrolysis, after acetylating with vinyl acetate, the anti-enzyme effect of the rice improved and the total digestibility decreased [7]. The viscosity was inversely related to the digestibility of the treated starches[1]. The digestibility of starch is highly sensitive to the retrogradation of amylose that occurs mainly in the early period of storage, whereas amylopectin recrystallization, which occurs more slowly, has little influence on the digestion[19].

4) Apparent amylose content and resistant starch content

Amylose content has significant effects on structural and functional properties of starch[19]. Starches with high-amylose content have a high content of resistant starch which is fermented by bacteria in the large intestine [19]. The study showed that amylose content in retrograded starches was not significant different from their native counterparts [4]. Whereas , resistant starch content was decreased after autoclaving of amylotype corn starch [5]. A positive correlation with amylose content among resistant starch of native, gelatinized and retrograded starches was reported [19]. In addition , the resistant starch yield of foods relates to the amylose/amylopectin ratio , the botanical source of the starch, the type of processing , cooling , physical form, thermal, the degree of gelatinization and storage conditions[26]. The amylose content of starch is the basis for the appearance of retrograded starch during the hydrothermal processing of food materials [27]. High-amylose maize has health benefits through its high resistant starch content[19] .

5) Swelling, solubility index, freeze-thaw stability of resistant starch

Autoclaving-retrogradation treatment decreased the swelling index of rice starch samples significantly ($P \leq 0.05$) where post autoclaving-retrogradation treatment, peak viscosity decreased from 2953.33 to 994.33 cp for SR-1 starch, 4438.66 to 1326.66 cp for SR-2 and significant reduction in swelling index of treated starch could be responsible for lowering of peak viscosity[15]. The higher RS content recorded for the autoclaved samples, which produced higher amount of insoluble material (decreased solubility values) and lower water retention features (decreased swelling power)[24].

Freeze thaw stability of starch is an important characteristic to be considered when formulating frozen and refrigerated foods[15]. In Cavendish banana , there were no significant differences in banana resistant starch sample swelling power among the five ripening stages[41]. It has also been reported that autoclaved samples presented lower solubility and swelling power than their corresponding native and lintnerized starches counter parts[24]. Higher syneresis of starch indicates lower freeze thaw stability , the decrease in swelling index of treated starches could be linked to increased crystallite perfection and to additional interaction between amylose α–amylose and/or amylose-amylopectin chains [15].

It has been demonstrated that high-temperatures drying reduce the swelling capacities of starch granules and their solubility indexes during gelatinization [41, 42].

IV. PREPARATION AND DEVELOPED PROCESSING METHODS OF SLOWLY DIGESTIBLE STARCH AND RESISTANT STARCH

A. Preparation and developed processing methods of slowly digestible starch production

The molecular structure of starch is responsible of its functionality in related to food and nutritional properties[33]. Recent studies on the production of slowly digestible starch using physical, chemical, and enzymatic methods have been reported [1]. Slow digestible starch are produced from sweet potato from Daeyumi starch by dual enzyme modification[6], enzymatic modification of corn starch with 4-α glucanotransferase[1] , heat-moisture-treated (HMT) starch from waxy potato starch[43] . Among them, enzymatic treatment has many advantages as it is safer for the environment as well as consumers and has more specific reactions and fewer by-products[6]. Heat-moisture treatment (HMT) refers to the exposure of starch granules to a temperature above the glass transition temperature, but below the gelatinization temperature for a certain time period and at restricted moisture content (below 35%) , it is a natural and safe and physical modification technique [11]. Chemical modification was also an important method to produce high contents of slowly digestible starch [7]. A maximum slowly digestible starch content (20.92%) was obtained using 4 _GT hydrolysis over 4 hours whereby the increase of both long chain fractions (DP < 30) and short chain fractions (DP < 13) resulted to a more slowly digestible starch and resistant starch [1].

The Vt-HMT25 (canna starch containing moisture content of 25% during heat treatment) when gelatinized for 5–20 min contained a higher amount of slowly digestible starch (SDS), compared to unmodified starch [11]. Various amylases and a transglucosidase have been used to control the branch density and length to produce slowly digestible starch using partial hydrolysis of normal maize starch [1, 6]. Canna starch modified by crosslinking had the highest slowly digestible starch content when gelatinized for 20–40 min [11] . Dual enzyme treatment with β-amylase and transglucosidase was used to obtain maize starch of increased slow digestion property[6]. The most effective modification method for resistant starch and slowly digestible starch formation was octenyl succinylation [11]. Enzymatic modification of starch can be used to improve sweet potato starch and facilitate the development of new dietary applications using the slow digestion properties[6].

B. Preparation and developed processing methods of resistant starch

Resistant starch can be found in foods naturally and can also be produced through processing at home or in a factory[4].

For improving and stabilizing functional properties of starch like of gelatinization and pasting different modification method are used to produce resistant starch[38]. Nowadays, resistant starch(RS) is manufactured by a enzymatic modification[18] , physical modification like heat moisture treatment[17], heating-cooling process and chemical modification [26] . In addition , different plant sources are used to produce resistant starch with a different crystal structure and/or to modify the structure of starch by hydrolyzing it with enzymes like isoamylase or pullulanase by hydrolysis of the amylopectin fraction through the elimination of α-d-(1 → 6) glycosidic linkages[4].

The industrial flour production from green banana is of interest in view of its nutritional value, especially its high quantity of RS (approximately 40.9–58.5%) and dietary fibre (6.0–15.5%)[25]. Many high-amylose cereal varieties have been developed via mutation or transgenic breeding approaches[29] .Chemical modification may have safety problems and resistant content may be low by heating-cooling process alone due to the structure of nature starch[40]. Most studies on resistant starch have focused on resistant starch derived from potato, wheat, maize and sorghum sources [1, 5, 19, 40, 43]. Some other studies have reported preparation of resistant starch from rice starch [15, 37, 44]. Moreover, combination of α-amylase, pullulanase and heat-moisture treatment was used to produce resistant starch from indica rice starch [2]. It is produced by gelatinization after disruption of the granular structure by heating starch with excess water and by retrogradation [24]. Resistant starch is prepared also by autoclaving-retrogradation treatment [15]. In the cooling step retrogradation of starch , the linear flexible amylose chains recrystallize and form tightly packed double helices stabilized by hydrogen bonds that are resistant to enzymatic hydrolysis[4]. On the other hand, partial acid hydrolysis (lintnerization) and debranching of amylopectin are very effective in generating resistant starch from various starches [24].

The method of enzyme hydrolysis was reported in preparation of RS3 [37] whereby, starch paste was treated with thermostable α-amylase and pullulanase was added (EC 3.2.1.41) to hydrolyze the α-1, 6-glucosidic linkages in starch , produces amylose and may increase resistant starch content [4, 26].

Gelatinization and cooling processes which are generally referred to as annealing procedures, are the common methods used to enhance the formation of RS3 (retrograded starch)[16]. It has been found that maize starch was treated by autoclaving–cooling cycles, coupled with pullulanase hydrolysis to prepare resistant starch (RS) that could be highly resistant to hydrolysis by α-amylase during processing [4, 37, 45] . The mixture was treated with a thermostable α amylase (1%, w/w) and incubated in a boiling water bath (95 °C) for 45 min then centrifuged (4,000 ×g, 15 min)[40]. The obtained RS3- rich starch was called “taro resistant starch” [4], whereas the 4- α-Glucanotransferase (4 _GT) modified starch synthesized then novel amylopectin clusters with slow digestible and resistant character[1]. Indica Rice – Resistant Starch were prepared using a method that combined physical modification and enzyme modification, and the resistant starch content was 47.0%[2]. Some researchers have reported increased resistant starch using a different preparation method [1, 5, 26] as shown in Table II.

Under the different conditions of preparing RS, the RS content of DMT starch was significantly higher (47.0%) than that of the other two samples and the hydrolysis rate of the Dual modified treatment (DMT) starch was significantly less than that of the other two samples because after dual enzyme treatment with amylase and pullulanase[1]. Resistant starch formation in lintnerized starch is also affected by strength of acid, incubation time and temperature [24] . Generally, native starches with A-type crystalline structure are more susceptible than B-type starches to enzymatic hydrolysis , A- and B-type crystallites differ in the mode of double-helix packing and in water content[43].

TABLE II. METHODS OF PREPARATION OF RESISTANT STARCH

Method of preparation Of resistant starch	**Raw material**	
	Raw material	**References**
Dual modification-treated (DMT) starch	Indica rice starch (IR-RS)	[6]
Enzymatic modification with4-α glucanotransferase	Corn starch	[1, 43]
Heat-moisture-treated (HMT) starch	Indica rice starch (IR-RS)	[2, 11, 16, 17]
Chemical modification	Acetylated indica rice	[7]
Dual autoclaving-retrogradation treatment	Rice	[15]
Single modification-treated (SMT) starch	Indica rice starch (IR-RS)	[26]
Enzymatic debranching in legume flours	Legume flours	[18]
Lintnerization (acid hydrolysis)	culled banana	[24]

Crystalline short-chain amylose (CSCA) from debranched waxy potato starch had a higher peak melting temperature (116.2 ◦C) and higher resistant starch content (77.8%) than that from debranched waxy wheat (67.7%) and waxy maize starches (68.1%)[37].

It has been reported that no increase in RS content during rice storage was observed, the enthalpy for retrogradation and the intensity ratio 1047/1022 cm (-1) during storage were correlated negatively with rapidly digestible starch and positively with slowly digestible starch [22]. Heat moisture treatment(HMT) yam, taro, cassava, potato and new coco yam starches have also been studied and found that in potato and yam starches, HMT changed B-type X-ray diffraction patterns to combined B- and A-type patterns and caused relative crystallinity and retrogradation levels to decrease[43]. It has been shown that the ratio of vinyl acetate to rice reached 2.0:10 and produced most resistant starch (66.35%) and increased the acetyl content, too[7]. Modification of canna starch by heat-moisture treatment resulted in a lower content of RS [11]. Sources of cereal grains, roots, tubers and legumes produce resistant starch through the process of cyclic heating, autoclaving and extrusion methods[16].

V. APPLICATIONS OF SLOWLY DIGESTIBLE STARCH AND RESISTANT STARCH

A. General applications in food and non-food industry

Starch plays a major role in food industry in providing the structural, thickening, gelling, thermal, functional properties and consistency to a wide range of food systems [13, 14].

Starches have been used as functional ingredients in food because they can yield highly viscous pastes or gels when added in sufficient concentrations [46]. Distinctive characteristics of rice starch manifest its usage in food, pharmaceutical, cosmetic and packaging industries[30] . Starches like corn, potato, cassava etc. due to ease in availability and extensive industrial utilization as thickener, stabilizer, gelling agent and bulking agent[47] . However, native starches nevertheless of their sources have less applicability because of their incapability to tolerate processing conditions , the general disadvantages are low paste clarity, pH sensitivity, heat and shear, high retrogradation [14] , poor thermal stability and syneresis [13]. As one of the main food materials providing energy for humans, starch normally consists of two d-glucan polymers, i.e. amylopectin, mainly a 1,4-α-d-glucan with a large number of 1,6-α linkages at the branch points, and amylose, mostly a linear 1,4-α-d-glucan with a small number of long branches [38] .

Starch is a promising low cost, renewable, abundant, and bio-based source for aerogel formation[48]. Starch is the most important macromolecule being used diversely to meet technological needs of today due to its low-cost, abundance, edibility, biodegradability and good film forming properties[47] . In the native starch granule, these two biopolymers are organized on different length scales to form a hierarchical semi-crystalline system, comprised of the semi-crystalline lamellae, the long-range crystallites and the short-range orders[38] . The different structural and functional properties result in the different end uses[29].

However, starch use in the food industry is limited by their weak-bodied, cohesive, poor thermal, shear and acid stability [14, 47]. Because of that, physical, chemical and enzymatic modifications have been proposed for modulating the functional properties of native starches [14]. A great range of food textures can be acquired using starch products that act as thickening or gelling agents under different circumstances[38]. For example, the starch with predominantly small B-type starch can be used as a fat substitute, a paper coating, and a carrier material in cosmetics, while the starch with a high percentage of large A-type starch has applications in the manufacture of biodegradable plastic film, carbonless copy paper and brewing beer[29]. Potato starch is one of the worldwide starch resources and has been widely used in foods and non-food industries , which is a typical B-polymorphic starch[38]. Among starch sources, wheat starch has the potential for the formation of starch hydrogels with three dimensional polymeric network structures and it has an important role in many foods[48].

Starch is widely used as a functional ingredient in food systems as thickening, gelling and stabilizing agent [14]. Flours and starches are generally used to control structure, texture and stability of sauces because they enhance thickness and viscosity of the continuous phase inhibiting the tendency of the dispersed phase to migrate and flocculate or coalesce [12]. starch is one of the most widely used additives in surimi-based products due of its high capacity to swell and retain water, which enhances gel strength, reduces the amount of surimi used, and ensures storage stability for frozen crab sticks[39]. For the applications of starch, it is necessary to investigate the functional properties including swelling power, water solubility, thermal property, hydrolysis property, digestion property[29].

The functional and rheological properties of avocado seed starch suggest applications as an ingredient in food systems and other industrial applications[34]. Wheat starch aerogels with their outstanding properties will provide many opportunities for food applications, bioactive protection and delivery[48]. Starch, in particular, has attracted great attention, since not only can starch be used as a thickening and gelling additive in food systems but also it is a main food ingredient which provides energy for humans[38]. It has been reported the effects of various starches on the gelation properties of surimi and reported to significantly increase surimi gel strength for starch concentrations of 50 g/kg [39].

An amylose content in starch of around 39.0% means that Tartary buckwheat starch has potential for producing functional foods with retrograded starch and thus with a low glycemic index[27]. Starch content has influence on improving the viscoelastic properties of surimi gels[39]. The appearance of retrograded starch is thus expected during hydrothermal processing of products containing buckwheat starch[27]. In recent years, rice, especially rice flour, because of its unique functional properties, is used in a number of novel foods such as tortillas, beverages, processed meats, puddings, salad dressings and gluten-free breads[33] . Wheat starch aerogels with large surface area, nanoporous structure, and ultra-low density can be used for several purposes such as bioactive carriers, fillers in food preparations, and solid supports for biocatalysts[48]. Pea starch has been reported to produce films with improved physical and mechanical properties in comparison with films prepared from other starches due to the high amount of amylose[49]. These novel foods usually require rice flours and starches having known physicochemical properties, which could indicate market value, utilization and consumer preferences of rice cultivars[33]. Avocado seed starch has potential applications in products such as babyfood, sauces, bread products, jellies, candies and sausages as well as biodegradable polymers for food packaging [34].

B. Physiological applications and health benefits of slow digestible starch

Slowly digestible starch (SDS) results in a slow increase of postprandial blood glucose levels and sustained blood glucose levels over time in comparison to rapid digestible starch (RDS), which is advantageous for physical and mental performance, satiety, and diabetes management [10] . Low glycemic index (GI) foods, due to the slow digestion and absorption of their carbohydrates, produce a more gradual rise in blood glucose and insulin levels, and are therefore associated with reduced incidence and prevalence of diabetes, heart disease, and some cancers [4, 6] . Therefore, slowly digestible starch is the most desirable starch type from a nutritional point of view [10]. It can be used in the development processes for designing a novel slowly digestible starch for controlling postprandial hyperglycaemia [1]. Slowly digestible starch provides a sustained supply of glucose that may help control and prevent hyperglycaemia-related diseases[4]. Foods containing a substantial amount of slowly digestible starch may also be advantageous to satiety, physical performance, glucose tolerance enhancement, and blood lipid level reduction in healthy individuals and those with hyperlipidemia[43].

Slowly digestible starch has thus received much attention as a new functional food component in innovative food-product development [11]. The glucose release property of slowly digestible starch satisfies the fundamental basis for the beneficial effects of a true low-GI food with a slow and prolonged release of glucose[6]. Heat moisture treatment (HMT)-induced structural changes in waxy potato starch has found to affected its mice digestibility and the blood glucose levels [43]. The combined enzymatic treatment improves sweet potato starch and facilitates the development of new dietary applications using the slow digestion properties[6].

C. Physiological applications and health benefits of resistant starch

The demand of consumers for healthier food products has forced the food industry to produce high-quality products with functional properties[4] . As a functional ingredient, resistant starch has physiologic effects that are similar to dietary fiber [2, 4, 8] . It can affect body weight, energy balance, increase lipid excretion to reduce calorie intake and decrease the serum lipid levels [2, 6, 50] . Moreover, resistant starch also has a bile acid binding capacity and has been shown to be effective in lowering plasma cholesterol levels in genetically obese and lean rats as well as in diabetic rats[4]. Dietary resistant starch (RS) use in food may provide therapeutic opportunity to attenuate excessive fat gain in infants and children by reducing the caloric density while improving dietary quality[28]. For that reason , it is used in low-moisture food products, particularly in bakery products such as bread and muffins, and in breakfast cereals to improve human health and lower the risk of many diet-related diseases [26].

Resistant starch was found to effectively control diabetic liver, kidney and spleen hypertrophy in mice [2, 10]. In addition , resistant starch containing food products have lower Glycemic Index (GI) values and therefore, can be used for controlled glucose release applications[4] for prevention of several diseases, such as colon cancer, diabetes(T2DM) , cardiovascular diseases, and obesity[2, 15] . Moreover, resistant starch also has beneficial physiological effects such as increasing absorption of minerals like zinc, calcium and magnesium ions, lowering plasma triglyceride and cholesterol levels [4, 8] . Thus , resistant starch can effectively control the symptoms of high cholesterol by lowering Triglyceride levels and similar High Density Lipoprotein levels[2] as well as prevention of osteoporosis [18] . Resistant starch has attracted great interest in nutrition and food industry, due also to its increased faecal bulk, and short-chain fatty acid (SCFA) production through fermentation in the large intestine[26]. The ingestion of resistant starch can decrease insulin secretion and reduce intestinal emptying time and also lower the intestinal pH [2].

Diets rich in resistant starch have been associated with improved health and resistant starch diets are also known to alter the taxonomic composition of the gut microbiota in both animals and humans [51] . The prebiotic properties of resistant III (RS3) have been studied recently and results have shown that RS3 increases the growth of bifidobacteria in the gastrointestinal tracts of rats[52]. Among four types, RSIII seems to be attractive because of its polymorphic crystallinity and survives most food-processing conditions as well as preserving its nutritional characteristics [24] .

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