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Resistant starch in banana: influencing factors, functional properties and potential health effects

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Abstract

Resistant starch is known as a functional fibre, as it exhibits a similar effect of indigestibility in the gastrointestinal tract. Even so, resistant starch has its distinguished characteristics. This article focused on resistant starch that specifically found in banana, a well-known source of resistant starch type 2, RS2. The intrinsic and extrinsic factors that affect the level of resistant starch, as well as the functional properties and potential health benefits of resistant starch, are reviewed based on the findings of past research. Higher amylose level, lower stage of banana maturity, and desirable processing condition is associated with a higher level of resistant starch observed. Bland flavour, small particle size and white are some of the desirable functional properties of resistant starch. Lastly, resistant starch has been demonstrated to provide a satiety effect that aids in body weight management, improves constipation and glycemic control, other than lowers the risk of colon cancer.

1. Introduction

Resistant starch is growing in popularity for its functionality and nutritional effects that have been long recognised (Raigond *et al*., 2019; Haini *et al*., 2021; Haini *et al*., 2022). Resistant starch is defined as a starch fragment that resists the action of the digestive enzyme, α-amylase in the small intestine. As it escapes digestion and absorption in the intestine, it enters the colon and gets fermented by gut microbiota (Nugent, 2005; Birt *et al*., 2013). As resistant starch and dietary fibre showed similar behaviour of indigestibility in the gastrointestinal tract, resistant starch has been acknowledged as a functional fibre (Fuentes-Zaragoza *et al*., 2010; Charoen *et al*., 2020). Resistant starch is divided into four classes, namely RS1: physically inaccessible starch, RS2: ungelatinized, granular starch, RS3: retrograded starch and RS4: chemically modified starch (Sajilata *et al*., 2006). Some studies have mentioned amylose-lipid complexes as the fifth class of resistant starch, RS5 (Raigond *et al*., 2015; Detchewa *et al*., 2021). Resistant starch types 1 and 2 are native starches that are easily demolished by processing. However, it was reported that resistant starch type 2 can also be non-naturally generated by genetic engineering and selective breeding (Zaman and Sarbini, 2016). Further detail of resistant starch is shown in Table 1.

Resistant starch type 2 (RS2) is a type of starch that is present in granule form, protected from hydrolysis by digestive enzymes by the crystallinity and compact structure of the granules (Nugent, 2005; Sajilata *et al*., 2006). The granule structure of RS2 is shown in Figure 1. Green banana is known as one of the richest sources of naturally occurring RS2 (Raigond *et al*., 2019). However, green bananas are unlikely to be directly consumed in raw form due to their hardness and

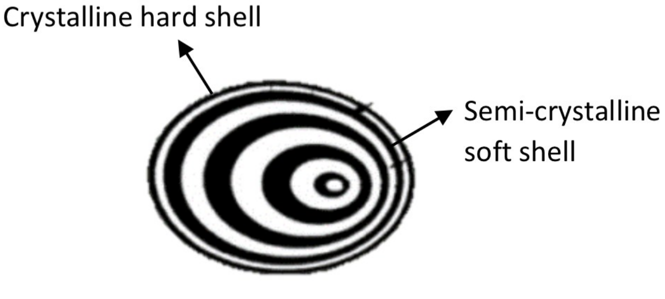

Figure 1. The compact structure of RS2 granule (Tang and Wang, 2006).

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Table 1. Brief summary of resistant starch.

Classes	Description	Food Source	Reference
RS1	Physically inaccessible starch, protected by an intact cell wall	Pasta made with durum wheat, legumes	Sajilata (2006), Birt *et al*. (2013)
RS2	Naturally occurring starch in a compact, crystalline structure of a granule	Uncooked potato, green banana, high-amylose maize	Nugent (2005), Sajilata (2006)
RS3	Retrograded starch, physically modified using high and low temperature alternation	Cornflakes, moist-heated food, cooked and cooled potatoes	Raigond *et al.* (2015), Tian and Sun (2020)
RS4	Chemically-modified starch, obtained through cross-linking or the addition of a chemical derivative	Unavailable information	Birt *et al*. (2013), Raigond *et al.* (2015)
RS5	Amylose-lipid complex is formed during processing through the interaction of starch and lipid	Unavailable information	Raigond *et al.* (2019), Tian and Sun (2020)

astringent taste. It often undergoes processing before consumption (Falcomer *et al*., 2019). Banana flour is an example of a derivative product of green banana (Hasmadi *et al*., 2021). High level of resistant starch content in green banana flour was found in several studies, ranging from 32.24 - 48.99% (Juarez-Garcia *et al*., 2006; Haslinda *et al*., 2009; Menezes *et al*., 2011; Bezerra *et al*., 2013; Charoen *et al*., 2020). Various influencing factors of resistant starch content have been reported that lead to differences in the results obtained from these studies.

The promising potential of resistant starch in human health and the food industry has led to the recognition of banana flour as a functional ingredient (Rayo *et al*., 2015; Sarda *et al*., 2016). Much research on banana flour has been conducted to study its feasibility in various food product applications, including the health benefits gained upon consumption. This article will discuss the influencing factors, functional properties, and health benefits of resistant starch originating from banana.

2. Influencing factor of resistant starch level in banana

The factors affecting resistant starch content in banana pulp and banana derivatives have been studied in detail in previous research. These factors can be broadly divided into two types: intrinsic factors and extrinsic factors (Udomkun *et al*., 2021). Intrinsic factors refer to the inherent characteristics of the banana itself that can influence the level of resistant starch. These factors include banana variety or cultivar, as different varieties may have different levels of resistant starch (Magallanes-Cruz *et al*., 2017). The maturity of the banana at the time of harvest also plays a role, as the starch content and composition can change as the fruit ripens. In addition, the presence of enzymes such as amylase and glucanase in the banana fruit can influence the breakdown and formation of resistant starch.

Extrinsic factors, on the other hand, include external conditions and processing methods that can affect the level of resistant starch in banana products. A key extrinsic factor is the processing technique used, such as cooking, drying, or fermenting (Singh *et al*., 2010; Chen *et al*., 2019). Each process can change the starch structure and make it more or less resistant to digestion. The duration and temperature of processing also play an important role. In addition, storage conditions and duration can affect resistant starch content, as prolonged storage or improper storage conditions can lead to starch degradation. By understanding and manipulating these intrinsic and extrinsic factors, researchers and food manufacturers can effectively modulate resistant starch content in banana products to meet specific nutritional requirements or desired functional properties.

2.1 Intrinsic factor

2.1.1 Amylose level

Starch granule is mainly composed of amylose and amylopectin. Generally, amylose is a linear polymer, while amylopectin is a larger, branched molecule of polymer (Fuentes-Zaragoza *et al*., 2010). The ratio of amylose; amylopectin in starch is important, as high level of amylose will reduce the digestibility of starch, increasing the resistance toward enzymatic hydrolysis. Subsequently, higher amylose content will result in a higher level of resistant starch (Sajilata, 2006; Raigond *et al*., 2015; Tian and Sun, 2020). The association between amylose and resistant starch had been demonstrated in many studies. The study conducted by Izidoro *et al*. (2011) found the highest resistant starch in banana flour with the highest amylose level. The finding was also in accordance to Charoen *et al*. (2020), which observed positive correlation of amylose and resistant starch level in all flour samples.

This correlation can be explained by the role contributed by amylose in maintaining the crystalline and compact structure of starch granule. Therefore, higher amylose content results in increased strength of the granular compact structure, and ultimately require higher temperature to destroy the internal starch structure (Khoozani, Bekhit and Birch, 2019; Ahmed *et al*., 2019). In addition, the hydrogen bonding that forms the glucose linkage in amylose also contributes to the increased resistance towards enzymatic hydrolysis (Zaman and Sarbini, 2016).

2.1.2 Banana varieties

Banana originates from the genus *Musa*, with more than 200 cultivars worldwide derived from the wild species namely *M. accuminata, M. balbisiana, M. schizocarpa* and *M. textilis* (Li *et al*., 2013; Pareek, 2016). In general, banana varieties that exist today can be classified into two types; dessert banana and cooking banana (plantain). Dessert banana can be directly consumed in raw form, while plantain is often processed prior to consumption (Padam *et al*., 2014; Razali *et al*., 2020).

Gao *et al*. (2016) had analysed the resistant starch content in both the plantain and dessert varieties of banana. The study had found that plantain had significantly higher resistant starch content compared to the dessert variety at the same maturity stage. This finding is explained by the fact that plantain variety contains a higher level of starch than the dessert variety. In fact, the breakdown of starch to sugar at the end of the ripening process of plantain is incomplete, which means traces of starch is still present in ripened plantain (Pareek, 2016; Singh *et al*., 2018).

Another study conducted by Thakorlal *et al*. (2010) also reported differences in resistant starch content found in different varieties of banana at the same maturity stage. There were five types of banana varieties studied, which showed resistant starch ranging from 7 - 35%. The author concluded that the differences in resistant starch are associated with the compositional differences between the varieties, which is supported by Pareek (2016), who mentioned that biochemical composition is affected by genomic differences in banana species.

2.1.3 The maturity stage of the banana

Banana maturity stage has been reported to influence the level of resistant starch. Moongngarm *et al*. (2014) conducted a study on banana flour prepared from different stages of banana maturity: the first and third stages of maturity. The study has found that the sample prepared from banana at the first maturity stage had a significantly higher level of resistant starch compared to the sample prepared from the third maturity stage, which was 44.89% and 32.26% respectively. A similar outcome was reported in Gao *et al*. (2016), in which the least ripened banana had the highest level of resistant starch (18.1%), while the most ripened banana had the lowest level of resistant starch (2.7%). The main constituent of unripe banana is starch, and it is subsequently converted to sugar throughout the process of maturation and ripening (Zhang *et al*., 2006; Sarangi, 2014). Therefore, a high level of starch is present in an unripe green banana, while a high sugar level is present in a ripe banana. This explains the lower level of resistant starch found in more matured bananas, as starch has been broken down into sugar in greater quantity than in the less matured banana (Pareek, 2016).

2.2 Extrinsic factor

2.2.1 The effect of processing

Drying has been extensively used as a processing technique of agricultural products to ensure the longevity of perishable fruits as banana (Calín-Sánchez *et al*., 2020). Different processing conditions have been observed to influence the level of resistant starch. The section below discusses the effect of the drying method and the temperature employed during the drying process.

The effect of different drying methods used in the preparation of banana flour has been found to influence the resistant starch content. Ahmed *et al*. (2019) had used freeze-drying and tray-drying methods in sample preparation. The result showed significantly higher levels of resistant starch found in freeze-dried flour (38.87%) than in tray-dried flour (38.87%). This result is in agreement with Khoozani, Bekhit and Birch (2019), which freeze-dried flour (46.72%) had a higher level of resistant starch compared to oven-dried flour (44.58%). It was suggested that this finding is associated with the better performance of freeze-drying, which managed to minimise the chemical changes of the product during the moisture removal process, compared to other drying methods (Calín-Sánchez *et al*., 2020).

The study of Izidoro *et al*. (2011) demonstrated the effect of processing temperature on resistant starch content. It was found that the resistant starch obtained from the oven dryer (temperature of 50°C) was significantly higher than spray-dryer (temperature of 147°C), which was 79.89% and 68.51% respectively. The result is in agreement with Khoozani, Bekhit and Birch (2019), who found the highest resistant starch at 50°C temperature of oven dryer, compared to 110°C of a similar drying method. In fact, a similar finding was also found in Tribess *et al*. (2009), where significantly higher level of resistant starch was observed at 55°C of drying temperature compared to 58°C of drying temperature. The lower level of resistant starch obtained at higher drying temperatures illustrated the effect of high heat, which destroyed the crystalline structure of starch.

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Subsequently, the loss of starch crystallinity led to the increased accessibility towards the enzymatic hydrolysis, reducing the resistance capacity to digestive enzymes (Sajilata, 2006)

2.2.2 Phosphate fertilisation during cultivation

The effect of phosphate fertiliser application during banana cultivation was studied by Leonel *et al*. (2020), who reported that the fertilisation has decreased the level of resistant starch formed in the cultivated banana. Resistant starch content was found in the range of 17.0% - 29.8%, with low level of resistant starch found in a higher rate of phosphate fertilisation. A similar finding of the phosphate fertilisation effect was also found in Mesquita *et al*. (2010). The fertilisation had resulted in the increment of phosphorus level in banana pulp, that led to the changes in starch granule structure. The disruption in the crystalline structure of starch granules increases the susceptibility of resistant starch towards the enzymatic hydrolysis (Sajilata, 2006; Raigond *et al*., 2015).

3. Functional properties of resistant starch

Resistant starch has gained recognition as a functional ingredient due to its physicochemical properties and health-promoting effects (Rayo *et al*., 2015; Sarda *et al*., 2016). These unique properties have led to its use in food production (Sarangi, 2014). An advantage of resistant starch is its mild taste and white colour, which minimises the deterioration of the taste and appearance of the final product (Sajilata, 2006). In addition, the low water absorption capacity and fine particle size facilitate processing and improve the texture of the product (Fuentes-Zaragoza et al., 2010; Tian and Sun, 2020). In a study by Sarawong *et al*. (2014), improved crumb strength and volume were observed in bread with banana flour, demonstrating the role of resistant starch in improving baking properties, as also reported by Horstmann *et al*. (2017). Although resistant starch is classified as a functional dietary fibre, it not only provides nutritional benefits but also improves the overall palatability of foods through its mouthfeel and organoleptic properties (Fuentes-Zaragoza *et al*., 2010; Sarangi, 2014). It succeeds in improving the final quality of foods while preserving their functional properties.

4. Health benefits of resistant starch in banana

In general, the health effect offered by resistant starch is associated with the formation of short-chain fatty acids (SCFA) that result from colonic fermentation of resistant starch after it escapes digestion in the intestine. As resistant starch enters the colon, it becomes the substrate of fermentation for gut microbiota that produce acetate, propionate and butyrate as the main SCFA (Wong *et al*., 2006; Baboota *et al*., 2013; Zaman and Sarbini, 2016). This section discusses the health benefits obtained from the supplementation of banana derivative products that have been found in past studies.

4.1 Increased satiety and better body weight management

Satiety is defined as the feeling of appetite satisfaction after food intake, which ultimately inhibits the feeling of hunger (Forde, 2018). According to the study by Sarda *et al.* (2016), non-daily but regular consumption of green banana flour significantly increased the feeling of satiety in human subjects. It was reported that the feeling of hunger was reduced, resulting in lower food intake at the next meal. A similar result was found by Ble-Castillo *et al.* (2010), in which supplementation of green banana starch led to a reduction in body weight with no change in physical activity or diet of the subjects. This result was associated with the feeling of satiety, leading to lower food intake at the next meal (Slavin and Green, 2007).

Research suggests that the increased feeling of satiety associated with the consumption of resistant starch is due to enzymatic changes in gut hormones that lead to a reduction in energy intake. This phenomenon can be explained by the fact that resistant starch provides fewer calories with a lower energy value compared to digestible starch. The energy value of resistant starch is reported to be about 8 kcal/g, while digestible starch provides about 15 kJ/g (Higgins, 2014; Raigond *et al*., 2019). This discrepancy in energy content is due to the unique properties of resistant starch that make it resistant to digestion in the small intestine. Instead of being rapidly degraded and absorbed, resistant starch enters the large intestine intact, where it is fermented by the gut microbiota.

During the fermentation process, resistant starch is converted into short-chain fatty acids, such as butyrate, propionate, and acetate. These short-chain fatty acids play a critical role in altering gut hormones, including increasing the release of peptide YY (PYY) and glucagon-like peptide-1 (GLP-1). PYY and GLP-1 are hormones known for their appetite suppressant effects by signalling a feeling of fullness and reducing food intake. By triggering the release of PYY and GLP-1, resistant starch can effectively regulate appetite and promote a feeling of fullness. This modulation of gut hormones, combined with the lower energy value of resistant starch, contributes to its potential for weight management and energy control (Mishra *et al*., 2016).

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4.2 Improved glycemic control

Glycemic index is the incremental measure of blood glucose in response to the intake of carbohydrate-containing food (Jenkins *et al*., 2002; Hatekar and Ghodke, 2009). High glycemic index food is defined as carbohydrate-rich food that is rapidly broken down and absorbed, releasing glucose into the blood, elevating the blood glucose level (Batista *et al*., 2008). Resistant starch is reported to have a positive effect on blood glucose level, due to its undigestible nature in the gastrointestinal tract, which leads to colonic fermentation (Robertson, 2012; Birt *et al*., 2013). As it is not digested or absorbed in the small intestine, it reduces the glycemic load and improves the postprandial glycemic response for the next meal. In addition, short-chain fatty acids formed from the colonic fermentation also result in increased insulin response and sensitivity (MacNeil *et al*., 2013; Dan *et al*., 2015).

4.3 Improvement of constipation symptoms

Constipation is a condition associated with several consistent symptom: low frequency of defecation, difficulty in defecation, abdominal pain, and faecal incontinence (Tabbers *et al*., 2014). According to Zaman and Sarbini (2016), resistant starch is able to promote regular defecation by increasing stool bulk while providing a mild laxative effect. The action of resistant starch in improving constipation symptoms through green banana supplementation has been reported in several studies.

The study conducted by Cassettari *et al*. (2019) reported easier defecation with reduced pain and strain in human subjects, as a result of green banana biomass supplemented with laxative consumption. Similar finding was found in Wang *et al*. (2014), in which defecation process of constipated mice was initiated in shorter time, due to the accelerated bowel movement. The outcome of this research is the result of SCFA formed from colonic fermentation that increases osmotic load, initiating the changes in intraluminal microbiome, which results in shorter time of colon transit (Topping and Clifton, 2001; Bae, 2014).

4.4 Reduced risk of colorectal cancer

Colorectal cancer is one of the predominant malignant cancers in the human gastrointestinal tract (Granados-Romero *et al*., 2019). The potential of resistant starch in preventing colon cancer has been identified, but the working mechanism is still unclear. It was proposed that the role of resistant starch in altering the composition and activity of colonic microbiota greatly contributed to reducing the cancer risk (Zaman and Sarbini, 2016). As is known, resistant starch undergoes fermentation in the colon, forming short-chain fatty acids as the fermentation products. Butyrate is one of the short-chain fatty acids formed, which is believed to reduce tumour cells by hindering the malignant transformation of cells (Amini *et al*., 2016). It was observed that a lower incidence of colorectal cancer is parallel with increased production of butyrate (Wanikar and Kotwal, 2021).

5. Future trend

The recognition of resistant starch as a functional fibre has paved the way for the use of banana flour in the development of innovative food products. Extensive research has been conducted to investigate the feasibility of using banana flour in various foods, with a focus on the production of gluten-free and functional foods. The development of banana flour-based foods represents an excellent opportunity to harness the health benefits of resistant starch to meet the growing demands of health-conscious consumers (Khoozani, Birch and Bekhit, 2019).

Banana flour, derived from bananas, is a versatile ingredient that has unique functional and nutritional properties (Dibakoane *et al*., 2022). It contains a significant amount of resistant starch, which has been linked to several health benefits, including improved blood sugar control, improved digestive health and increased feelings of satiety (Escobar *et al*., 2020). By using banana flour in foods, these health-promoting properties can be passed on to consumers.

One of the most important uses of banana flour is in the production of gluten-free foods. Banana flour has shown promise as an alternative ingredient in gluten-free recipes, contributing to the texture, structure and overall quality of gluten-free products. Its ability to improve the rheological properties of doughs, bind moisture and enhance the sensory characteristics of gluten-free products makes it an attractive option for people with gluten intolerance or celiac disease (Rachman *et al*., 2019; Olawoye and Gbadamosi, 2020; Guadalupe-Moyano *et al*., 2022)

In addition, banana flour offers opportunities for the development of functional foods. By adding banana flour to various foods, manufacturers can improve their nutritional profiles and promote health benefits beyond basic nutrition (Khoozani, Kebede and Bekhit, 2020). The high resistant starch content in banana flour can contribute to the development of products with improved glycemic control, helping to manage blood sugar levels (Khoozani *et al*., 2020). In addition, the prebiotic properties of resistant starch may support intestinal health by stimulating the growth of beneficial gut bacteria (Alvarado-Jasso *et al*., 2020).

The increasing demand for health-conscious and nutritionally enhanced foods has created a favourable environment for the development of banana flour-based foods (Dhull *et al*., 2021). Consumers are actively seeking functional ingredients that offer both nutritional value and health benefits. The versatility of banana flour allows it to be used in a wide variety of foods including baked goods, snacks, cereals, beverages and more.

6. Conclusion

The beneficial effect of resistant starch offered in food applications and nutritional aspects has drawn much attention and interest from researchers. Unripe banana is one of the rich sources of resistant starch. With regard to its climacteric nature, unripe banana is often processed into banana derivative products, such as banana flour, to preserve the high level of resistant starch. This explains the vast application of banana flour used in the study of resistant starch characteristics. The development of food product from banana flour is an equivalent alternative to dietary fibre. However, the influencing factors of resistant starch discussed earlier must be considered in order to achieve product with high resistant starch, so that the health benefits can be delivered to consumers accordingly.

Conflict of interest

The authors have declared no conflicts of interest for this article.

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