ROLE OF RESISTANT STARCH FOR HEALTHY AND FOOD APPLICATION

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Abstract

Resistant starch (RS) is an insoluble fibre stable under various food processing conditions, including high temperatures and pH levels. RS has many beneficial effects on human health, such as positive effects on digestive tract activity, microflora, blood cholesterol levels, glycemic index, diabetes control, increased satiety and effective weight loss. Recently, RS has emerged as a comprehensive health improvement solution. This report helps to clarify the basis of the effects and applications of this type of starch.

Keywords: applications, health benefits, resistant starch

1. Introduction

Resistant starch was first studied in the 1980s by Englyst et al. (1982), a type of starch that is not digested in the small intestine for 120 minutes. When it reaches the large intestine, this starch is a source of nutrition for beneficial intestinal bacteria such as Ruminococcus, Faecalibacterium and Bifidobacterium. This soluble fibre, RS, is not digested in the small intestine and digested in the colon. Here, short-chain fatty acids such as butyrate, propionate, and acetate are produced, which help maintain intestinal health and the immune system, metabolism, and brain health. Additionally, RS increases faecal bulk and lowers pH, improving digestive function and protecting the intestinal lining (Perera et al., 2010; Raigond et al., 2015).

RS is particularly valuable in the prevention and management of chronic conditions such as obesity and type 2 diabetes. RS improves metabolic health by lowering blood glucose, increasing insulin sensitivity, and reducing inflammatory markers. However, the efficacy of RS varies depending on individual factors, including dietary habits, health status, gut microbiota composition, and the type and dose of resistant starch used. (Bojarczuk et al., 2022; Raigond et al., 2015).

In Vietnam, research on resistant starch has gained momentum in recent years, focusing on both the identification of natural sources and the development of processing techniques to enhance RS content for health benefits. One notable study investigated the diversity of RS content in 75 Vietnamese rice accessions from various ecosystems. The findings revealed significant variation, with Indica subgroups and medium- to short-grain rice exhibiting higher RS levels compared to Japonica subgroups and long-grain varieties. This suggests the potential for breeding rice varieties with enhanced RS content to support dietary interventions for metabolic health. (To et al., 2023).

Further genetic analysis through genome-wide association studies (GWAS) on 146 Vietnamese rice varieties identified seven quantitative trait loci (QTLS) associated with RS content. Key candidate genes, including Osbzip12, were found to influence starch biosynthesis pathways, offering insights for future rice breeding programs aimed at increasing RS levels (To et al., 2025). Beyond rice, Vietnamese researchers have explored other indigenous crops as RS sources. For instance, mung bean starch underwent enzymatic and microwave-assisted treatments to enhance RS content, resulting in a product with improved functional properties suitable for food processing applications. (Nguyễn, 2022).

Similarly, jackfruit seed starch was subjected to heat-moisture treatment, effectively increasing its RS content from 25.97% to 52.26%. This modified starch demonstrated potential as a prebiotic ingredient, particularly beneficial for individuals with diabetes due to its ability to modulate glycemic response (Vu et al., 2024). In the realm of product development, a Vietnamese company successfully produced a mung bean-based powder containing 7.01g of RS per 100g, a concentration surpassing typical levels found in similar products globally. This achievement underscores the feasibility of creating high-RS functional foods within Vietnam. Collectively, these studies highlight Vietnam's active engagement in RS research, encompassing agricultural, biochemical, and industrial perspectives. The integration of traditional crops and innovative processing techniques positions Vietnam to contribute significantly to the global understanding and utilisation of resistant starch for health promotion.

RS represents a promising functional food component with significant potential to improve gut and metabolic health. Continued research and innovation in RS applications could play a vital role in preventing and managing prevalent chronic diseases.

2. Definition and types of resistant starch

In our diet, most carbohydrates are starches. Starch is a long chain of glucose found in potatoes, cereals, and various foods. Among these starches, a special type of starch does not break down during digestion in the small intestine. Instead of being broken down like regular starches, it “resists” digestion and goes straight to the large intestine. Simply put, digestive enzymes do not change this type of starch – hence the name “resistant starch.” Its function is similar to soluble fibre; this unique characteristic of RS brings many benefits to the intestines, such as improving digestive function, helping to stay full longer, and controlling blood sugar levels, which in turn leads to other physiological benefits. RS is classified into five distinct types based on its origin, structure, and resistance to enzymatic digestion. (Bojarczuk et al., 2022; Chen et al., 2024).

RS1 (Physically Inaccessible Starch)**:** RS1 is physically protected by food matrices such as the intact cell walls of grains, seeds, or tubers. This physical inaccessibility prevents digestive enzymes from breaking down the starch. Familiar sources include whole grains and seeds. RS1 remains resistant even during most cooking processes.

RS2 (Granular or Native Starch): RS2 comprises uncooked starch granules with a high degree of crystallinity, making them resistant to enzymatic hydrolysis. RS2 is found in starchy foods such as fresh potatoes and green bananas. The starches of these two foods often have a reasonably high amylose content. The compact molecular arrangement of RS2 provides thermal stability during cooking and increases its resistance to digestion.

RS3 (Retrograded Starch): RS3 forms when gelatinised starch is cooled, allowing the starch molecules to recrystallise in a process known as retrogradation. This type is found in cooked and cooled foods such as rice, potatoes, and cereals. RS3 has high thermal stability, making it suitable for various food applications.

RS4 (Chemically Modified Starch): RS4 is produced through chemical modifications such as esterification, etherification, or cross-linking. These chemical treatments alter the starch structure, making it resistant to enzymatic digestion. RS4 is commonly used in processed foods to improve texture, reduce caloric value, and increase dietary fibre content.

RS5 (Amylose-Lipid Complex Starch): RS5 is formed when amylose interacts with lipids, creating complexes that are resistant to digestion. These complexes are particularly effective in enhancing the resistant properties of the starch. RS5 is being increasingly explored for its functional properties in novel food products.

The classification of resistant starch highlights its versatility and functional applications in food science. Each type of RS contributes to dietary fibre intake and offers distinct health benefits, making it an essential component of functional and health-promoting foods.

3. Food sources of resistant starches

Resistant starch is a form of starch found in many different foods and can also be produced through various modification methods. Unprocessed sources of RS include cereals, legumes, tubers, and unripe fruits. Unripe bananas, raw potato starch, and certain cereals are among the richest natural sources of RS. Some contain 70% to 80% RS in their total starch content. Whole grains and seeds contain RS1 due to their intact cell walls, which physically restrict access to starch. Similarly, legumes like lentils and chickpeas are rich in RS because of their high amylose content and compact crystalline structure, which resist enzymatic digestion.

RS2 is commonly found in raw starch granules in unripe bananas, raw potatoes, and high-amylose maize starch. These foods retain their resistance due to their dense crystalline structures that protect the starch from enzymatic breakdown. Cooked and cooled starchy foods, such as rice, pasta, and potatoes, are notable sources of RS3. During the cooling process, gelatinized starch molecules realign to form retrograded starch, which resists digestion in the small intestine. Additionally, processed foods can increase the amount of RS4, a chemically modified starch designed to increase its resistance to digestion. Foods include snacks, baked goods, and ready-to-eat meals, where RS4 provides both functional and health benefits.

These natural and processed sources of RS significantly contribute to improved dietary fibre intake and overall health (Ashwar et al., 2016).

4. Health effects of resistant starch

Several physiological effects of resistant starch have been demonstrated that are beneficial to health.

4.1. Colon cancer prevention

Resistant starch is fermented in the colon to produce fatty acids such as acetate, propionate, butyrate, lactate and gases such as H_2, CO_2 and CH_4. Recent studies have shown that butyrate inhibits the malignant transformation of intestinal epithelial cells (Bird et al., 2000; Raman et al., 2016). This makes resistant starch particularly valuable in colon cancer prevention. Experiments in mice have shown that RS increases soluble fibre increases stool volume, increases SCFA production, reduces stool pH, and reduces the incidence of obesity and metabolic disorders (Grubben et al., 2001). Some reports (Hamer, 2009; Hamer et al., 2009; Khan, 2000) have also shown that butyrate increases the resistance of colon cells to dietary toxins and increases glutathione levels in the colon mucosa. Significant reductions in faecal bile acids were observed in healthy adults after consuming foods rich in resistant starch for four weeks. Since healthy individuals excrete fewer bile acids and steroids in their stool than those with colon cancer, this highlights the protective role of resistant starch in the disease.

4.2. Hypoglycemic effects

Resistant starch reduces the glycemic response mainly due to its indigestibility, not specific physiological effects (Liu et al., 2022). Glycemic index (GI) values range from 10 for legume starches to nearly 100 for rice, potatoes, or certain cereals. Taro starch has a GI of 60.6 ± 0.5, while resistant taro starch has a lower GI of 51.9 ± 0.9, a statistically significant reduction. Studies show that RS-enriched foods slow digestion, lower GI, and provide controlled glucose release, benefiting diabetes management. Consumption of RS3, for example, reduces postprandial glucose and insulin levels compared to other carbohydrates (Saxby, 2020). RS must constitute at least 14% of dietary starch to effectively control glycemic and insulin responses. RS digestion occurs over 5-7 hours, prolonging satiety and reducing post-meal glucose spikes. Some studies also indicate that chemically modified RS, such as acetylated potato starch, effectively lowers blood glucose. Additionally, RS-enriched diets have shown reduced insulinotropic mRNA levels and slower gastric emptying, making RS particularly beneficial for managing type 2 diabetes (Alzaabi, 2023).

4.3. Resistant starch as a prebiotic

Prebiotics are non-digestible food substances that enhance the host's health by promoting beneficial probiotics' growth or activity in the digestive system (Quigley, 2019). Natural prebiotics, such as inulin and oligofructose, are commonly found in foods like onions, garlic, leeks, chicory, Jerusalem artichokes, bananas, and wheat (Gupta & Chaturvedi, 2020). The prebiotic properties of resistant starch have gained attention in recent studies. RS promotes the growth of beneficial bacteria such as Bifidobacteria and Lactobacillus while enhancing their survival in acidic or bile conditions (Fuentes-Zaragoza et al., 2011).

Since RS largely escapes digestion in the small intestine, it serves as a substrate for probiotic growth in the colon. RS-rich diets significantly increase *Lactobacilli, Bifidobacteria*, and *Streptococci* populations while reducing harmful Enterobacteria. Experimental studies in pigs and humans show that RS positively influences short-chain fatty acid (SCFA) profiles, indicating favourable interactions between probiotics and RS. High-amylose maize (HAM RS2) starch has also demonstrated its ability to support probiotic survival and boost faecal Bifidobacterium counts, showcasing its prebiotic potential (Li et al., 2021; Markowiak-Kopeć & Śliżewska, 2020).

4.4. Cholesterol-lowering effects of resistant starch

The cholesterol-lowering properties of resistant starch have been widely documented in animal studies. Significant reductions in total lipids, total cholesterol, low-density lipoprotein (LDL), very-low-density lipoprotein (VLDL), intermediate-density lipoprotein (IDL), high-density lipoprotein (HDL), triglycerides, and triglyceride-rich lipoproteins were observed in rats fed RS-rich diets. Additionally, an increase in cecum size, elevated short-chain fatty acid (SCFA) levels, improved SCFA absorption, and lowered plasma cholesterol and triacylglycerol concentrations were noted in these studies (Han et al., 2003, 2004).

Research on RS3's effects on cholesterol metabolism in humans and hypercholesterolemic mice revealed no impact on normal cholesterol metabolism (Chen et al., 2023). However, in hypercholesterolemic mice, RS significantly reduced free and total plasma cholesterol levels (Jiang et al., 2015). Similarly, RS from adzuki bean starch (AS) and tebou bean starch (TS) demonstrated cholesterol-lowering effects by increasing hepatic SR-B1 receptor levels and mRNA expression of cholesterol 7α-hydroxylase (Ashwar et al., 2016). These starches also reduced serum cholesterol, boosted SCFA production in the cecum, and enhanced neutral sterol excretion (Bede & Zaixiang, 2021).

Comparisons between RS and cellulose in hamsters show a greater serum cholesterol reduction with RS (16.2%) than with cellulose (13.5%) (Cross, 1993). While some human studies corroborate RS's cholesterol-lowering effects, others report no significant impact. Thus, further research is necessary to clarify RS's role in human cholesterol metabolism (Adorni et al., 2021; Baratta et al., 2023).

4.5. Inhibition of fat accumulation

Resistant starch has significant potential in regulating lipid oxidation (Si et al., 2017). Replacing 5.4% of total dietary carbohydrates with RS significantly enhanced postprandial lipid oxidation, highlighting the role of RS in reducing fat accumulation (Bojarczuk et al., 2022; Raza et al., 2023). Diets rich in RS have been shown to increase fat mobilisation and utilisation due to reduced insulin secretion (Paniagua, 2016; Robertson et al., 2005).

High-amylose maize RS2 (HAM RS2) reduces body fat and increases lean muscle mass (Maziarz, 2014). Specifically, RS consumption leads to noticeable decreases in epididymal and retroperitoneal fat deposits (Charrier, 2011). Short-chain fatty acids (SCFAs) like butyric, acetic, and propionic acids, produced during RS fermentation, also play a role in inhibiting lipolysis in adipose tissue (Xiong et al., 2022). Additionally, acetate has been found to suppress glycogen breakdown in the liver, conserving carbohydrates and promoting increased fat oxidation (González Hernández et al., 2019). This makes RS a promising agent for managing body fat distribution.

4.6. Reduction in gallstone formation

Digestible starch contributes to gallstone formation by increasing insulin secretion and stimulating cholesterol synthesis (Adam-Perrot et al., 2006). In contrast, resistant starch reduces the risk of gallstone formation. Gallstones are more prevalent in North India, where refined wheat flour is consumed instead of whole grains, as in South India (Niharika, 2019).

Highly digestible starch is common in rice and wheat due to milling processes that enhance starch digestibility (Šárka et al., 2024). Populations in countries like India and China consume 2-4 times more RS than those in the U.S., Europe, and Australia (Sharma et al., 2008). This dietary difference is reflected in the higher prevalence of gallstones in countries with lower RS intake. RS offers a promising dietary approach to mitigating gallstone risks (Swinburn et al., 2004).

4.7. Mineral absorption

Resistant starch is believed to enhance mineral absorption in the gut (Lopez et al., 2000). Research on rats has demonstrated that a diet high in resistant starch enhances the absorption of minerals like calcium, magnesium, zinc, iron, and copper in the ileum (Lopez et al., 2000). However, in humans, resistant starch primarily improves calcium absorption, while the absorption of other minerals remains largely unaffected (Nugent, 2005). Another study comparing resistant starch with digestible starch found that resistant starch significantly boosts the absorption of calcium and iron, highlighting its benefits for mineral health (Niu et al., 2025).

4.8. Reduction in gallstone formation

A diet high in resistant starch has been shown to have laxative effects (Maki et al., 2009). Supplementing 25g/day of RS in healthy individuals increases daily stool output above normal levels while minimising gastrointestinal discomfort (Yang, 2019). In children with shigellosis, green bananas (a diet rich in RS) have demonstrated beneficial effects in disease management (Sarmin et al., 2021). RS also helps reduce stool volume, bowel frequency, and the presence of red blood cells in stool. Despite ciprofloxacin's negative impact on SCFA production in the colon, SCFA levels such as acetate, propionate, and butyrate were elevated by the fifth day of green banana consumption (Sharma et al., 2008; Shen et al., 2017).

The potential of RS to alleviate inflammatory bowel disease (IBD) symptoms, such as ulcerative colitis, has been explored (Caetano & Castelucci, 2022; Montroy et al., 2020). RS increases SCFA production and is vital for treating chronic, recurrent inflammation of the colon's mucosa and submucosa (Amansec, 2005). In chemically-induced colitis in rats, a diet high in RS (15.38g/100 g) for 21 days improved inflammation, normalised apoptosis, and enhanced colonic cell proliferation and SCFA utilization (Ashwar et al., 2016; Sharma et al., 2008). Additionally, RS diets have been found to promote gut bacteria associated with improved health. Short-chain fatty acids are essential in maintaining blood pressure regulation (Pakhomov & Baugh, 2021; Topping & Clifton, 2001).

5. Food applications of resistant starch

Resistant starch provides health benefits and improves the quality and functionality of foods. Its incorporation in the food industry is becoming increasingly popular, especially in developing healthy and functional foods. RS also contributes to reducing glycemic response and calorie content while improving product stability and functionality. RS is commonly used to improve the dietary fiber content of various foods, including bakery products, cereals, and snacks (Arribas et al., 2017; Dhingra et al., 2012; Lin, 2022; Redgwell & Fischer, 2005; Walsh et al., 2022). Its ability to withstand high-temperature cooking and processing ensures that it retains its functional properties even in thermally processed foods like bread, biscuits, and pasta. Furthermore, RS has been utilised in creating healthier bakery products by reducing the glycemic index without compromising taste or texture (Nugent, 2005; Sharma et al., 2008; Zhang & Bao, 2023).

In addition to traditional applications, RS is used to develop specialized products targeting specific health benefits. For example, RS4-enriched cookies and muffins have been shown to significantly reduce postprandial glycemia and insulin levels, supporting its role in managing diabetes and metabolic disorders. In the dairy industry, RS improves texture and mouthfeel in products like yoghurt and ice cream, enhancing consumer appeal. Similarly, in meat products, RS acts as a fat replacer, reducing fat content while maintaining desirable texture. RS also has applications in gluten-free and speciality foods, where it improves the texture and nutritional profile of gluten-free baked goods (Cervini et al., 2021; Šmídová & Rysová, 2022; Witczak et al., 2016). This makes RS particularly beneficial for individuals with celiac disease or gluten sensitivity. Additionally, RS's compatibility with plant-based and low-FODMAP formulations expands its use in vegan, vegetarian, and gut-friendly products (Jo Stepaniak, 2020; Simons et al., 2024).

RS is utilized in functional food and beverage formulations due to its prebiotic properties, which support gut health by fostering beneficial microbial growth. This has spurred its use in health-focused products such as protein bars, meal replacement shakes, and fortified cereals. RS is also incorporated into functional foods designed to address specific health concerns like obesity, cardiovascular health, and glycemic control, highlighting its growing importance in personalised nutrition. (Bojarczuk et al., 2022; Lockyer & Nugent, 2017; Obayomi et al., 2024). The diverse applications of resistant starch in food manufacturing demonstrate its critical role in addressing modern dietary needs, enhancing product quality, and promoting health. The expanding body of research on RS and its innovative uses ensures its continued significance in food science and public health.

As the global focus on health and wellness continues to grow, RS represents a vital ingredient for future food innovation. By bridging the gap between nutrition and convenience, RS not only addresses modern dietary challenges but also opens avenues for the creation of functional foods that deliver health benefits alongside culinary satisfaction. Its role in shaping healthier eating habits is indisputable, making RS a cornerstone of both modern food science and public health strategies.

6. Conclusion

On the basis of the findings of this study, several recommendations could be made for Resistant starch is a groundbreaking ingredient in health science and food technology, thanks to its dual role as a dietary fibre and functional component. Its integration into various food products has significantly benefited consumers and manufacturers alike. RS provides extensive health advantages, including enhanced colonic health, better glycemic control, reduced cholesterol levels, and prebiotic effects that promote a healthy gut microbiome. These properties make it invaluable in managing chronic conditions like diabetes, obesity, and cardiovascular diseases. In addition to its health benefits, RS offers remarkable functional properties for food applications. It enriches the nutritional value of bakery, dairy, and meat products, improves texture, lowers caloric content, and extends shelf life. Furthermore, RS plays a key role in developing innovative gluten-free and low-glycemic index products, meeting the needs of consumers with specialised dietary preferences.

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