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Review Article

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Exploration of Food Industry Waste for Extraction of Resistant Starch: A Step Towards the Sustainable Approach

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Abstract

Resistant starch (RS) has gained considerable attention due to its health benefits, bioavailability, and potential as a dietary fiber source. It resists enzymatic degradation and remains intact as it passes through the large intestine. This unique property of RS offers several potential health benefits, including improved bowel function, enhanced satiety, better glycemic control, and increased production of beneficial fatty acids with a short chain by gut bacteria which have been connected to modifications in the body metabolism. Furthermore, it has been associated with controlling fasting plasma triglycerides, improving cholesterol profiles, and enhancing mineral absorption. This review focuses on RS, exploring its composition, structure, and factors contributing to its indigestibility. Additionally, it introduces the utilization of agricultural waste, such as pseudo-stem banana, potato, jackfruit, and black longan seeds, for extracting RS which can be used in various food applications.

Keywords

Resistant starch, Extraction, Food industry waste, Valorization, Rapidly digestible starch, Slowly digestible starch

Introduction

Starch serves as a vital source of energy and essential nutrients for most people worldwide. It plays a significant role in providing nutrient-rich food for sustenance and vitality [1]. Starch is the main element that ensures the population has an adequate calorie intake, accounting for around 40% of the world's energy consumption [2]. Starch that is highly digested results in inadequate nutritional issues which causes an initial calorie surplus that makes it difficult to absorb healthy nutrients and just absorb energy in excess, increasing the probability of obesity and further health issues. Secondly, eating meals that are high in starch frequently causes a significant glycaemic reaction, which increases the risk of diabetes type 2 and heart conditions [1].

Polysaccharide digestion in humans is facilitated by the action of enzymes such as amylases and amyl glucosidases, which break down these molecules into glucose [3]. One of the polysaccharides is starch, which is the main form of preserving carbohydrates in plants. It is typically found in fruits, roots, grains, seeds, leaves, tubers, stem cores, and rhizomes, among other plant parts [4, 5]. From a dietary standpoint, starch in food can be split into three categories: Rapidly digestible starch (RDS), slowly digestible starch (SDS) and RS as shown in figure 1 [6, 7]. Starchy items cooked over moist heat, such as bread and potatoes, are among the most prevalent forms of RDS, which is comprised of dispersed and amorphous starch. Chemically, it is considered as starch that follows the enzymatic digestion for 20 min and is converted into glucose molecules. SDS exhibits a slower breakdown rate in the small intestine compared to RDS. Amor-

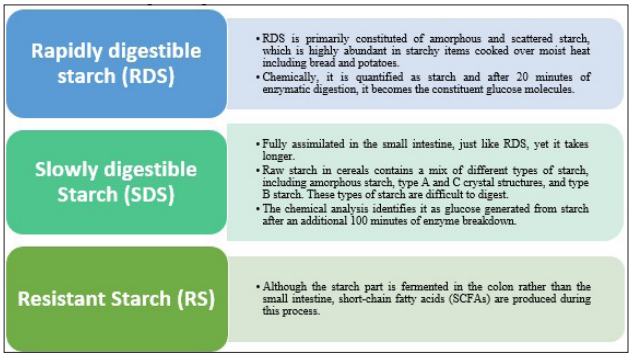

Figure 1: Types of starch [8, 12, 13].

phous starch, type A or type C crystalline raw starch (usually present in cereals), type B starch, which is present in granule form or as retrograded starch in cooked foods, are among the different forms of starches that make up SDS. To determine the presence of SDS, glucose synthesis from starch is analyzed chemically after an additional 100 min of enzyme digestion [8]. On the other hand, the short-chain fatty acids (SCFAs) are produced in the colon because of the fermentation of RS, a component of starch that is tough to digest in the small intestine [3, 9-11].

To evade intestinal digestion, RS undergoes fermentation by the bacteria present in the gut. As a result, biomolecules made of SCFAs like acetic acid, butyric acid, and propionic acid are created and released [14]. RS is a dietary fiber source that may enhance blood lipid profiles, reduce dysbiosis of the gut microbiota, and improve glucose metabolism, among other nutritional advantages. Most RS components can be categorized as low-viscosity fermentable filaments and soluble, making them easily assimilated into an extensive range of diets. Consuming together with other fiber isolates with various physicochemical characteristics, such as nonfermentable, soluble, and viscous fibers, or as a component of a healthy diet (high in whole grains, fruits, and vegetables), RS-enhanced foods may help to maintain a diverse and healthy microbiota and reduce the risk of contracting several chronic diseases.

Due to their small particle size, relatively bland flavor, and white appearance, high RS components (at the right replacement level) may be more palatable to consumers than traditional fiber sources (such as bran and gums). This is true even though substituting RS components for conventional flours may provide technical difficulties due to diluted gluten and decreased maillard browning. Such unique items may appeal to the typical western customer as well as the health-conscious buyer, whose palate may favor processed refined grains. Access to foods enriched with RS and greater public knowledge of its advantages may also contribute to the growth in RS's acceptability.

Reformulating stable food items to contain high RS components may result in a high-fiber, low-energy, functional food product with a lower glycaemic index, higher satiety markers, and prebiotic effects than their conventional equivalents, according to the findings given in this review. Market research shows that there are many RS components that food companies can easily use in everyday foods. This could help people to eat more dietary fiber and reduce their risk of developing chronic diseases that are common in western countries. However, there are still very few food products (especially in European countries) that contain high levels of RS [15].

Extensive research has been conducted on the extraction of functional compounds such as polyphenols, alkaloids, flavonoids, and terpenoids from various plant sources. However, the extraction of RS from food processing waste has received relatively little attention.

Considering the points, this review aims to present a thorough understanding of the extraction of resistance starch from waste generated by food industries as well as its beneficial effects on human health.

RS

In the 1980s, Englyst coined the phrase "resistant starch" for the first time [16]. The results of RS on lipid and glucose absorption, as well as its prebiotic attributes, favorable consequences on gut flora, and positive aspects for satiety and body weight were all evaluated at the same time [17-23]. In the small intestine, RS resists digestion and largely remains intact in the large intestine. It behaves more like dietary fiber and is not broken down by digestive enzymes. This characteristic of RS has the probability to improve several body functions, like bowel function, satiety, glycaemic control, and the amount of good gut bacteria that create SCFAs. Some foods, like legumes, unripe bananas, and cooked and cooled potatoes, naturally contain RS. Other foods can also be processed to produce RS. The potential to improve general health and well-being has drawn attention to the dietary addition of RS [13].

Structure and composition

The nutritional value of starchy foods can differ tremendously based on different criteria, including the source, composition, and methods of processing the starch [24]. It is made up of α-D-gluocse, a polymer that is present in grains, tubers, and seeds in the shape of granules. Starch is comprised of two polymers: amylose and amylopectin, which have various spatial structures and distributions inside the granules [25]. A linear polymer of glucose known as amylose is comprised of molecules connected by α-(1-4)-glycosidic linkages. Short, straight chains with several glucose units joined by α-(1-4)-glycosidic bonds and inter-connected by α-(1-6)-glycosidic bonds make up the branching substance known as amylopectin [26].

What makes a starch "resistant"?

Starches are made up of two polysaccharides: amylopectin and amylose. Amylopectin, with its highly branched structure, has a higher surface area for digestion. As a result, it quickly broke down, causing a rapid rise in blood sugar levels and a considerable increase in insulin release. Comparatively, amylose is a straight-line chain with a little surface area for digestion. This characteristic is common in RS. Foods with a higher amylose content take longer to digest, which reduces the risk of insulin or blood sugar rise. As a result, the term "resistant starch" refers to compounds that are resistant to digestion [8].

Types of RS

In contrast to being metabolized to D-glucose in the small intestine, RS is defined as something that does not ferment in the colon within 120 min of intake. Based on its composition or means of avoiding digestion, RS is segregated into five categories (Table 1) [27].

RS1: Starch that is not readily available

In fully or partially milled grains, tubes, and seeds, RS1 binds to proteins, pieces of cell walls, and other physical obstacles. It is physically impossible for digesting enzymes to access RS1. The RS in pasta is a prime example of RS1. According to reports, pasta possesses a more compact protein matrix than other wheat products, which accounts for its higher RS concentration [28]. The physical barriers in food can be segmented by grinding and protease hydrolysis, which lowers the RS1 concentration [1].

RS2: B or C type polymorph in raw granular starch

Native, uncooked granules like those seen in unripe bananas, undercooked potatoes, and high-amylose maize starches make up with RS2. These granules contain B or C-type polymorphs. Enzymes are unable to hydrolyze them due to their granule crystallinity. The heat sensitivity of RS2 makes it challenging to incorporate into food products. Since it has long-chain double-helical crystallites, a specific type of RS2 known as high-amylose maize starch is entirely dependable on most methods for cooking [29].

RS3: Retrograded starch

RS3 is heated, then it is gelatinized in hot water to retrograde it. Retrogradation causes the two polymer chains to reassociate, forming double helices that are fortified by hydrogen bonds, which increase the structure's resistance to hydrolysis by enzymes. For the manufacture of RS3, linear amylose molecules are preferred over amylopectin because they retrograde more quickly and generate stronger crystallites [30]. Heat and moisture treatment used in food processing usually destroy RS1 and RS2, although they occasionally create RS3. Because it generally withstands heat treatments and survives in nearly all types of food processing [31].

RS4: Chemically modified starch

It is a kind of starch that has undergone esterification, etherification, or cross-linking alterations through chemical means. Based on its water solubility and the scientific techniques used for the investigations, RS4 is further divided into subgroups. By producing steric obstacles at the locations of enzyme action, biochemical processes impede the digestion of starch. For instance, when starch is modified by octenyl succinic anhydride, hydrophobic octenyl succinate groups are added to the starch molecules, preventing amylolytic enzymes from binding to the starch [32]. Another efficient method for producing RS4 is cross-linking starch [33].

RS5: Maltodextrin with a resistant lipid structure and amylose

RS5 consists of two distinct parts. The first part consists of amylose-lipid complexes (ALC), which are created when lipids and amylose combine to form a single helical structure [34]. In order to create resistant maltodextrin, native starch must first undergo pyroconversion and then enzymatic hydrolysis. Non-sweet, dietary fiber, molecules with a minimal molecular weight with native α (1-4) and α (1-6) bonds in addition to β (1-2) and β (1-3) bonds and levoglucosan have characteristics like resistant maltodextrins [35]. Most reports refer to RS5 as complexes of amylose as well as lipid [1].

Factors affecting starch digestion

Starch digestibility

Previously, starchy foods were frequently restricted for those who are overweight and diabetic since it was assumed that all carbohydrates in food were fully digested and absorbed. However, further study has shown that different types of starches break-down at different speeds or could even remain undigested in the small intestines of humans. Rapidly digested starch is not suggested for people with diabetes or obesity because it significantly raises postprandial blood glucose levels. However, due to their capacity to be fermented by the colonic microbiota and their function in the production of SCFAs, SDS and RS have been linked to several health benefits, including satiety, low glycemic and insulinemic responses, and a potential prebiotic effect. Physical, chemical, and enzymatic processes can be used to create SDS and RS with distinct structures, which enables the production of both molecules with beneficial health effects. The release of glucose is caused by two processes: SDS hydrolysis in the small intestinal lumen and the impact of RS fermentation on the differing rates of growth of various bacterial groups in the human colon (Figure 2) [36, 37]. Apart from this, the rate at which starch is digested can be influenced by different factors that includes plant genotype, storage duration, food processing techniques, milling, frying, processing under high pressure, autoclaving, radiation, extrusion, and storage conditions.

Table 1: Characteristics of RDS and SDS.

Parameters	RDS	SDS	RS (Type 1-4)
Timeline and location of *in vitro* digestion	The mouth and small intestine in 20 min	Small intestine, 20–120 min	Effect in the colon, not the small intestine, after more than 120 min
Examples	Freshly prepared meals	Native legumes, millet, and waxy maize starch	Raw potato, stale bread
Amount (g/100 g dry matter)	Boiled hot potato: 65	Stew millet: 28	Raw potato starch: 75
Primary physiological characteristic	Rapid energy source	A slow, consistent energy source that maintains blood glucose levels	Effects on gut health, such as prebiotics and butyrate fermentation that may have anti-cancer qualities
Structure	Typically, amorphous	Crystalline/Amorphous	Various types, primarily crystalline

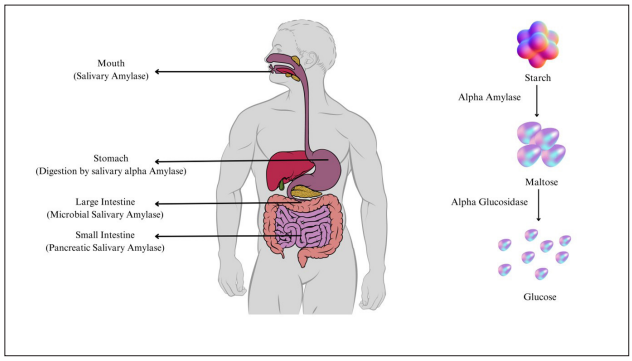

Figure 2: Enzymes responsible for starch hydrolysis in human digestive [47].

Inaccessibility of starch

The degree to which starch is digested can be significantly reduced if foods that are high in starch are not adequately crushed. The digestibility of a meal is influenced by various factors, including the types of food consumed, the structural rigidity of the food, and the presence of other matrices surrounding the starch granules. Food created from barley flakes has a starch digestibility of 83.5%, which is lower than food made from milled barley, that has a digestion of 99.1%. Due to improper chewing and the associated huge particle sizes, the ability to digest starch of whole canned beans is likewise exceptionally low, at about 64.1% [38]. This form of RS (RS1) is used in many common meals because of its relative stability in most cooking processes. Therefore, the processes such as fine grinding, which can reduce the amount of RS1, will be lessened by processes including milling, which can disrupt the structure of the plant tissue or cell [1].

Amylose/amylopectin ratio

The digestion of starch is reduced by its high amylose concentration [39]. Interactions between amylose and amylopectin limit the presence of enzymes and bloating of starch that can hydrolyze starch molecules. Additionally, very long chains of high-amylose maize starches with double helical arrangements that are precisely organized can generate B-type crystallinity.

Hylon VII (high-amylose genetic modification corn starches) contained more RS than Hylon V, which may be due to Hylon VII's higher amount of amylose. According to a few research studies, using high-amylose maize starches, the amount of amylopectin in maize ae-mutant starch is inversely linked with the RS content, showing that amylopectin has little to no impact on the synthesis of RS in the maize ae-mutant starches [40].

Retrogradation of amylose

The starch granules are damaged during the gelatinization process, which includes boiling in excessive amount of water. Retrogradation is the process whereby molecules of starch reassociate and form densely enclosed structures because of cooling, which is maintained by hydrogen bonds. It is true that RS3, also known as retrograded amylose, is exceedingly challenging to digest. Starch with high amylose is a rich source of RS2, but warming and chilling operations also produce large amounts of retrograded starch or RS3 [41]. The presence of amylopectin inhibits the retrogradation of amylose. However, if amylopectin is degenerated by an enzyme such as pullulanase, there may be an increase in the formation of retrograded amylose. The yield of RS3 is influenced by the extent of amylose polymerization [42]. It is well recognized that the formation of double helices is more prominent within the glucose unit range of 10 to 100 [1].

Lipids' impact on the absorption of starch

Some studies suggest that amylose can form a single helical complex with lipids like free fatty acids, monoglycerides, phospholipids, and long-chain alcohols [43]. The type I or type II of the lipid-amylose complex is determined by the temperature at which the crystalline components separate. In contrast to type II, which typically disintegrates between 105 and 125 ˚C, type I typically does not. Contrary to type II complexes, which are made up of discontinuous crystalline or semicrystalline structures, type I complexes have a more organized structure and lack in any clearly defined crystalline regions. Type II b is a subtype of type II. The most stable form of the ALC, RS5 is type IIb, and there are only minor differences between them in terms of how perfectly crystallized or ordered the domains are [44]. Typically, the temperature at which an ALC dissociates increases as fatty acid chains lengthen and the number of double bonds decreases. Trans-double-bonded fatty acids create ALC at a greater dissociation temperature than cis-double-bonded fatty acids among unsaturated fatty acids. When amorphous type I ALC is heated above a certain temperature, it changes into a different structure called lamellar crystallites (type II) [1]. These crystallites are more stable when heated (they can withstand temperatures above 100 ˚C) and have a different X-ray diffraction (XRD) pattern [45]. To stop amylose from being hydrolyzed by enzymes, a single helix form. The ALC also limits the development of starch granules, which further lessens the starch molecules' susceptibility to amylolysis [1].

According to studies on wheat, endogenous lipids have an impact on starch, and defatting starch samples results in a drop in RS concentration. The production of RS was greatly reduced when defatted wheat or amylo-maize starch was combined with SDS [46]. However, when RS is made by combining lipids and starch, the yields of RS5 from complexed lipids are lower than those of retrograded RS3, and the complex formation of amylose with lipids has a detrimental effect on amylose recrystallization, which is essential in the production of RS [1].

Extraction of RS Generated from Food Waste

It is essential to turn agro-industrial waste, which is widely available and inexpensive, into products with value addition. These approaches offer advantages in terms of both environmental sustainability and economic viability, particularly for emerging countries. For instance, by-products of different food commodities like banana, potato, jackfruit, black longan, rice bran, etc., used to extract the resistance starch (Figure 3 and table 2). Recent studies demonstrated that starch,

Table 2: Extraction of RS from food industry waste.

S. No.	Type of waste	RS content present (approx. %)	Method of extraction	Ref.
1	Banana peel	60.6	Ultrasound technique	[49]
2	Potato peel	45 (R3)	Debranching by PulM treatment	[48]
3	Jackfruit seed	30 (R2)	Chemical treatments	[54]
4	Rice bran	R3	Ultrasonication	[55]
5	Banana pseudo-stem flour	12.81	Conventional technique	[56]
6	Black longan seeds	49.9 – 59.4	-	[57]

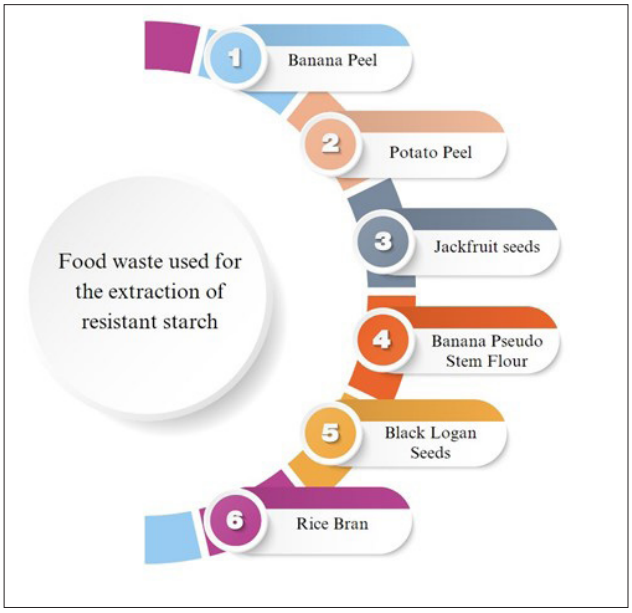

Figure 3: Waste valorization through extraction from various food industry waste.

which later changed into RS3 molecules, could be produced in huge quantities from potato industrial waste biomass. The digestible component of the starch was also converted during this process into malt oligosaccharides, a valuable by-product. The conversion of biomass from potato peels into biomolecules with prebiotic activity may be a promising solution to deal with the huge amounts of agro-industrial waste produced, especially considering the growing need for functional components (e.g., resistance starch) made from natural sources. Along with this bioprocess, other high-value compounds from potato peel biomass, such as polyphenols and glycoalkaloids, can be recovered [48].

Banana peel

The yield and extraction efficiency of RS can be improved using sustainable practices like ultrasound. The outcomes showed that an effective approach for the valorization of banana peels may be produced by combining ultrasonic treatment with enzymatic extraction of RS. An efficient sustainable method with wide industrial use is the ultrasound extraction of RS from peels of green bananas. The optimal conditions of treatment were 30:1 liquid-to-solid ratio, a temperature of 35 ˚C for 6 min of duration and a yield of 60.6% RS was obtained. Bananas peels are a great source of RS since they have a high concentration of it, making them perfect for use as functional foods [49].

Potato peel

In the potato industry, food processing operations result in significant amounts of potato peel production. Between 15% and 40% of the biomass of potatoes is thought to be produced as peel using different peeling techniques in various industrial processes [50]. Antioxidants and antibacterial substances, such as bioactive phenolics and glycoalkaloids are abundant in potato peel [51]. The starch content of potato peel is high (approximately 25%), but the number of fermentable sugars is very low [52]. The caloric starch extracted from potato peel had a yield of around 45% RS3. By using type 1 pullulanase (PulM) which was discovered from a thermal spring metagenome, the starch in peel was exposed to debranching, and then RS3 was prepared via a retrogradation. It was attempted to convert the potato starch that couldn't be turned into RS into malto-oligosaccharides. From biomass made of potato peels, starch was recovered. To extract the starch, the potato peel was scraped. About 40%, 3.7 g of starch might be produced from one kilogram of peel of potato. The environment as well as the internal and external qualities of the potato may influence starch yield [53]. It was shown that more washing steps were required to get pure starch from potato pulp than from peel starch [48].

Jackfruit seed

Jackfruit seeds (*Artocarpus heterophyllus* Lam.) from canned food industry considers to be biowaste, have been linked to numerous research studies as an emerging form of starch for commercial use. Because it includes 30% weight-for-weight of the material, native seed starch of jackfruit has the capability to develop as a novel commercial origin of type II RS (RS2) for use in culinary and medical applications. Increases in RS quantity was typically seen when temperatures between 80 ˚C and 110 ˚C were combined with moisture levels of 20 to 25%. In samples exposed to high moisture/temperature, moderate alterations in scanning electron microscopic and XRD patterns were seen. As the moisture content was raised in the samples, differential scanning calorimetry studies revealed rises in the gelatinization temperature. Although there was little variation in amylose contents which was a correlated with RS content. Less swelling was present in samples with greater RS, nonetheless, the solubility was considerably unaffected.

Commercial-RS, which is now required by the food and

pharmaceutical industries, may be made using this supply of starch and the heat-moisture treatment technique [54].

Rice bran

Rice bran is a solid waste product that is left over when rice is milled. It can be used to extract the RS using ultrasound technology. For instance, a study on sonicated rice bran at 850 kHz for different times (15-35 min) and temperatures (30-70 ˚C) at 50% ultrasound intensity that affect the production of RS type 3 was conducted. After sonication, each sample was dried for 24 h at 50 ˚C and its starch content was separated and quantified. It reported that the ultrasound treatment changed the chemical composition of the RS and decreased its crystallinity from 23.85% to between 18.37% and 4.43%. It also improved the heat and mechanical stability of the RS pastes, suggested a higher tendency for the granules to retrograde. The RS40C sample, which was sonicated at 40 ˚C, produced the thickest paste. This demonstrates a strong interaction between the soluble polysaccharide molecules and the colloidal particles. This discovery may explain why this starch has a higher concentration and is more resistant to digestive enzymes. The ultrasound treatment also significantly improved ($p < 0.05$) the swelling power, solubility, gelation characteristics, and oil and water absorption capacities of the RS [55].

Banana pseudo-stem flour

Total starch and RS concentrations are high in both the banana pulp and the unpeeled banana. Furthermore, it has been claimed that the banana pseudo-stem contains RS in addition to high-quality starch. The banana pseudo-stem is still regarded in the food sector as agricultural waste even though it is used to make sanitary products. In addition, it was found that banana pseudo-stem flour contains 28.6% total starch, of which 12.81% is RS and the remainder 15.45% is digestible starch. It concluded that banana pseudo-stem flour could be added to food products to increase dietary consumption of RS [56].

Black longan seeds

The longan is a well-liked tropical fruit that is grown in Asia and is also known by its botanical name, *Dimocarpus longan* Lour. Longan fruits are grown in such large quantities that numerous goods can be prepared from them. Black longans, known for their medicinal properties, have been traditionally used in medicine, primarily utilizing the dried, dark-brown flesh. However, the starch-rich seeds of black longans are often overlooked and discarded [57]. A possible new commercial source of starch has been identified in the longan seed due to its abundance as an agricultural crop and the presence of starch among other natural components in longan seeds. In a study, longan seeds showed the high starch content (59.4% weight-for-weight) and amylose content (25.1%) [58]. Individually, the seeds had starch contents in the range of 49.5%–59.4% (w/w) and amylose contents of 26.6%–30.1% [59].

Four times more RS was discovered in black longan seed samples than in fresh longan seeds. Researchers found that starch inclusion complexes, which are formed when starch interacts with other components in seeds, may increase RS content. This is supported by the additional peaks in XRD patterns, changes in transition parameters in differential scanning calorimetry scans, and a decrease in the paste viscosity of barley leaf gum suspensions. Complexes, which were produced by interactions with other elements in the seeds during the temperature-time-controlled incubation, were the key to developing black longan seeds with a high RS concentration. The ideal incubation period for dried longan fruits was 20 to 30 days at 60 to 70 ˚C [57].

RS's Effects on Human Health

Gut health

RS is a type of starch that is not digested by the small intestine. It is fermented by bacteria in the large intestine, which produces SCFAs. SCFAs have several health benefits, including boosting butyrate levels, which is beneficial for gut health. Nevertheless, the response to RS supplementation varies among individuals, suggesting the significant influence of individual microbiome variations on RS digestion. More research is needed to understand the relationship between RS consumption and butyrate generation, as well as the other health benefits of RS (Figure 4) [13].

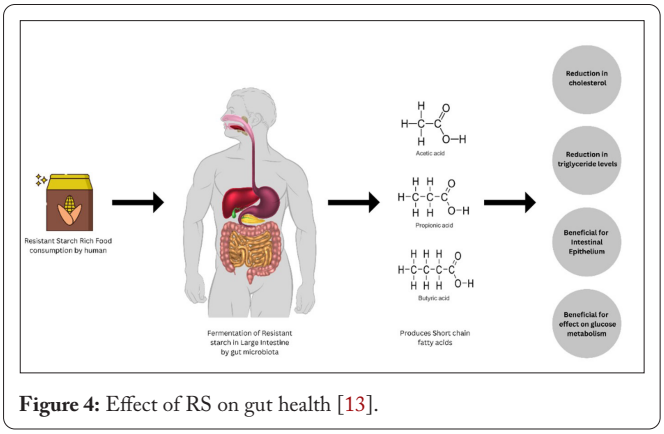

Figure 4: Effect of RS on gut health [13].

Type 2 diabetes

In chronically fed adults, RS reduces the insulin resistance by altering the metabolism of both adipose tissue and muscle. Postprandial glycemia is decreased when available RS replaces carbohydrates in a meal. Resistance to insulin in hepatic and peripheral (adipose and muscle) tissues is one of the long-term benefits of RS for the prevention of type 2 diabetes. When assessing insulin sensitivity in people using the hyperinsulinemia-euglycemic clamp technique, the gold standard, RS consumption increases insulin sensitivity. Humans decreased adipose tissue lipolysis, higher skeletal muscle glucose uptake, decreased muscle triglyceride storage, increased muscle, and adipose SCFAs uptake, and improved meal fat oxidation are all signs of a metabolic shift [60].

Cholesterol

A considerable reduction in blood cholesterol and low-density lipoprotein levels and cholesterol concentrations is linked to adding RS to the diet (Figure 5). RS impacts the body's lipid metabolism, and it may depend on the production of SCFAs, related microbial changes, and large intestine RS fermentation [13]. Colon epithelial cells, which use butyrate

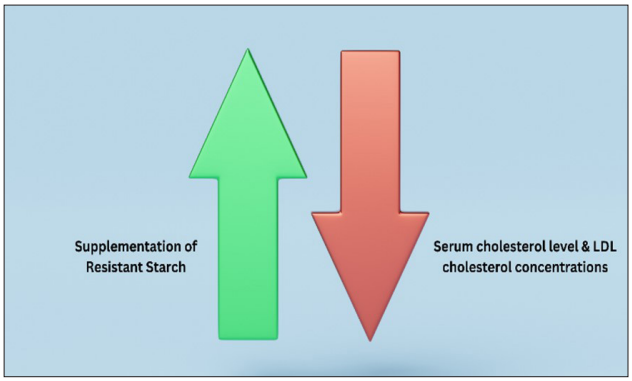

Figure 5: Relationship between cholesterol and RS supplementations [13].

as their main energy source, liver cells, which metabolize the majority (50–70%) of the acetic acid and the remaining propionate and butyrate, and muscles, which oxidize the remaining acetate to produce energy, are just a few of the cells throughout the body that use SCFAs [61]. Propionic acid and acetic acid control the metabolism of lipids and cholesterol [62, 63]. Acetic acid is also a crucial precursor in the synthesis of cholesterol [64].

Aiming to avert colon cancer

In the colon, RS is broken down by probiotic bacteria, causing the synthesis of gases like H_2, CO_2, and CH_4 as well as SCFAs including lactate, butyrate, acetate, and propionate [65]. They are made up primarily of butyrate, which colonocytes primarily use, and other SCFA, which pass past the intestinal wall and are subsequently utilized by the host organism after being delivered to the liver via portal circulation [66]. High butyrate yields have been seen when RS is fermented *in vitro* using human faeces as the inoculum [67]. Considering butyrate as a primary energy source for large intestinal epithelial cells, it prevents the malignant transformation of *in vitro* intestinal epithelial cells [27].

Implications for body weight

RS may aid in weight management and so lessen the risk of being overweight and obese. Studies on humans and animals indicate that RS may be an effective weight-controlling food. This advantageous result could be based on a variety of mechanisms. The inability to digest RS and get digested in the small intestine, therefore substituting it for some of the meal reduces the calorific density of the food [68].

By raising overall energy expenditure and fat oxidation, the SCFAs created during fermentation may also contribute to this pathway [69]. Finally, due in part to a rise in the production of satiety signals like peptide YY and glucagon-like peptide-1, RS may influence calorific intake reduction and appetite suppression [70].

Application of RS in Food Products

RS has gained prominence as an important food ingredient in recent years. This is stated by the fact that it functions as a dietary fiber and has advantageous qualities such as its small size, neutral flavor, and a low water holding capacity. Thus, adding RS to beverages, pasta, and baked items improves their textural properties and provides health advantages [71, 72].

Experts in nutrition and culinary science are very interested in RS for two main reasons. The first is the known for its physicochemical properties which includes gel formation, swelling, water holding capacity and the second is the distinctive functional qualities that lead to the creation of high-quality goods that would not otherwise be possible with conventionally non-soluble fibers [73, 74].

Compared to processed food, food containing RS is typically thicker, less palatable, and grosser. Compared to conventional fibers like bran and gum, the use of RS in food ingredients typically improves the sensory qualities rather than changing the flavor or texture [75]. Good physicochemical qualities of RS, such as swelling, raising viscosity, gel formation, and water-binding ability, are very beneficial for a range of food products [75]. Due to its small water-holding capacity, it retains water better and produces a higher-quality finished product [76]. Compared to traditional insoluble fiber, RS exhibits improved color and taste, increased softness, expansion, and mouthfeel in some goods. Customers are more likely to eat more of these goods as a result, increasing their consumption of dietary fiber [77]. Gelatinization and retrogradation will have an impact on the quality of RS during processing [78]. The amount of RS in the meal will rise due to technical modifications in processing circumstances, such as temperature, pH, time, cooling cycles, freezing, and drying [79]. Thin boiling starches, or RS, are a type of starch that has undergone hydrolysis. This starch has the benefit of having a high concentration and the capacity to solidify into a paste with a low viscosity. RS4 starch has been helpful in formulations for pulpy texture, smoothness, fluidity, low-pH storage, and high-temperature storage [80]. A softer texture was produced by adding more RS to muffins, according to a study that examined the instrumental characteristics of the baked goods. Samples were less elastic, rigid, and cohesive and revealed a more tender structure; these changes were more noticeable at higher RS concentrations [81].

Several key contributions have been identified in understanding the impact of RS on bread qualities. Notably, the use of banana starch has been associated with highly gelatinized bakery products characterized by a high structure and elevated SDS content [82]. Faba bean starch has demonstrated improvements in the nutritional indices of composite bread, with a notably low anticipated glycaemic index and the highest scores in free amino acids, protein chemistry, and biological value [83]. Pea starch, with higher SDS and RS fractions (23.9% SDS and 30.2% RS), exhibited satisfactory palatability compared to a white bread reference [84]. Corn starch, as more RS preparation was incorporated, led to a decrease in crumb hardness [85]. The inclusion of phosphorylated cross-linked RS4 resistant wheat starch showed no effect on dough extensibility or strength, and the bread volume remained unaffected by RS4 additions up to 20%, while providing sufficient fiber for a "good source of fiber" claim [86]. Additionally, the complexation of palmitic acid with starch significantly reduced insulin and plasma-glucose responses after meals in human participants [87, 88].

Future Trends

RS has received a lot of attention in recent years because of its unique features and health advantages. There is a rising interest in generating new and creative RS-rich food products. Researchers are further investigating new ways to extract RS from agricultural waste items such pseudo-stem banana, potato, jackfruit, and black longan seeds. This could help to reduce food waste and provide a sustainable source of RS. Additionally provides insightful information for researchers studying the sustainable use of agricultural waste and the development of novel foods with enhanced nutritional profiles, as well as business professionals, educators, and food scientists. Additionally, the creation of novel and inventive food items like pasta, bread, and snacks that might be made using components rich in RS. It might result in updated guidelines for RS consumption and the formation of focused RS-based interventions for specific medical issues.

Conclusion

RS can be used as a functional component in food items to boost nutritional value and health benefits. It can be used to improve dietary fiber content and promote digestive health in bread items, snacks, beverages, and dairy products. Apart from this, in the large intestine, microorganisms break down RS to create SCFAs that help to control blood sugar levels and reduced calorie intake, making it beneficial for weight management and controlling appetite. Therefore, it is important to recover value added compounds from biomass or plentiful agro-industrial wastes and utilization in the food applications. RS can be extracted from enormous sums of food industry waste such as potato peel, banana peel, jackfruit seeds, black longan seeds, banana pseudo-stem flour, rice bran, etc., using various methods like debranching by PulM treatments, chemical methods, and ultrasonication techniques. The extracted RS from food waste can be used in food (e.g., nutritional supplements), pharmaceutical (e.g., drug delivery systems, controlled release formulations, and encapsulation of bioactive compounds), and related industries.

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Conflict of Interest

None.

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