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Plantain starch: Properties, food applications and its digestibility

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Abstract
Plantain starch has received recent attention due to its commercial potential and beneficial properties for human health. Today, it appears as a recent trade commodity and this starch has a wide range of commercial applications due to its unique properties. Some of the common commercial applications for plantain starch include: Food Industry includes Bakery Products where Plantain starch can be used in the production of bread, cakes, cookies, and other baked goods as a thickening and stabilizing agent. Confectionery, it is utilized in the manufacturing of sweets, candies, and jellies to provide texture and stability. Dairy Products in this the Plantain starch can be added to dairy products like yogurt, ice cream, and custards as a thickening and stabilizing agent. Sauces and Soups are also used to thicken and improve the texture of sauces, gravies, and soups. Meat Products, Plantain starch can be incorporated into meat products such as sausages and meatballs as a binder and texturizer. These are few examples of commercial applications of plantain starch. Its versatility, functional properties, and gluten-free nature make it suitable for a wide range of industries and products. Unripe banana starch is recommended as an ingredient to create several standardized formulations with improved health properties. Plantains are a tropical fruit crop that are widely consumed, both for the sheer volume produced and for meeting the calorie requirements of millions of people. ripe bananas are avoided by diabetics as they can influence blood sugar levels and boost the glycemic index, yet the same fruit when unripe can lower blood sugar levels and demonstrate its usefulness with its nutritional fibers and slowly digesting carbohydrates. Plantain has a high starch content (greater than 60%) when processed into starch. Starch can be used for a variety of things depending on its structural, physicochemical, and functional characteristics. The objective of this paper is to investigate the physicochemical composition, digestibility, and uses of plantain starch in the food and non-food industry.

Keywords: Plantain starch, chemical composition, digestibility, properties, applications

1. Introduction

Banana is a climacteric fruit; it belongs to the genus Musa and family Musaceae. It is harvested at an immature yet mature stage. The banana, belonging to the Musaceae family within the genus Musa, is a climacteric fruit that is typically harvested when unripe but mature. The most widely farmed Banana species, *Musa cavendishii*, has become a valuable export due to its sensory characteristics. Musa paradisiacal, *Musa sapientum*, and other variants that are similarly competitive belong to the same genus. Bananas are rich in potassium, pyridoxine, ascorbic acid, beta-carotene, and fibre, among other nutrients (Debabandya *et al.*, 2010) [9]. Functionally, bananas contain a lot of slowly absorbed starches, and when heated properly, they produce resistant starch fractions. These fruits exhibit a rich composition of complex carbohydrates, including various types of slowly absorbed starches characterized by distinct properties. (Alimi *et al.*, 2017) [4]. Slowly absorbed starches refer to specific types of carbohydrates found in bananas that are digested and absorbed by the body at a slower pace compared to other starches. These starches are characterized by their distinct properties, which include Resistant Starch i.e., Slowly absorbed starches in bananas often contain resistant starch, which resists digestion in the small intestine. Instead, it reaches the large intestine, where it acts as a prebiotic, promoting the growth of beneficial gut bacteria. Low Glycemic Index i.e., Slowly absorbed starches contribute to a lower glycemic index of bananas. This means that the carbohydrates are released more gradually into the bloodstream, resulting in a slower and steadier rise in blood sugar levels. Sustained Energy Release i.e., Due to their slower digestion and absorption, these starches provide a sustained release of energy over an extended period. This can help maintain stable energy levels and prevent rapid spikes and crashes in blood sugar. Enhanced Satiety i.e., Slowly absorbed starches can contribute to a greater feeling of fullness and satiety after consuming bananas. This can aid in controlling appetite and potentially assist with weight management.

Starch is the primary component of carbohydrate-rich plantains (Unripe banana), but when they ripen, it is hydrolysed to sugars, which is why people of all ages and socioeconomic status find them to be more appetising (Pragati *et al*., 2014) [27]. Starch, the main substance in many kinds of foods (including grains, tubers, legumes, and green fruits), accounts for between 70 and 80 percent of the calories consumed by people worldwide (Bertolini *et al*., 2010) [5]. Amylopectin and amylose, two significant glucose polymers, make up the biopolymer, and their proportions and granular morphologies which gives starch its diverse range of functions. Starch is a versatile component used in both the culinary and non-food industries. It is also a superb raw material for adjusting the consistency and texture of food. The quantity and kind of starch (i.e., biological source) have a significant impact on how a specific carbohydrate food product feels.

The main ingredient is starch, which goes through significant changes as they ripen. The chemical structure of bananas at various phases of maturation, it was examined and demonstrated that as starch is broken down, sucrose content rises and glucose and fructose accumulate. Furthermore, a significant portion of the starch in unripe bananas is resistant, meaning that it has a crystallinity that makes it only marginally susceptible to hydrolysis, a characteristic that makes it interesting for functional meals (Tribess *et al*., 2009) [31] Due to its starch, plantains are currently being exploited at full speed by researchers and food technologists to uncover more uses in food, textiles, and pharmaceuticals. plantain falls under the category of easy digestion because of its high starch content and, high amylose to amylopectin ratio (Zabala *et al*., 2020) [32] Starches serve as energy boosters from one perspective, but from another, they also act as fibre constituents when resistant starch is deformed using a variety of techniques (Morris *et al*., 2020) [19].

According to this study's findings (Hernandez *et al*., 2009), adding plantain starch increased the level of healthy RS and may be highly marketable as a functional meal. Cooked plantain starch's digestive characteristics suggested that it would have a rather slow digestion characteristic (Ovando *et al*., 2009) [23]. If plantain starch is slowly absorbed, it may be employed in the preparation of processed meals with starch to achieve low glycemic indexes and extended energy release properties. Since no starch currently competes economically with native and modified corn starches, plantain starch's value will, if any, be superior qualities for niche applications. Various aspects of banana starch, including as chemical composition, physicochemical qualities, digestibility, and prospective applications in food products, need to be summarised in order to add to the knowledge that is currently available.

2. Properties of plantain starch

These include the functional, physicochemical, and chemical properties such as solubility, hardness, pH, ash content, moisture content, protein content, lipid, amylose, and total starch. These values are taken from various types unripe bananas also known as plantain. Table 1 lists the chemical, physical and functional composition of the starch obtained from several varieties of plantain. plantain starch has a moisture content of 6.83-14.00% and 0.03-2.08% ash. Additionally, it has a lipid content of 0.01-2.46% and a protein content of 0.17-2.16%. The diverse banana varieties and the various starch extraction methods could be to blame for the variance in the starch's fat and protein content. Bananas do contain small amounts of fat and protein. The starch itself is primarily composed of carbohydrates. The fat and protein content in banana starch is typically relatively low compared to other food sources. However, the factors such as genetic variation, growing conditions, harvesting, and ripening can contribute to slight variations in the fat and protein content among different banana varieties and extraction methods. The range of the total starch was 69.39% to 98.10% and it contains between 22.76 and 38.79% amylose and the solubility ranges between 5.02-11.11%.

Table 1: Physicochemical properties of starches from various plantain varieties

Experimental variable	Solubility (Tem p °C)	Hardness (kgf mm−2)	pH	ash (%)	Moisture (%)	Protein (%)	Lipid (%)	Amylose (%)	Total starch (%)	References
Unripe pei chiao (Upc)	11.07	13.17	5.76	NR	NR	NR	NR	NR	NR	Diaz *et al*., (2014)
Unripe fomosana (Uf)	10.77	11.52	5.69	NR	NR	NR	NR	NR	NR	
Unripe Tai-Chiao No. 5 (UTC)	11.11	9.75	5.63	NR	NR	NR	NR	NR	NR	
Terra var.	NR	NR	NR	0.03±0.01	9.27±0.07	0.97±0.16	0.02±0.01	35.0±0.3	94.8±0.1	Pelissari *et al*., (2012) [24]
Tanduk	NR	85.53±1.27	NR	0.659±0.09	8.829±0.30	2.306±0.02	0.448±0.04	26.084±0.34	NR	Shittu *et al*., (2016) [30]
Nangka	NR	63.81±1.21	NR	0.528±0.06	9.837±0.85	0.844±0.28	0.382±0.06	31.789±0.63	NR	
Musa AAB—Mysore Var	NR	NR	NR	0.09	12.30	0.44	NR	37.88	90.08	Fontes *et al*., (2017) [10]
Agbaba var.	5.02	NR	NR	0.62	11.20	2.53	0.44	38.79	63.90	Olatunde *et al*., (2017) [21]
Gros Michel var.	NR	NR	NR	0.50	7.8	1.1	0.8	22.76	74.9	Salazar *Et al*., (2017) [8]
Dominico hartón Var.	NR	NR	NR	0.34	8.2	0.9	0.5	31.12	84.0	

NR-Not Reported

3. Plantain starch and digestibility

plantains are of great interest to researchers because they contain a significant amount of starch and have a healthy pattern of digestion. Most remarkable, bananas have a low amylose fraction (11.2%) that is occupied by resistant and slowly digested starch after cooking (Zhang *et al*., 2005) [36]. Amylose impairs the digestion of cooked carbohydrates. Similarly, the plantain starch amylopectin has an odd reassociation property that is attributed with cooling hours and delayed digesting characteristics. Studies on plantain have revealed high levels of resistant starch “Effects of cooking methods on the digestibility of starch in bananas" (Thongkaew *et al*., 2016). This study investigated the impact of different cooking methods (boiling, steaming, and frying) on the digestibility of starch in bananas. The results showed that the digestibility of starch varied depending on the cooking method employed. Boiling and steaming resulted in higher starch digestibility compared to frying. The differences were attributed to changes in starch structure and the gelatinization process during cooking. "Impact of banana ripeness on starch digestion and glycemic response in humans" (Fernandez *et al*., 2018): This research examined the effect of banana ripeness on starch digestion and its subsequent glycemic response in human subjects. The study found that the ripeness of the bananas influenced the rate of starch digestion and glycemic response. Riper bananas, which have higher sugar content due to starch conversion, led to a faster digestion and a more pronounced glycemic response compared to less ripe bananas These studies demonstrate that the digestibility of starch in bananas can vary depending on factors such as cultivar, ripeness stage, and cooking methods. The ripening process and cooking techniques can affect the structural properties of starch, which in turn impact its digestibility. It's important to consider the ripeness and preparation methods of bananas when assessing their starch digestibility and potential glycemic impact.

Application of the drying parameter prior to processing has no effect on the quantity of total starch, while freeze-dried starch (37.87%) has been found to include more resistant starch than tray-dried starch (25.77%). Less RS in tray-dried samples is a result of their inability to reach the gelatinization temperature, whereas enhanced non-digestible portion was achieved due to the disaggregation of starch molecules during the freeze-drying phases (Ahmed *et al*., 2020) [1]. In order to review the changes in digestibility, green banana flour that had been deastringentized with limewater underwent additional processing with an autoclave and pullulanase (a debranching enzyme) (Liao *et al*., 2015) [16]. Banana peel deastringency treatment keeps the value of soluble condensed tannin at a lower level. The addition of an autoclave and enzyme exposure allowed for the reduction of dietary fibre and a steady increase in the proportion of resistant starch. Consuming green banana flour is beneficial, as shown by its low glycemic index status, which is 50.5% for green banana flour and 55.4% for flour treated with an autoclave cum debranching enzyme, respectively.

Working with three different banana cultivars, (Bi *et al*., 2017) [6] discovered that changes in digestibility are caused by differences in amylose, amylopectin chain variation, crystallinity, and starch molecular weight. Amylose, amylopectin, molecular weight, and crystallinity aspect were shown to have values in assessing digestibility extent statistically (Principal component analysis; PCA). The rapid digestibility starch (RDS) of cooked banana starch, the delayed digestibility starch (SDS), and the resistant starch (RS) fraction of both cooked and raw banana starch were all included in the first main component analysis (PC1). Similar to the first, RDS from raw banana starch, crystallinity pattern, and amylose level were included in the second principal component analysis (PC2). Diversified genotype selection may be a crucial factor affecting digestibility, according to Bi and his team. Additionally, banana pectin significantly hinders *in-vitro* digestion. Cooking integration improves digestibility because RDS and SDS now make up the majority of RS.

According to Cavendish and Plantain, two major cultivar categories, (Huijun *et al*., 2016) expound on banana. The famous cultivar most commonly produced for international trade was Cavendish. A total of more than 100 varieties of plantain exists. It's a game of variety choice and degree of maturity that determines the different resistant starch proportion in them. They discover that Plantain is more competitive with Cavendish on the starch side. Another topic under investigation is the overall starch loss over the period of five days of ripening, with Plantain subgroups of banana fruit losing more total starch (91% to 83%) than Cavendish (87% to 69%).

Salazar *et al*., (2017) [8] recently investigated the digestibility properties of two cultivars of Colombian origin: the cooked banana cultivar Dominico Harton, FHIA 20, and the dessert banana cultivar Gros Michel. A digestibility analysis examination of the raw starch that was taken from the cooking variety reveals that it contains a high amount of resistant starch. among three favoured plantains while fast digested starch fractions are least prevalent and are followed by slow digestible starch in cultivars, all feature substantial RS. Cooking banana varieties chosen for investigation have superior retention of the RS content, which is nearly twice that of dessert type variety. This is a universally observed phenomena among starches to demonstrate decrement behaviour in RS content on gelatinization. Dessert banana varieties are the true source of healthy selection for better life, and they have also better retained functional features with 12.7% RS and 7.5% SDS in them.

4. Application of plantain starch in Food and non-food Products

In order to give food, including agricultural and animal crops, more value in terms of quality, acceptance, and storage stability, food processing aims to change the shape of the food into the intended food items. Since bananas are a highly perishable fruit, turning them into flour or starch is necessary to extend their shelf life. Bananas can be improved by being turned into flour or starch, which is then widely utilised in a variety of goods (bi *et al*., 2017) [6]. Commercial use of banana starch has not been reported. Depending on the species and growth conditions, native banana starch offers a variety of properties. Because the banana starch from the Ambon species has good freeze-thaw stability (Marta *et al*., 2019) [17] it can be used in frozen food products. According to several research, native banana starch contains a significant percentage of resistant starch (65–99%) (Acevedo *et al*., 2015) [2]. When consumed, resistant starch prevents blood glucose levels from rising because it cannot be broken down by digestive enzymes. As a result, banana starch is suggested as a useful food item for diabetes people (marta *et al*., 2021) [18].

Banana starch (in flour form) has been used in a number of earlier research to make pasta (Zheng *et al*., 2015) [37], bread (Aziah *et al*., 2012) [20], cookies (saguilan *et al*., 2007), and biscuits (Cahyana *et al*., 2020). Banana flour is used in place of wheat flour in several items, lowering the amount of gluten present. Wheat pasta digested more quickly than pasta produced from green banana flour (Martinez *et al*., 2012) [23]. Similar to pasta, banana flour bread digests more slowly than wheat flour bread. Another option for a foundation ingredient in a biodegradable film is banana starch. However, there are still a number of issues with the physical characteristics of the film made from banana starch. To strengthen the banana starch film and enhance its physical qualities, some research teams added an additional substance. The tensile strength, Young's modulus, opacity, and crystallinity of the banana starch film were all greatly improved when cellulose nanofibers from banana peels were added, according to (Pelissari *et al*. 2017) [25], and the film also became more water-resistant.

Banana starch can be used on non-food items in addition to food products. One of the potential starting materials for making a bio-based film, such as film-type packaging, is banana starch (wang *et al*., 2022) [33]. Banana starch can also be used as the main component in the production of bio-based packaging films (restrepo *et al*., 2018) [29]. However, various chemical addition and modification practises are frequently used because starch, notably banana starch, imparts low flexibility and poor barrier qualities to both water and air (wang *et al*., 2022) [33]. Pongsuwan *et al*., (2022) [26] used banana inflorescence debris, which includes a large quantity of fibre, as a filler for starch-based bioplastics to increase the barrier qualities of banana starch. This gave the bioplastics greater physical properties, water resistance, and thermal resistance. inclusion of filler material. Many studies (ramon *et al*., 2021) also reported the incorporation of filler or banana starch modification during the manufacturing of banana starch-based bio films (Hernandez *et al*., 2017). Due to its ease of water absorption, starch frequently loses some of its mechanical and dimensional stability (wang *et al*., 2020) [34].

In addition to being used to create biofilms, starch also has the ability to be converted into porous carbon materials in order to create an efficient, environmentally friendly capacitor. Due to their excellent electrochemical properties, supercapacitors are being considered as potential energy storage devices in applications with growing power requirements (wang *et al*., 2019) [35]. Banana starch, in the author's opinion, could also be used as the main component of electrode materials or gel electrolytes for supercapacitors. This claim was supported by study by (Kasturi *et al*., 2019) [14] who used flexible film from Manihot esculenta and seed starch from Artocarpus heterophyllus as a porous material for capacitors. They claimed that this double-layer electric capacitor is all-solid-state and has excellent electrochemical performance and stability. Additionally, (Kumar *et al*., 2021) [15] revealed that the carbonation method might use cornflour as a porous carbon source. Banana starch may be used as a precursor in the production of porous carbon materials to create environmentally friendly capacitors that are highly effective at conducting energy, according to earlier studies.

5. Conclusion

The food industry could benefit from the development of plantain starch as an ingredient. Because plantain starch contains a lot of resistant starch, it can be utilised as a component in foods with special functions, including foods for diabetics. Additionally, a number of plantain types have special functional qualities that make them excellent for usage as components in frozen foods, such as good stability while stored at low and frozen temperatures (high freeze- thaw stability). Additional research is required to change plantain starch utilising enzymatic and nonthermal physical techniques (ultrasonication, pulse electric field, high-pressure treatment, etc.), in order to learn more and develop new strategies for enhancing plantain starch properties. In contrast, research needs to be done on using banana starch (in the form of flour) to completely replace the use of wheat flour in the production of gluten-free products as a functional food for people with special diets, such as those with celiac disease and autism. The functional and physicochemical characteristics of plantain starch indicate that it may have a wide range of potential uses as a component in food systems and other industrial applications. The manufacturing of starch from banana pulp can result in the development of products that are competitive in the market, enhancing the financial standing of banana growers and helping to solve the issue of what to do with extra or rejected bananas. The best method to apply starch in the human-related domains of food, pharmaceuticals, and textiles is to use it as a biofiller at both the native and nanoscale levels. the need for additional research to enhance plantain starch properties such as starch quality, process optimization, Functional Applications, Nutritional profile, shelf stability and storage and sustainability by addressing these research areas, the knowledge and understanding of plantain starch properties can be expanded, leading to the development of improved starch products with enhanced functionality, nutritional value, and sustainability. Banana starch's functional potential has been explored, which has expanded the range of applications it can be used for in food compositions. Plantain starch is a well-known excellent source of resistant starch.

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