2

Review of Literature

The review of the literature pertaining to the study entitled "**Starch Characterization, Functional Properties, Prebiotic Potential of Unripe Banana Flours and Development of Ready-to-Eat and Ready-to-Cook Products**" is presented under the following sections.

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2.1.Unripe Banana Flour – Overview and Food Products

Unripe banana flour, derived from the green bananas of *Musa paradisiaca* cultivars such as Peyan and Monthan, has emerged as a promising ingredient in the realm of food science and nutrition. This unexplored treasure trove of nutritional benefits, with its versatile functional properties, is an invaluable resource for developing innovative food products. This review aims to provide a comprehensive understanding of unripe banana flour, shedding light on its composition, physicochemical characteristics, and the myriad ways it contributes to the health and well-being of consumers.

2.1.1. Musa Cultivars

Bananas (*Musa spp.*), originating in Southeast Asia, are widely cultivated throughout the tropics and sub-tropics and belong to the *Musa* genus and the Musaceae family. They are both edible fruits and herbaceous flowering plants. Ripe bananas, known as dessert bananas, are typically consumed fresh, while plantains, enjoyed in cooked form, serve as a staple food in many developing countries (Sidhu and Zafar, 2020) and are a vital source of nutrition for over 500 million people (Wang et al., 2019)

Banana (Musa sp.) is distinguished as one of the widely grown tropical fruits, encompassing cultivation of over 1000 varieties across the world. The Musa cavendish variety is particularly noteworthy in commercial terms, constituting approximately 45% of the global banana market. This dominance is attributed to its high per-hectare production and its resilience to environmental fluctuations (FAO, 2023).

Banana occupies a prominent global position as one of the most significant fruits, with its botanical nomenclature, Musa, deriving from the Arabic term "Mouz." This nomenclature pays tribute to Antonia Musa, a Roman physician from the first century (Qamar & Shaikh, 2018). Internationally, bananas emerge as a pivotal crop, renowned for their economic viability and widespread availability, encompassing a diverse array of over 1000 varieties that vary in color, taste, and chemical composition, thereby influencing broad-scale production and consumption patterns (Oyeyinka & Afolayan, 2020; Vu et al., 2017).

The primary species responsible for the majority of parthenocarpic edible bananas are *Musa acuminata* and *Musa balbisiana.* The haploid genome of *Musa acuminata* is classified as A, while that of *Musa balbisiana* is designated as B. Dessert varieties are typically diploid and triploid forms derived from *Musa acuminata*, whereas plantains and culinary types generally arise as triploids from hybridizations between *Musa balbisiana* and *Musa acuminata* (Hazarika et al., 2014). The genus Musa comprises approximately 35 species, among which the three most prevalent species are *M. cavendishii, M. paradisiaca*, and *M. sapientum*. Edible Musa variations include dessert bananas (AA, AAA, AAB) and cooking bananas (AAB, ABB, BBB) (Deka and Neog, 2021).

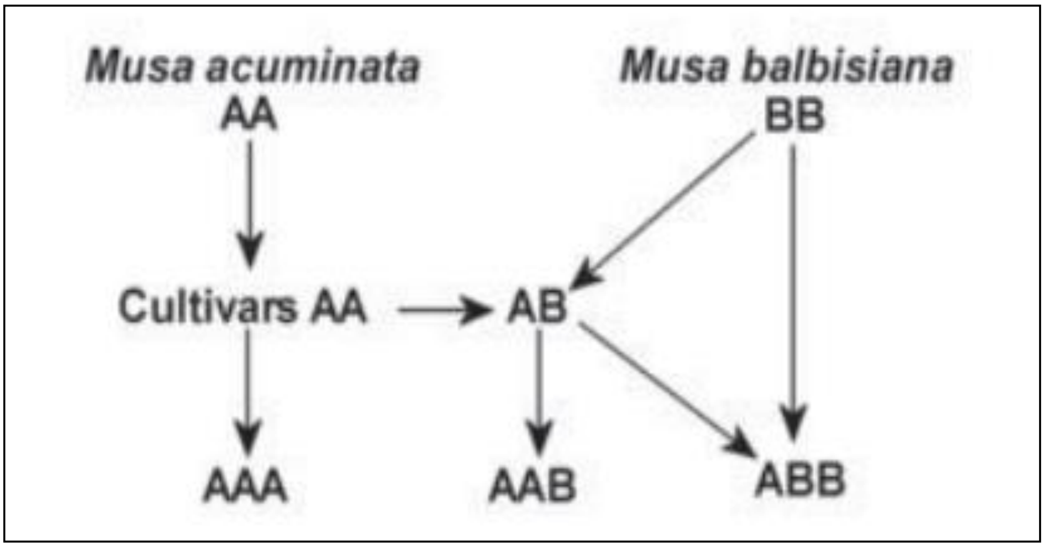


Figure 1: Crossing Relationship of Cultivated Musa

(Adapted from OECD 2009)

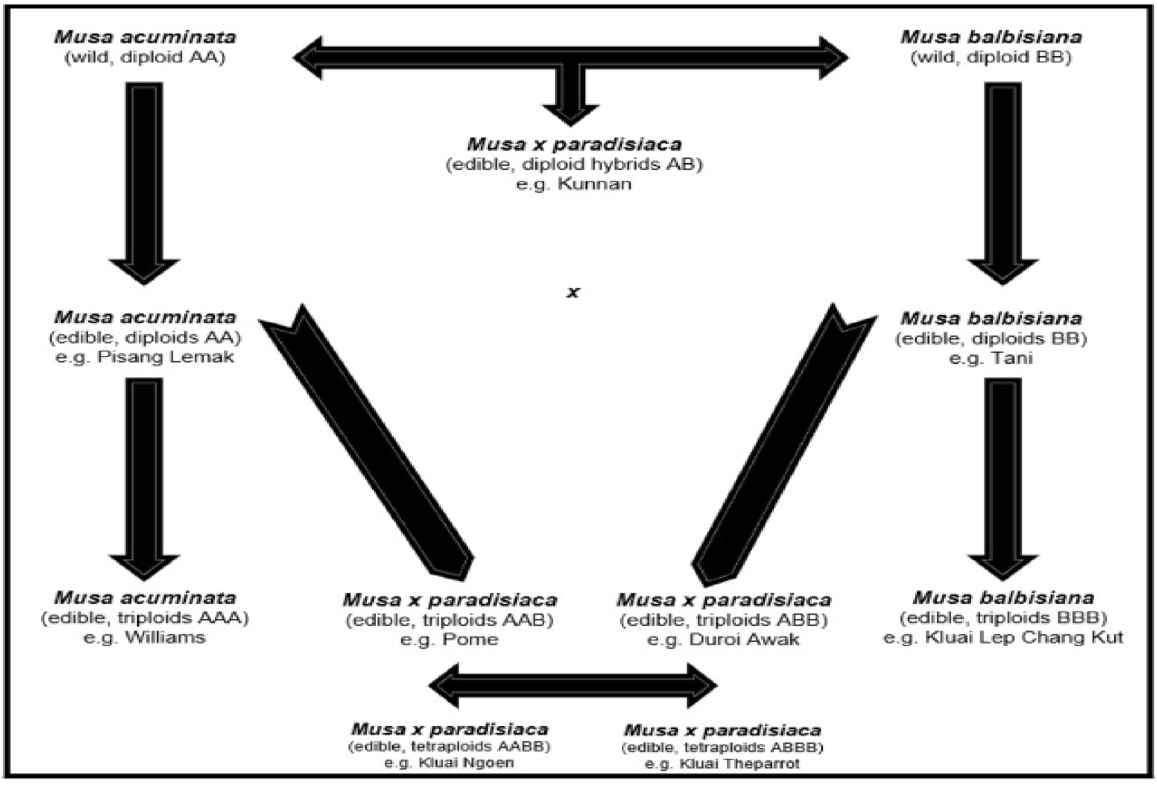


Figure 2: Edible Banana Hybrids (Maseko et al.,2023)

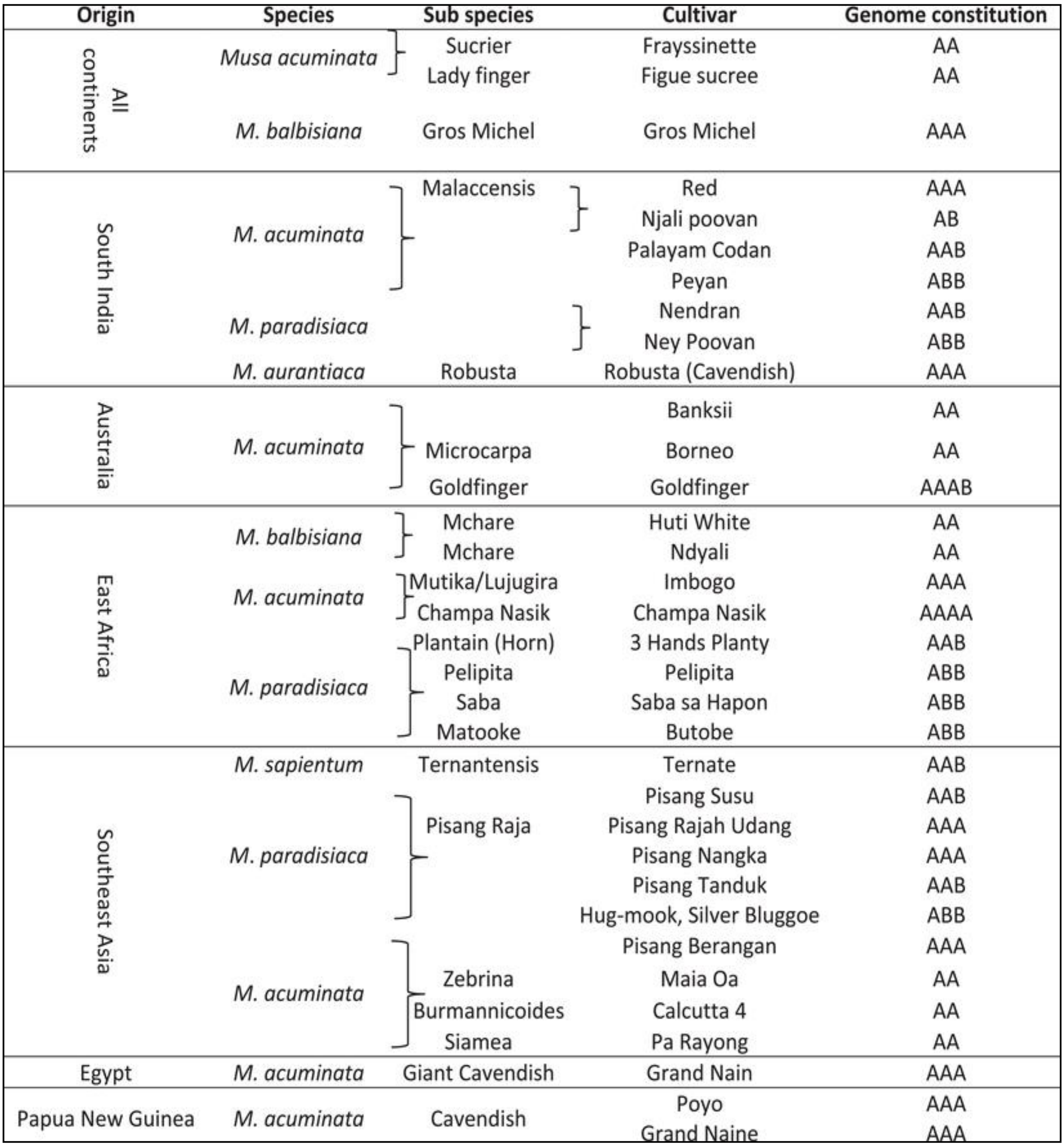
Table I

Musa Cultivars by Genomic Classification

(adapted from Pareek, 2016)

Genome	Cultivars
AA	'Inarbinal', 'Paka', 'Matti', 'Anakomban', 'Pisang Jari Buaya', 'Pisang Lilin', 'Senorita', 'Kadali', 'Sucrier' ('KulaiKhai', 'Lady's Finger', 'Orito', 'Pisang Mas')
AAA	'Ambon', 'Cavendish' ('Dwarf Cavendish', 'Giant Cavendish', 'Grand Naine', 'Williams'), 'Gros Michel' ('Cocos', 'Highgate', 'Lowgate'), 'Ibola', 'Basrai', 'Lujugira-Mutika' ('Beer', 'Musakala', 'Nakabulu', 'Nakitembe', 'Nfunka'), 'Pisang MasakHijau' ('Lacatan'), 'Red' ('Green Red'), 'Robusta' ('Harichal', 'Malbhog')
AAAA	'Pisang Ustrali'
BB	'Bhimkol', 'Biguihan', 'Gubao', 'Pa-a-Dalaga', 'Tani'
BBB	'Abuhon', 'Inabaniko', 'Lap Chang Kut', 'Mundo', 'Saba Sa Hapon', 'Saba', 'SabangPoti', 'Turrangkog'
AB	'Kunnan' ('Adukkan', 'Poonkalli', 'PoovillaChundan'), 'Ney Poovan' ('Kisubi', 'Safed Velchi'), 'SukaliNdizi' ('Kumarangasenge')
AAB	'False Horn' ('French', 'French Horn'), 'Laknau', 'Maia Maoli', 'Moongil', 'Mysore' ('Sugandhi'), 'Nendran', 'Pisang Raja', 'Plantain Horn', 'Pome' ('Pachanadan', 'Pacovan', 'Prata Ana', 'Virupakshi'), 'Popoulu', 'Ilohena', 'Rasthali', 'Silk'
ABB	'Bluggoe' ('NallaBontha', 'Pisang Batu', 'Punda'), 'Pisang Awak' ('KlueNamwa', 'Karpuravalli', 'PeyKunnan', 'Yawa'), '**Monthan', 'Peyan**', 'KlueTeparot', 'Pelipita', 'Kalapua', 'Cardaba'
AAAB	'Atan'
AABB	'Kalamagol', 'Laknau Der',
ABBB	'Bhat Manohar'
AS	'Aso', 'Kokor', 'Ungota', 'Vunamami'
AT	'Umbubu'
AAT	'Kabulupusa', 'Karoina', 'Mayalopa', 'Sar'
ABBT	'Giant Kalapur', 'Yawa 2'

Table II
Banana Cultivars, Species, and Their Origin
Adapted from Mostafa et al. (2021)



Origin	Species	Sub species	Cultivar	Genome constitution
All continents	*Musa acuminata*	Sucrier	Frayssinette	AA
		Lady finger	Figue sucree	AA
	M. balbisiana	Gros Michel	Gros Michel	AAA
South India	*M. acuminata*	Malaccensis	Red	AAA
			Njali poovan	AB
			Palayam Codan	AAB
			Peyan	ABB
	M. paradisiaca		Nendran	AAB
			Ney Poovan	ABB
	M. aurantiaca	Robusta	Robusta (Cavendish)	AAA
Australia	*M. acuminata*		Banksii	AA
		Microcarpa	Borneo	AA
		Goldfinger	Goldfinger	AAAB
East Africa	*M. balbisiana*	Mchare	Huti White	AA
		Mchare	Ndyali	AA
	M. acuminata	Mutika/Lujugira	Imbogo	AAA
		Champa Nasik	Champa Nasik	AAAA
	M. paradisiaca	Plantain (Horn)	3 Hands Planty	AAB
		Pelipita	Pelipita	ABB
		Saba	Saba sa Hapon	ABB
		Matooke	Butobe	ABB
Southeast Asia	*M. sapientum*	Ternantensis	Ternate	AAB
	M. paradisiaca		Pisang Susu	AAB
		Pisang Raja	Pisang Rajah Udang	AAA
			Pisang Nangka	AAA
			Pisang Tanduk	AAB
			Hug-mook, Silver Bluggoe	ABB
	M. acuminata		Pisang Berangan	AAA
		Zebrina	Maia Oa	AA
		Burmannicoides	Calcutta 4	AA
		Siamea	Pa Rayong	AA
Egypt	*M. acuminata*	Giant Cavendish	Grand Nain	AAA
Papua New Guinea	*M. acuminata*	Cavendish	Poyo	AAA
			Grand Naine	AAA

A pure triploid *M. acuminata* (AAA genome group) and *M. cavendishii* are distinguished by their sweeter and less starchy attributes. In contrast, *M. paradisiaca* and *M. sapientum* are characterized by elevated starch content in comparison to the pure *M. acuminata* species. Cooking bananas falling under the ABB genome group (such as Pisang

Awak and Bluggoe) and the BBB genome group (like Kluai Lep Chang Kut banana) are recognized for their starchier composition. In each country where bananas are cultivated, numerous instances of duplicate names and closely related clonal varieties exist. It is important to highlight that certain cultivars are assigned ambiguous common names (Pereira and Maraschin, 2014). Maseko et al. (2023) demonstrated that the differentiation of sub-genomic and genomic groups of unripe banana flour can be achieved through the application of multi-elemental fingerprinting.

Musa paradisiaca Peyan (ABB) is a unique banana variety grown in Tamil Nadu and Kerala. Due to its medicinal properties and refreshing effect, it is valued in the market, especially for pregnant women, children, and those with piles. Synonyms include Mada Vazhai, Pey Monthan, Pey Valai, and Peyan Mayil Vazha. (Venkataramani, 1946).

Figure 3: Peyan and Monthan Cultivars

(Adapted from Musa Germplasm Information, crop-diversity.org; tnau.org)

Musa paradisiaca Monthan (ABB) is a popular commercial banana cultivar in India, mainly used for cooking. In Tamil Nadu and Kerala, Monthan is valued for its cooling effect and is often consumed by those with chickenpox. Regional synonyms include Bontha, Kanch Kela, Bankel, Bantheesa, and Kalyanakai. (Venkataramani,1946). Cultivated for leaf production in the Trichy and Tanjore districts of Tamil Nadu, Monthan exhibits several desirable qualities. Notably, it experiences fewer incidences of leaf spot disease and displays salt tolerance. The cultivar maintains a normal bunch weight even under marginal conditions. (Ray, 2021)

Bananas are prized for their nutritional value, providing significant amounts of dietary fiber, essential vitamins, and minerals. (Gomes et al., 2020). Banana fruits are naturally elliptically shaped with creamy, firm flesh inside a thick peel. Banana fruit is consumed for its nutritional value all year round, as a green or ripe banana in many countries as an energy-giving food (Arinzechukwu & Nkama, 2019). In addition to their high proportion of sugar derivatives, polyunsaturated fatty acids, sterols, and minerals (e.g., potassium), and various vitamins (e.g., pro-vitamin A, B1, B2, C), bananas contain high concentrations of bioactive chemicals, such as glycosides, and acids like malic acid and oxalic acid (Mathew & Negi, 2016)

2.1.2. Unripe Banana Flour: Composition and Characteristics

As a paradigmatic climacteric fruit, commercial bananas are generally harvested at the stage of physiological maturity while still unripe, as discussed by Cordenunsi-Lysenko *et al.* (2019). This characteristic contributes to a notable increase in postharvest losses, predominantly occurring during transportation, handling, and storage within the supply chain (Pathare and Al-Dairi, 2021). Bruising, typically the most prevalent form of mechanical damage, is a major factor leading to the deterioration of fresh produce quality and substantial economic losses. Bananas exemplify a fruit crop wherein mechanical damages significantly compromise visual quality and skin color changes from brown to black (Fernando et al., 2019).

One specific goal in minimizing post-harvest losses is to uphold the quality of perishable fruits, thereby creating opportunities for increased international market presence (Aurore et al., 2009). Consequently, a vital economic approach involves dehydrating unripe bananas and processing banana flour into diverse innovative products. This approach not only fosters increased banana consumption but also plays a crucial role in ensuring food security and contributing to human health (Ovando-Martinez et al., 2008).

Banana flour is a product with high storability potential and long shelf life and can be readily applied to food products. The most common methods of drying include oven drying (Alam et al., 2023). Before the drying process of banana during flour production, the fresh-cut fruit pulp can be pre-treated by subjecting it to treatments such as potassium metabisulfite

(0.1-0.2%) or citric acid, or saline solution to inactivate oxidases that lead to enzymatic browning (Kamal et al., 2022).

In the postharvest processing of banana pulp into flour, the drying phase is pivotal in guaranteeing the flour's superior nutritional quality concerning resistant starch, vitamins, and minerals.

Drying temperature significantly affects the characteristics, sensory qualities, and microbial safety of green banana flour, with preparation methods (whole, paste, or slices) further influencing the final product (Khoozani et al., 2019). In their study, Khoozani et al. (2019) compared green banana flour processed by oven drying at 50, 80, and 110 °C and freeze drying (FDF) to wheat flour. Higher temperatures reduced lightness and yellowness. Oven drying at 50 °C had the highest emulsion activity, while freeze drying showed superior emulsion stability, and oil and water holding capacities. Both freeze drying and oven drying at 50 °C preserved high levels of resistant starch (46.72% and 44.58%).

Unripe banana flour is regarded as a well-suited product for incorporation into food processing, given its elevated RS2 content and lower digestible starch levels. A variety of processing techniques, such as autoclaving, microwaving, high hydrostatic pressure, extrusion, ultrasound, acid hydrolysis, and enzymatic debranching treatments, have made significant advancements in the preparation of resistant starch. The process of preparing green banana flour necessitates a drying method that ensures the preservation of nutritional properties, with a particular emphasis on retaining RS2 (Munir et al., 2024).

According to a study conducted with 15 banana cultivars, the pulp moisture varied from 66-74 g per 100 g (Dotto et al., 2019). Flours derived from unripe bananas consist of starch (78.19–81.82%), pectin (3.29–5.61%), protein (2.90–4.59%), lipid (0.32–0.57%), and ash (2.30–2.79%) (Bi et al., 2017)

Pico et al. (2019) noted that raw unripe banana flour is characterized by a substantial concentration of dietary fiber, with a noteworthy portion consisting of resistant starch, defined as the fraction of starch that reaches the large intestine. At its mature, unripe stage, a banana retains elevated levels of carbohydrates, predominantly in the form of starch, along with significant amounts of minerals, protein, and phenolic compounds. In dessert bananas, amylose content is below 19%, whereas in cooking bananas it exceeds 21% (Dufour et al., 2009). Studies on *in vitro* digestion and the structural characteristics indicate that the starch of plantains has an arrangement of granules more resistant to enzymes than the starch of dessert bananas (Soares et al., 2011).

Chang et al. (2022) reported the carbohydrate composition of five Tanzania banana varieties: "Mzuzu" (plantains), "Malindi" (*Cavendish sp.*), "Mshale" (*Musa* AA Pisane litin), "Bukoba" (East African highland banana, *Musa* AAA), and "Moshi" (*Musa acuminata*). The observed carbohydrate content ranged from 76.78% to 83.49%, with a total starch composition varying from 58.01% to 68.74%. All banana cultivars investigated in the study exhibited B-type crystals, aligning with the resistant starch characteristics of banana starch.

In a study, Wang et al. (2019) investigated seven banana cultivars from various locations in China. The starch granules were of different and irregular shapes, such as spheres, long spheroids, and polygonal granules for cultivars. The amylose content of these cultivars ranged from 22.59% to 38.40%. The banana cultivars exhibited a combination of B- and C-type crystallinity.

In their investigation into the nutritional value and antioxidant compounds of bananas and plantains cultivated in Brazil, Borges et al. (2019) proposed that dessert and cooking banana genotypes exhibiting higher resistant starch (RS) content were notably present in cultivars within the *Musa* spp germplasm, as opposed to commercially available ones. The study encompassed 22 *Musa* spp genotypes, including diploid (AB), triploid (AAA, AAB, and ABB), and tetraploid (AAAB, AABB, and ABBB) varieties, comprising dessert bananas, cooking bananas, and plantains. The analysis focused on total starch (TS) and RS content, revealing a TS content ranging from 42.3% (FC06–02, AABB) to 80.6% (Pelipita, ABB). Meanwhile, the RS content varied from 22.9% (Namwa Khom, ABB) to 49.9% (Terra Ana Branca, AAB) across all examined banana genotypes.

In an investigation by Kumar et al. 2019 the total starch (TS) content in green banana flour (GBF) exhibited significant variation ($p < 0.05$), ranging from 68.97 ± 1.51 g/100 g dry weight (Grand Naine) to 81.66 ± 1.50 g/100 g dry weight (Monthan). Higher amylose levels were observed in Saba (24.21 ± 1.03 g/100 g dry weight) and Monthan (23.00 ± 0.37 g/100 g dry weight), while Grand Naine recorded a lower amylose content (15.52 ± 1.58 g/100 g dry weight). Additionally, a higher amylopectin content was noted in Monthan (58.65 ± 1.33 g/100 g dry weight).

In research conducted by Li et al. in 2020, it was found that the resistant starch levels in unripe Taiwanese bananas, Pei Chiao, Fomosana, and Tai-Chiao bananas, were 42.33, 34.00, and 30.00 g/100 g of banana flour on a dry weight basis, respectively. These values were notably higher ($p < .05$) compared to the resistant starch content in ripe bananas, which were 19.40, 17.03, and 15.63 g/100 g, respectively.

Mondal et al. (2021) documented that *Musa acuminata Colla* had diverse health-promoting and disease-preventing effects due to its significant bioactive compounds. These compounds, comprising phenolics, carotenoids, biogenic amines, phytosterols, and volatile oils, are distributed across various parts of the plant, including the stem, fruit, pseudostem, leaf, flower, sap, inner trunk, root, and inner core. The pharmacological activities of bananas span a broad spectrum, including antioxidant, immunomodulatory, antimicrobial, antiulcerogenic, hypolipidemic, hypoglycemic, leishmanicidal, anthelmintic, and anticancer properties.

Campuzano et al. (2018) reported that flour obtained from Cavendish banana pulp during the initial maturation stage contains 16.54 mg of total phenols (gallic acid equivalents, GAE) per 100g and demonstrates an antioxidant activity of 195.41 µmol Trolox equivalents per 100g.

Savlak et al. (2016) observed that the total phenol content in green banana flours from the Nanica (Dwarf Cavendish) cultivar ranged from 19 to 31 mg GAE per 100g on a dry basis. The antioxidant activity, as measured by FRAP (Ferric Reducing Antioxidant Power), varied from 2315 to 3683 (Fe-II) mmol per 100g on a dry basis. Additionally, the antioxidant activity assessed by DPPH (2,2-diphenyl-1-picrylhydrazyl) ranged from 174 to 299 mg (Trolox Equivalent) per 100g on a dry basis.

In a study conducted by Menezes et al. (2010), green banana flour from the Nanicão cultivar at the first maturation stage exhibited a total phenol content of 50.65 mg GAE per 100g (dry basis) and antioxidant activity of 358.67 µmols of Trolox Equivalent per 100g (dry basis).

In a study by Anyasi et al. (2018), essential macro and trace minerals from four cultivars were analyzed. UBF was prepared with organic acid pretreatment and oven drying. Zinc was the least abundant mineral (3.55 mg/kg), while potassium was the most abundant (14746.73 mg/kg) reported in the study.

Ferreira and Tarley (2020) conducted a study on the total concentration and bioavailability of Mg, Ca, Zn, Mn, Cu, and Fe in various brands of green banana (GB) flours and reported higher concentrations of Zn (1.45 mg/100 g) and Cu (0.33 mg/100 g) in the GB1 sample. Manganese concentrations varied significantly across samples (5.20–8.09 mg/100 g), while Calcium and magnesium concentrations showed variations ranging from 27.9–74.7 mg/100 g and 99.2–161 mg/100 g, respectively. Iron concentrations in the samples ranged from 2.57 to 11.1 mg/100 g.

In a study by De Brito et al. (2017), different types of flour, including some commercial brands of green banana flour, were evaluated. They reported Ca concentrations of 45.3 mg/100 g and Mg concentrations of 88 mg/100 g.

2.1.3. Banana Flour based Food Products

The fresh green banana is not commonly consumed by people, primarily because of its characteristic hardness and high astringency, which is attributed to the presence of soluble phenolic compounds like tannins (Sarawong et al., 2014). Food processing involves altering the form of food, encompassing both agricultural and animal products, to enhance their quality, acceptance, and storage stability. Due to their high perishability, bananas require processing to extend their shelf life, commonly into flour or starch. This transformation not only prolongs the shelf life of bananas but also opens up diverse applications in various products.

Banana flour can serve as a substitute for wheat flour in pasta, cakes, bread, cookies, and biscuits, while banana starch finds use as a thickening agent, fat replacer, edible coating, and more (Marta, et al., 2022). The inclusion of unripe banana flour in food formulations holds the potential to provide substantial health benefits to consumers. These benefits encompass a reduction in glycemic and insulinemic responses, a decrease in plasma cholesterol and triglyceride concentrations, enhancement of body insulin sensitivity, improvement in satiety, and a reduction in fat storage. Moreover, this dietary incorporation may contribute to lowering the risk of non-communicable diseases (Sardá et al., 2016).

Unripe banana flour was used in biscuits to improve their functional qualities to compensate for the losses caused by banana ripening. Biscuits were made with 0%, 15%, and 30% unripe banana flour (UBF) or fermented UBF (FUBF). The inclusion of UBF or FUBF decreased biscuit hardness, increased antioxidant activity, and enhanced total phenolic content ($p < 0.05$). A TPC of 1167.88 mg GAE/kg was found in biscuits containing 30% FUBF. The glycemic index (GI) values were notably high across all biscuit samples, with the control at 78.59 and the 30% FUBF sample at 72.74 ($p < 0.05$), indicating all samples fell into the high GI food category. (Çetin-Babaoğlu et al., 2024)

In a research study by Lee et al. (2023), green Saba banana flour (GSBF) was utilized to create a gluten-free steamed cake. The impact of soy protein isolate (SPI) (0%, 10%, 15%) and Ovalette (0%, 3.5%, 7%) to address technological challenges associated with SGBF on cake quality was investigated. Both additives successfully, significantly improving batter characteristics and the overall cake quality. The best-formulated GSBF cake exhibited notable enhancements in protein, dietary fiber, and resistant starch contents, suggesting its potential to address low dietary fiber intake. However, Texture Profile Analysis (TPA) and sensory evaluation indicated suboptimal texture and color acceptance. The overall acceptability of the best cake formulation fell between "like moderately" and "like very much," suggesting the need for further improvements in texture and color in future work.

In a recent study by Balmurugan et al. (2022), banana flour noodles were developed as a nutritional alternative to traditional wheat noodles, addressing potential deficiencies and allergic reactions. Unripe banana flour was incorporated at varying levels (5-45%), and the noodles were subjected to organoleptic evaluation. The study found 45% incorporation to be highly acceptable. The noodles, enriched with unripe banana flour, exhibited favorable nutritional composition, with 8.49% moisture, 8.23% protein, 1.27% fat, 1.95% fiber, 71.11% carbohydrates, and 22.04% resistant starch per 100g of noodles. Cooking quality characteristics during storage were also assessed, revealing optimal values for cooking time, gruel loss, water absorption, and rehydration ratio.

Raveena et al. (2022) introduced a novel use for unripe Nendran banana, termed 'Banana Grits' (BG), suitable for daily consumption akin to cereals and tubers. The *in vitro* starch digestion pattern indicated that 21% of the total starch in BG is slowly digestible starch (SDS), while 42% is resistant starch (RS). The presence of SDS and RS suggests potential contributions to gut health and glycemic control. Additionally, BG exhibited a high carotenoid content exceeding 3000 μg/100 g in hexane or acetone extracts, making it a significant source of provitamin A to address Vitamin A deficiency. A detailed phytochemical analysis of BG and unripe Nendran bananas revealed the presence of glycolipids.

Salazar et al. (2021) aimed to develop a fiber-enriched Frankfurter-type sausage by substituting underutilized green banana flour for wheat flour (8%) as a meat extender. Additionally, a low-fat formulation replaced 12% pork fat with 24% banana peel flour. Sausages were stored at 4 °C for 15 days. Cooking loss remained low in all formulations, and the substitution of wheat flour with banana flour did not alter the moisture and protein composition. Carbohydrate, fiber, and ash content varied with flour composition, notably increasing in low-fat sausages. Sensory attributes were consistent for high-fat sausages, while low-fat sausages were well-accepted, presenting a novel product for the panellists. Green banana flour emerged as a viable ingredient to enhance the nutritional profile of Frankfurter-type sausages, catering to wheat-allergic individuals.

Shareenie et al., (2021) explored the potential of substituting wheat flour (WF) with unripe Saba banana flour (USBF) in biscuits to enhance nutritional content. Among the formulations, 50% USBF and 50% WF showed improved ash, resistant starch (RS), and dietary fiber with reduced moisture and protein. The inclusion of USBF had an adverse impact on the appearance and textural parameters desired by consumers.

Prasajak et al. (2021) explored the impact of substituting resistant starch (RS) rich banana flour on the quality of gluten-free rice cookies and compared it with 100% wheat flour cookies as a control. Rice flour was replaced with unripe banana flour at varying levels (0%, 50%, 60%, 70%, 80%, and 100%). The study assessed pasting properties, physical attributes, texture, RS content, and sensory evaluation. As banana flour substitution increased, the viscosity of the blended flour also increased. Cookies with banana flour had smaller diameters, reduced spread ratio, and higher hardness. The RS content ranged from 1.90% to 8.50%, surpassing the 2.85% found in wheat flour control cookies. Cookies with 70% banana flour received the highest overall sensory score, comparable to wheat control cookies. This study suggested that replacing rice flour with unripe banana flour had the potential to yield gluten-free rice cookies with elevated RS content.

Ho et al. (2022) formulated snack bars with a low glycemic index (<55) by incorporating green banana flour (GBF). Subsequent studies included konjac glucomannan to improve the textural and nutritional quality of the GBF-based snack bars.

Ahmed et al. (2020) studied mature green bananas from the 'Williams' and 'Baradika' varieties. Both flours exhibited suitable pasting properties for baked and fried tortilla chips. Sensory evaluations indicated that fried products were more acceptable than baked ones, although the differences between cultivars were not significant. The study highlights the potential of utilizing banana fruit in food products to reduce postharvest losses.

Horie et al. (2020) developed Banafine®, a food powder derived from the enzymatic hydrolysis and fermentation of green unripe bananas. The researchers reported that this innovative product addresses the astringent and bitter taste associated with unripe bananas. According to the study, Banafine® exhibits concentration-dependent immunostimulatory effects, particularly in increasing TNF-α release in the RAW 264.7 cell line. Compared to the original unripe banana powder, Banafine® was found to demonstrate significantly enhanced immune-stimulating properties, suggesting that enzymatic hydrolysis and fermentation contribute to the development of potent immune-stimulating macromolecules in the product.

Netshiheni et al. (2019) reported that the inclusion of banana-enriched drinks and other food products has been shown to mitigate the risk of muscular contractions in athletes, attributable to the adequate concentration of minerals such as potassium (K) and magnesium (Mg), along with essential vitamins.

De S Viana et al. (2018) developed sliced bread incorporating green banana flour (GBF) to achieve both high resistant starch content and favorable acceptance. Four bread formulations were examined, with GBF concentrations of 0% (control), 15%, 20%, and 25% (Terra Maranhão variety). Flour and bread were analyzed for chemical composition, total starch, and resistant starch. GBF content did not significantly affect moisture, ash, or lipid levels. The breads with 15% and 20% GBF showed over 90% acceptance for all sensory attributes, resulting in a product with high sensory acceptance and resistant starch content 4.2 times higher than conventional sliced bread.

Segundo et al. (2017) explored the impact of mechanically fractionated green banana flour on sponge and layer cakes. They demonstrated a successful 30% substitution of banana flour in layer cakes, resulting in minimal sensory decline. However, sponge cakes were adversely affected, showing reduced specific volume, poorer sensory attributes, and increased hardness, although these effects were less pronounced with fine flour. Both cake types exhibited improved resistant starch and dietary fiber content with banana flour, up to a fivefold increase in resistant starch. Sponge cakes also showed higher polyphenols and antioxidant capacity, especially with the coarse fraction. Mechanical fractionation allowed the practical nutritional enhancement of cakes using banana flours.

Almanza et al. (2015) suggested using unripe plantain flour (UPF) in bakery and pasta for its cost-effectiveness and utilization of plantain pulp components. Acid-treated UPF (modified unripe plantain flour: MUPF) was created to enhance the indigestible carbohydrate content in spaghetti. Substituting semolina with MUPF tripled total dietary fiber, while UPF doubled it. MUPF spaghetti showed the lowest hydrolysis rate and glycemic index. MUPF and UPF spaghetti showed similar antioxidant capacities, but MUPF spaghetti had a slightly lower overall acceptability than the control.

2.2.Health Benefits of Unripe Banana Flour

2.2.1. UBF Resistant Starch and Health Benefits

The primary energy source in the typical human diet is starch. Salivary and pancreatic α-amylase break down starch into smaller saccharide molecules, which are further degraded by brush border enzymes into glucose for absorption. Starch granules have intricate and hierarchical structures, making them more bulky than other nutrients. Consequently, a portion of starch may remain undigested in the small intestine and proceed to the colon, where it can undergo fermentation by gut microbiota (Guo et al., 2020). Resistant starches (RS) are those that, due to their localization, physical attributes, or chemical characteristics, remain inaccessible to enzymatic digestion, essentially functioning as dietary fiber within our bodies (Arp et al., 2021). Resistant starch can be classified into five types based on its structural characteristics, chemical modification, the effects of cooking, or linkage with lipids.

The resistance properties of starch to digestion are influenced by various factors including the physical form of stored starch in grains or seeds, the type and size of starch granules, and the interactions between starch and other nutrients (e.g., lipids, sugars, proteins, gums, and plant bioactive components inhibiting α-amylase) (Oyeyinka et al., 2021). Additionally, RS content is affected by food processing methods such as cooking, annealing (physical modification of starch in water at temperatures lower than gelatinization), milling, high-pressure treatment, autoclaving, extrusion, as well as storage conditions and time (Fonseca et al., 2021).

According to Kraithong et al. (2021) the barrier properties of RS1 play a crucial role in slowing down digestive enzyme activities. Chemical composition, cell wall thickness, porosity, permeability, and structural integrity significantly influence starch hydrolysis. Attributes like wall thickness, particle size, and encapsulation efficiency determine the resistance of encapsulated starch to enzymatic digestion. A more complex food matrix and denser protein bodies within intact cells further enhance the hindrance to starch digestion, promoting reduced enzymatic breakdown.

Table III

Characteristics and Occurrence of Different Types of Resistant Starch.
Adapted from Bojarczuk et al. (2022)

Type of starch	Characteristics	Occurrence
RS1	Physically inaccessible starch that cannot be hydrolyzed due to the cell wall barrier.	Products from coarsely ground or whole grains (e.g., bread, seeds, and legumes).
RS2	Raw starch (ungelatinized starch) with intact starch granules	Raw potatoes, green bananas, and high-amylose corn.
RS3	Retrograded starch is formed when starchy foods are cooked and then cooled- reassociation between amylose-amylose, amylose- amylopectin and amylopectin-amylopectin.	Cooked and then cooled starchy foods such as potatoes, rice, pasta, oatmeal, and stale bread.
RS4	Resists enzymatic hydrolysis by modifying its original molecular structure and the addition of certain chemical functional groups by chemical modification.	Foods with chemically modified starches, such as cross-linked starch (e.g., some commercially produced breads and pastries).
RS5	Combination of long and unbranched starch chains with free fatty acids, forming a helical structure that is difficult to digest, and intentional rearrangement of starch molecules – resistant maltodextrin.	Foods containing naturally occurring amylose–lipid complexes, for example, bread containing fat as an ingredient, or foods which contain artificially produced amylose–lipid complexes and also a new, non-viscous type of dietary fiber, produced by the intentional rearrangement of starch molecules - resistant maltodextrin

Resistant starch (RS) exhibits physiological functions comparable to fermentable dietary fibers. It regulates glycemic response by slowing glucose release and promotes gut health by stimulating the growth of beneficial bacteria. These effects, among others, contribute to its overall positive impact on health (Du et al., 2020).

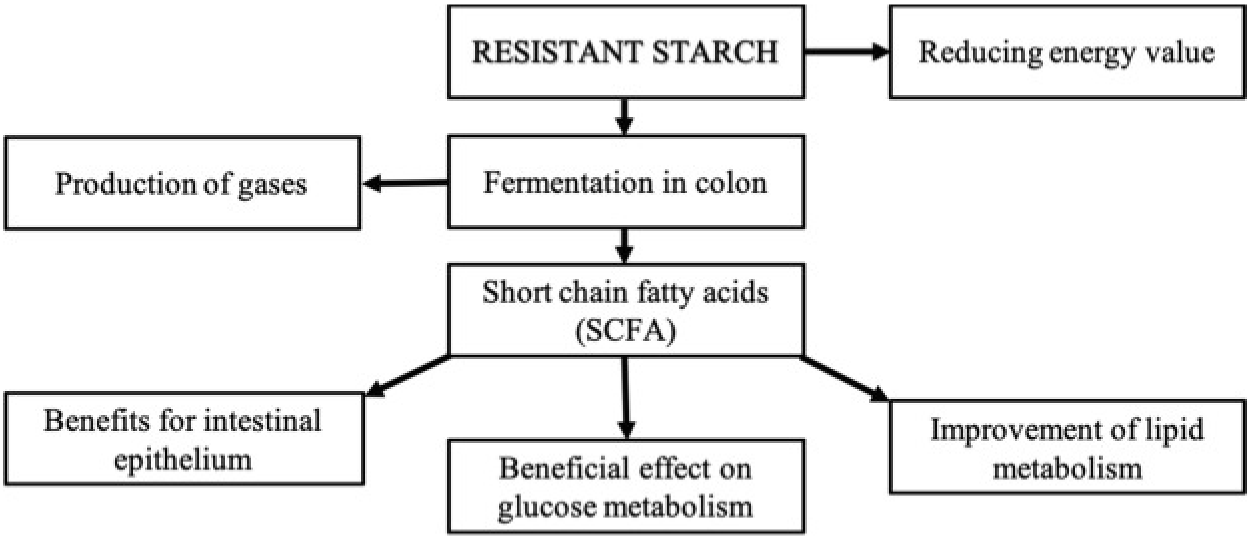


Figure 4: Potential Benefits of Resistant Starch

Adapted from Bojarczuk et al. (2022)

Wen et al. (2022) suggested that incorporating resistant starch into the diet can be beneficial for specific medical conditions such as diabetes, metabolic syndrome, chronic kidney disease, constipation, and colitis. The positive health effects are linked to the modulation of gut microbiota and the conversion of resistant starch by gut microbes into active and bioavailable metabolites that support intestinal health, including SCFA, bile acids, and amino acids. A potential mechanism that could influence insulin sensitivity involves a change in fatty acid flux. (Wong & Louie, 2016) The fermentation of resistant starch (RS) in the colon results in the secretion of short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate. These SCFAs may stimulate the production of hormones associated with insulin metabolism, such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), which induce insulin secretion. The consumption of RS may positively impact insulin sensitivity by reducing ectopic adipose tissue and regulating adipogenesis likely influenced by the effects of SCFAs (Keenan et al., 2015).

Dodevska et al. (2015) in their study involved 47 overweight and obese individuals (aged 45–74) with disordered glucoregulation and dyslipidemia, divided into RS and Fiber groups. Participants underwent a 12-month lifestyle and dietary intervention featuring a low-fat, high-fiber diet (>25 g/day). The fiber group received guidance to increase total fiber intake, while the RS group focused on boosting resistant starch (RS) intake. The RS group showed a greater reduction in total cholesterol and non-HDL cholesterol, whereas the Fiber group demonstrated improved glucoregulation, with a significant decrease in glycemia after a 2-hour oral glucose tolerance test.

Maziarz et al., (2017) in a randomized controlled trial, 18 overweight, healthy adults consumed either muffins enriched with 30 g high-amylose maize resistant starch type 2 (HAM-RS2) ($n = 11$) or 0 g HAM-RS2 (control; $n = 7$) daily for 6 weeks. The HAM-RS2 and control muffins were similar in total calories and available carbohydrates. Consuming 30 g HAM-RS2 daily for 6 weeks improved glucose homeostasis, lowered leptin concentrations, and increased fasting PYY in healthy overweight adults without impacting body composition and may aid in the prevention of chronic disease.

Bodinham et al., (2009) in a crossover study demonstrated that overweight male subjects experienced a significant reduction in energy intake during the subsequent meal after consuming breakfast and lunch meals containing RS2. Vahdat et al., (2020) reported the consumption of resistant starch (RS) significantly decreased levels of inflammatory biomarkers, including IL-6 and TNF-α.

The study by Xu et al. (2020) evaluated the anti-obesity effects of two types of resistant starch: RS2 (from untreated lentil starch) and RS3 (from autoclaved and retrograded lentil starch) in mice with high-fat diet-induced obesity, focusing on the relationship between their supramolecular structure and physiological functionality. After six weeks, mice receiving RS3 exhibited a more pronounced effect in controlling body weight, reduction in blood glucose and triglycerides.

Gourineni et al. (2019) conducted a trial with healthy adults, demonstrating that nutritional bars containing potato-based RS4 significantly lowered postprandial glucose and insulin levels. In their double-blind, randomized, placebo-controlled crossover study, 38 participants consumed bars with either control (2 g), medium (21 g), or high (30 g) fiber in 2-4 visits. Both fiber-enriched bars reduced peak capillary glucose and venous insulin compared to the control. These findings suggest that potato-based RS4 fiber effectively mitigates postprandial glycemic and insulinemic responses in healthy individuals.

Han Zhuorui et al. (2021) used green unripe fruits to produce resistant starch-rich flour to assess its anti-obesity effects in high-fat diet-induced obese rats. Three doses (1.25, 2.5, 5.0 g/kg BW/day) and an orlistat control were tested over six weeks. Body weight reductions in the three dose groups were 13.77%, 8.44%, and 11.82%, with the low dose also reducing fat accumulation by 21.11%. Total cholesterol and triglycerides decreased significantly, with the low dose showing reductions of 43.85% and 66.67%, respectively. Liver fat and inflammation decreased, and blood sugar dropped by 19.31%, improving liver function. Plantain flour demonstrated promising anti-obesity and liver-protective effects.

In a six-week, double-blinded trial by De Oliveira Lomeu et al. (2021) with 60 females aged 20 to 50, the impact of cocoa and unripe banana flour (UBF) beverages on overweight markers was assessed. The cocoa beverage had 3.07 g dietary fiber/serving, while cocoa with UBF contained 8.48% resistant starch. Both beverages reduced waist circumference and lowered body fat percentage.

Cassettari et al. (2018) conducted a randomized clinical study to evaluate the effects of green banana flour and laxatives on chronic constipation in children and adolescents. The need for laxatives significantly decreased when green banana biomass was combined with sodium picosulfate (87%) or PEG 3350 with electrolytes (63%). Green banana biomass, alone or with laxatives, was well tolerated with no reported adverse effects.

In a research study by Sardá et al. (2016), healthy volunteers consumed unripe banana flour (UBF), a rich source of resistant starch (5 g per 8 g of UBF), three times a week over six weeks. The intake of resistant starch (15 g per week) significantly reduced hunger and enhanced satiety, as assessed by the visual analogue scale (VAS) and the area under the curve (AUC) for ghrelin and peptide YY hormones.

Due to their high resistant starch (RS) content and palatability, green bananas emerge as a preferable dietary option, particularly for individuals dealing with diabetes, nephro-diabetes, and obesity (Bi et al., 2017)

2.2.2. Prebiotics and Health: Prebiotic Potential of Unripe Banana Flour

There is a belief that the association between gut microbiota and functional foods, such as prebiotics, can potentially reduce the risk of diseases. Studies are increasingly focused on investigating the mechanisms that contribute to maintaining the host's health.

(Thompson et al., 2022). Gibson et al. (2017) stated that the International Scientific Association of Probiotics and Prebiotics (ISAPP) defined dietary prebiotics during their 6th meeting in 2008 as “Selectively fermented ingredients that induce specific changes in the composition and/or activity of the gastrointestinal microbiota, ultimately benefiting the host's health”.

Prebiotics encompass a category of biological nutrients that can be broken down by microflora in the gastrointestinal tract (GIT), particularly *Lactobacilli* and *Bifidobacteria*. Upon ingestion, whether as a food additive or supplement, these prebiotics undergo degradation by colonic microflora, resulting in the production of short-chain fatty acids (SCFA) that are absorbed into the bloodstream (Bamigbade et al., 2022).

The primary prebiotic groups that were extensively studied for their impact on human health are fructo-oligosaccharides (FOS) and galacto-oligosaccharides (GOS). However, recent investigations have expanded the scope of prebiotics beyond carbohydrates, acknowledging other non-carbohydrate compounds that fulfil prebiotic criteria. Polyphenols extracted from berries are now recognized as prebiotics (Gu et al., 2020).

While dietary fibers are classified as non-digestible polysaccharides, not all dietary fibers qualify as prebiotics. Therefore, not every non-digestible polysaccharide can be considered a prebiotic (Bamigbade et al., 2022). Prebiotics encompass four criteria as outlined by Bindels et al. (2015)

(1) resistance to hydrolysis by mammalian enzymes, gastric acidity, and gastrointestinal absorption;
(2) exclusive fermentation by the gut microbiota (GM);
(3) elicitation of systemic or luminal effects that benefit host health; and
(4) selective stimulation of the growth and activity of GM associated with health and well-being.

Prebiotics can be derived or extracted from various food sources, including seeds, whole grains, legumes, chicory roots, Jerusalem artichokes, onions, garlic, and certain vegetables (Singla & Chakkaravarthi, 2017) Prebiotics encompass a wide range of forms, including FOS, GOS, human milk oligosaccharides (HMO), lactulose, lactosucrose, inulin, resistant starches (RS), arabinoxylans (AX), xylooligosaccharides (XOS), and pectin (Davani-Davari et al., 2019)

Inulin refers to a group of linear fructans characterized by β (2→1) fructosyl–fructose glycosidic bonds, which contribute to its unique physiological and structural properties. Due to these β configuration bonds between fructose monomers, inulin-type fructans resist enzymatic hydrolysis by digestive enzymes (Cardoso et al., 2020)

FOS consists of a sucrose molecule attached to a chain of 3–30 fructosyl units. They are oligomeric linear fructans with β-(2–1) or β-(2–6) fructosyl-fructose linkages, where the first monomer in the chain is either an α-D-glucopyranosyl or β-D-fructopyranosyl residue. The degree of polymerization (DP) for inulin can reach up to 60, the DP for FOS is typically less than 10 (Ibrahim, 2018).

GOS are the product of lactose extension and are included among non-digestible oligosaccharides. They are arranged in two subgroups: (i) with excess galactose at C3, C4 and C6; and (ii) manufactured from lactose through enzymatic trans-glycosylation (Mahoney, 1998).

Starch that resists digestion in the upper gastrointestinal tract is referred to as resistant starch (RS). RS bypasses enzymatic breakdown by human pancreatic amylase in the small intestine and reaches the colon, where it promotes health benefits by generating high levels of butyrate, supporting its classification as a prebiotic (Fuentes-Zaragoza et al., 2011).

Arabinoxylans (AX) are the primary non-cellulosic polysaccharides found in plant cell walls. Their structural properties, heterogeneity, and extraction are influenced by their location and interactions with other cell wall components. Known as "pentosans," AX are composed of the pentose sugars xylose and arabinose (Kamel et al., 2020).

XOS, also known as xylan, is the second most abundant biopolymer in the plant kingdom. These sugar oligomers consist of β-1,4-inked xylose, a pentose sugar, and are naturally present in food sources like honey, bamboo shoots, fruits, vegetables, and milk. Based on their substituent groups, xylan is classified into three types: (i) glucuronoxylan, (ii) neutral arabinoxylan, and (iii) glucuronoarabinoxylan (Berger et al., 2021)

The mechanism of action of prebiotic supplementation involves enhancing bacterial growth and functionality of specific species or genera in a regular diet. This leads to the modulation of the gut microbiota (GM) and a pronounced bifidogenic effect. Goblet cells play a crucial role in mucus production, contributing to the protection of the mucous membrane. This mucus layer in the colon helps reduce inflammation caused by bacterial interactions with intestinal epithelial cells. The gut microflora ferments prebiotics, yielding short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate, which contribute to various health benefits. Additionally, prebiotic supplementation induces antimicrobial agent production and lowers the intestine's pH levels. These effects work together to suppress and restrict the growth of pathogenic bacteria, ultimately leading to positive health outcomes. (Megur et al., 2022).

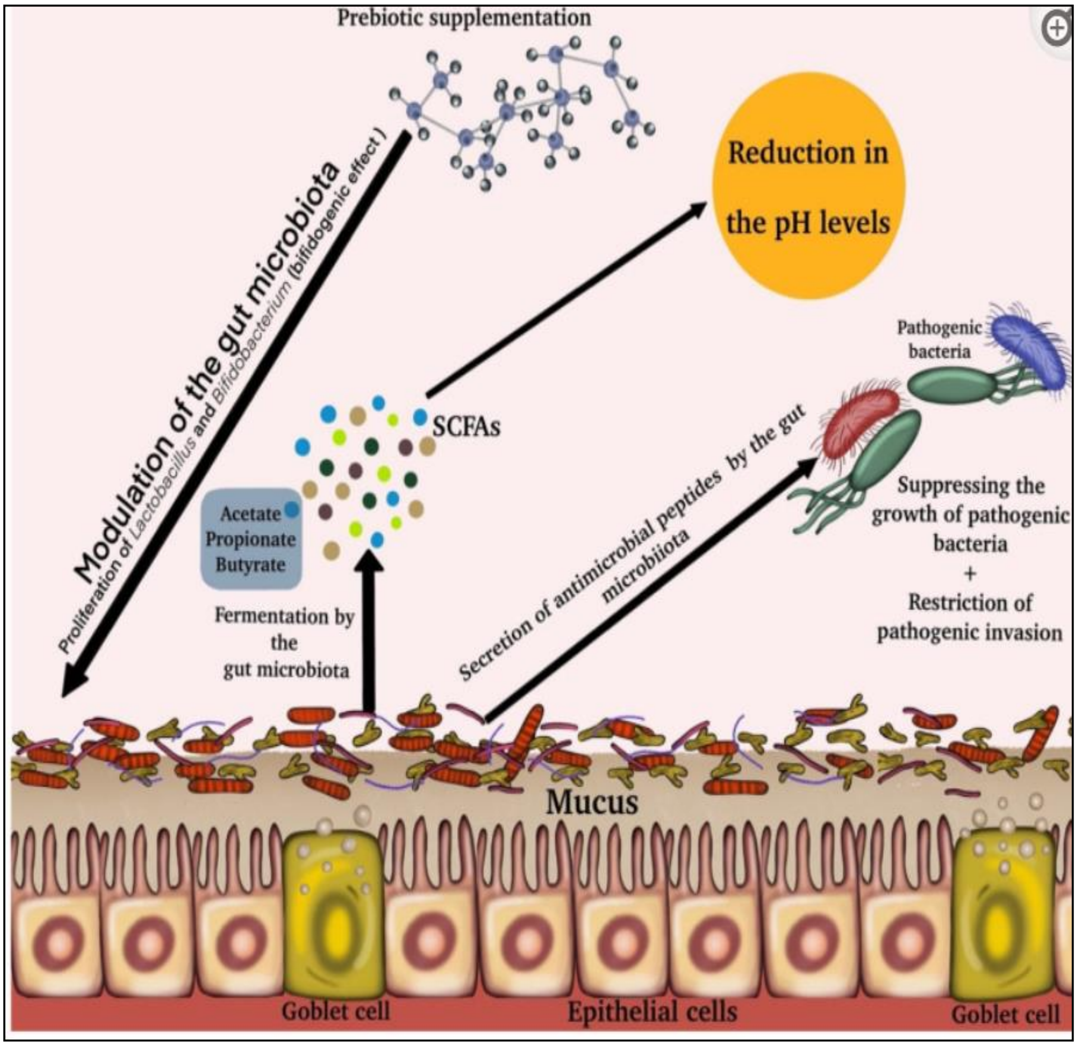


Figure 5: Mechanism of Action of Prebiotic Supplementation

Illustration by Megur et al. (2022)

The selective utilization of prebiotics in the gut promotes the growth of microbiota, which exerts immune-boosting effects at both species and strain levels. The bacterial cell wall and biomass enhance immunomodulation and contribute to fecal bulking, supporting healthy bowel movements. Metabolites such as organic acids lower luminal pH, creating an environment unfavorable for pathogens while improving the solubility and absorption of minerals like calcium. These metabolites also regulate hormones and maintain epithelial integrity (Ashaolu., 2020).

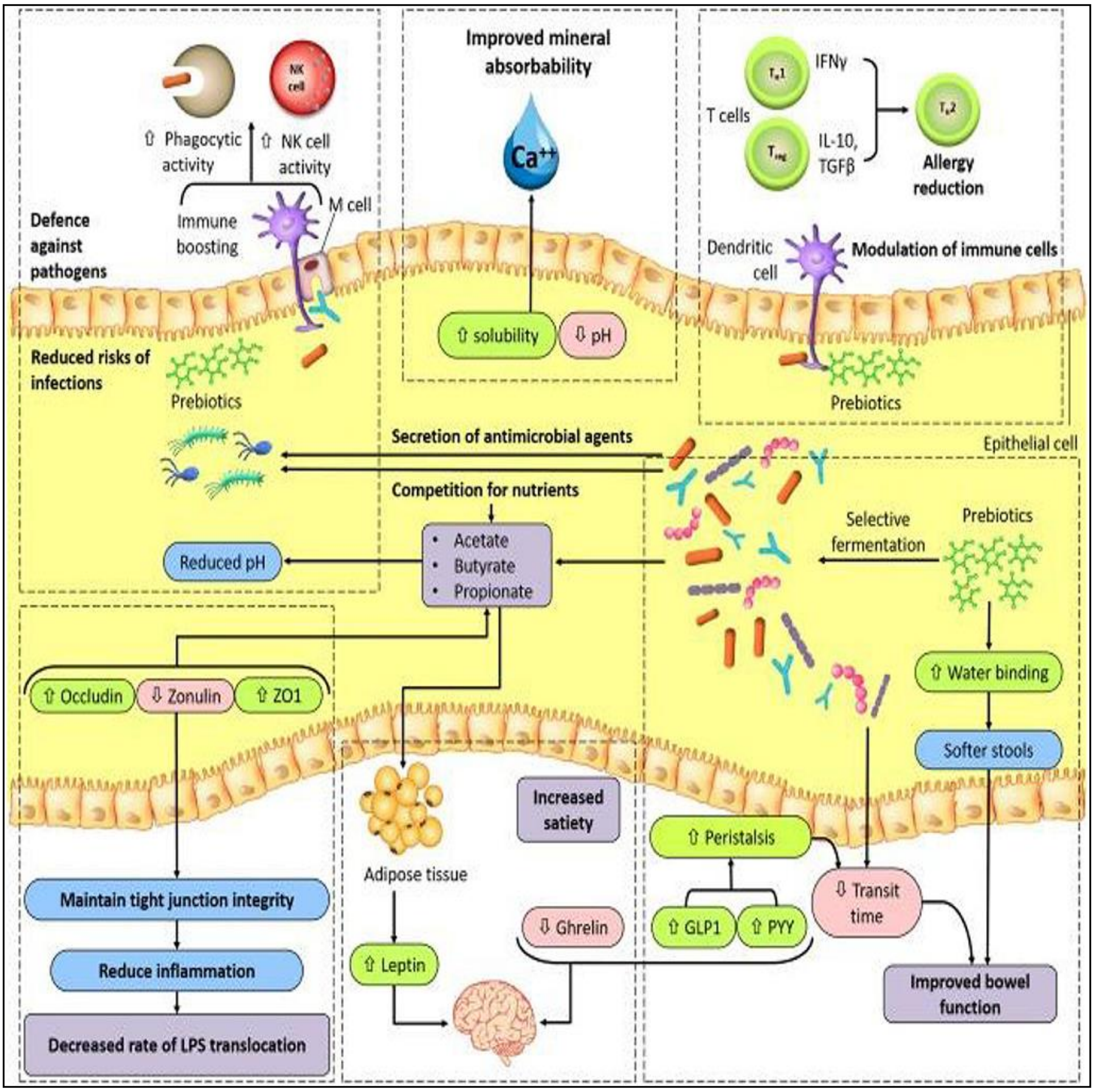


Figure 6: Possible mechanisms of prebiotic benefits to human health

(Illustration by Ashaolu., 2020).

GLP1- glucagon-like peptide1; M cell- microfold cell; NK- natural killer; PYY- peptide YY; TGFβ -transforming growth factor-β; TH1, TH2- type 1 T helper, type 2 T helper; Treg-regulatory T; ZO1- Zonula occludens 1.

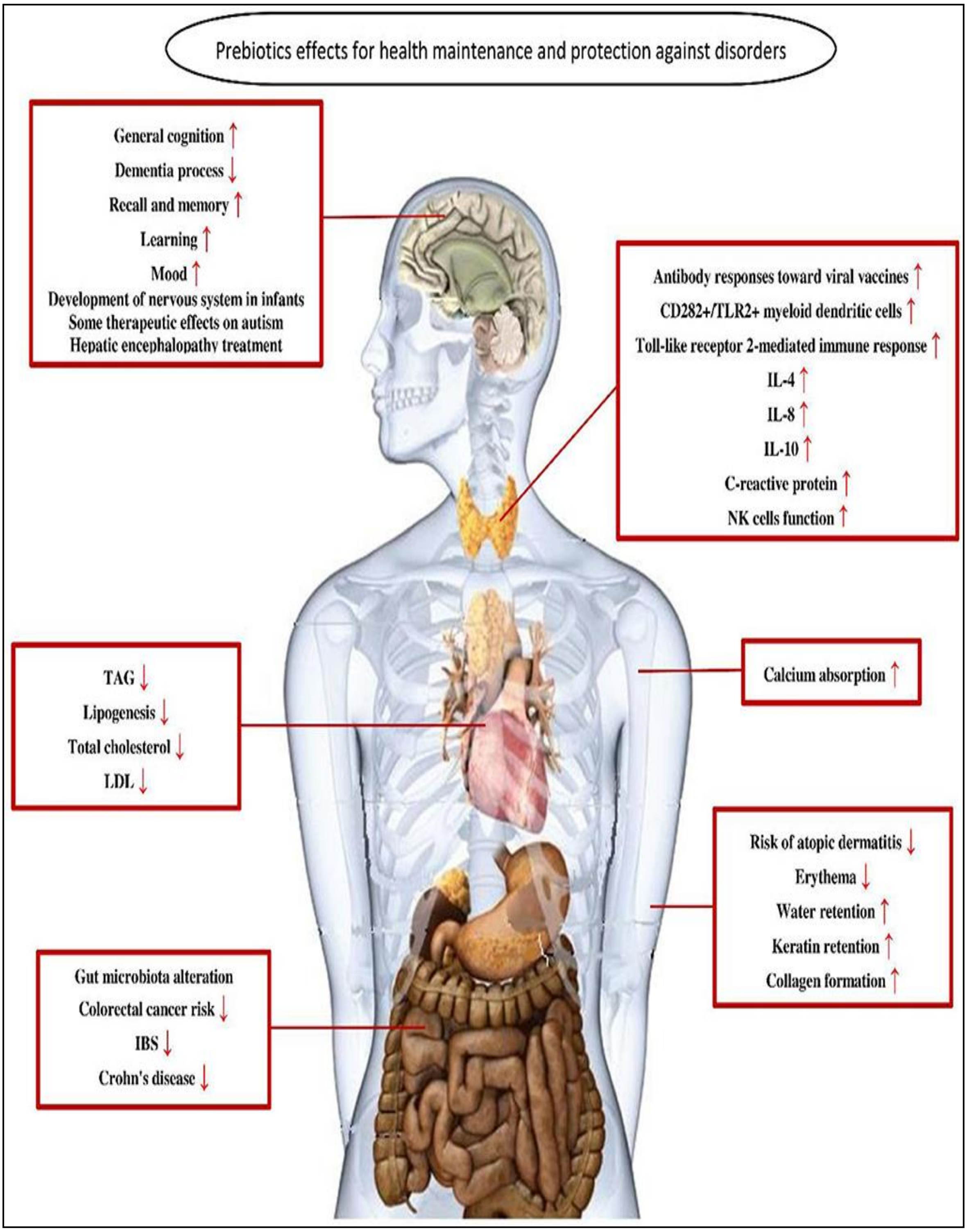


Figure 7: The Role of Prebiotics in Maintaining Health and Preventing Disorders

Illustration by Davani-Davari et al., (2019)

TAG, triacylglycerol; LDL, low-density lipoprotein; IBS, irritable bowel syndrome; IL-4, interleukin 4; IL-8, interleukin 8; IL-10, interleukin 10.

Nogacka et al. (2020) aimed to evaluate the fermentative dynamics of various prebiotic substrates and their effects on the composition and metabolic activity of the intestinal microbiota in lean and extremely obese individuals. Prebiotic modulation increased Bacteroides and *Faecalibacterium* in obese subjects, while normal-weight individuals showed rises in *Bifidobacterium* and *Faecalibacterium.*

Khan et al. (2022) aimed to validate the physiological and functional health benefits of enzymatically prepared resistant starch (EM-RSIII) from maize flour. EM-RSIII was included in rat diets to evaluate its prebiotic effects. After 21 days, EM-RSIII-fed rats exhibited significant reductions in body weight gain, fecal pH, glycemic response, serum lipid profile, and insulin levels, alongside improved gut microbiota and increased short-chain fatty acids (SCFAs). Consumption of medium and high doses of EM-RSIII elevated butyrate-producing and starch-utilizing bacteria such as *Lactobacillus, Enterococcus,* and *Pediococcus*, while *E. coli* was completely suppressed at high doses. Fecal SCFAs were notably increased in EM-RSIII-fed rats

Baxter et al. (2019) conducted a study to analyze butyrate production in the gut microbiome by supplementing the diets of 174 healthy young adults for two weeks with different fermentable fibers. Resistant starch from potatoes (RPS) resulted in the greatest increase in total short-chain fatty acids (SCFAs), including butyrate. Resistant starch from maize (RMS) and inulin from chicory root induced different changes in fecal communities but did not significantly increase fecal butyrate levels. The study emphasized that not all fermentable fibers are equally effective, highlighting the role of individual microbiota composition in dietary supplement response.

Baek et al. (2023) studied the prebiotic properties of green banana flour to evaluate its impact on intestinal microbiota composition in C57BL/6N mice. Over a 3-week period, mice received either a low dose (500 mg/kg/day) or a high dose (2000 mg/kg/day) of green banana flour daily. Faecal samples collected on days 0, 14, and 21 were analyzed for microflora composition. By day 21, a significant shift in intestinal microbiota composition was observed, regardless of the administered dose. The consumption of green banana flour was associated with an augmentation of beneficial bacteria.

Jaiturong et al. (2020) reported that unpeeled raw banana (URB) and banana starch (BS) from Kluai Namwa Luang were rich in nutrient sources with digestive benefits. They noted that URB was rich in dietary fiber (9.7 ± 0.2 g per 100 g dwb), while BS was a significant source of RS (74.1 ± 0.1 g per 100 g dwb). According to the researchers, the crystalline structure of the powder and starch restricts access to digestive enzymes, resulting in digestive-resistant properties. They observed that both URB and BS exhibited prebiotic qualities promoting the growth of probiotics comparable to commercial inulin. The researchers suggested that URB and BS should be considered for development as health promotion products.

Tian et al. (2020) demonstrated that bananas, rich in indigestible carbohydrates, act as potential whole-fruit prebiotics. *In vitro* fermentation of ripe banana powder with faecal samples from six donors revealed up to 80% degradation of banana polysaccharides and increased production of SCFAs, particularly acetate. High-throughput 16S rRNA sequencing showed significant changes in gut microbiota, including increased Bacteroides and maintained Bifidobacteria. Although Lactobacillus proportions increased, the change was not significant. This study highlights banana powder's role in improving gut microbial diversity and SCFA production, supporting its potential as a prebiotic in diets and functional food applications.

Alvarado-Jasso et al (2020) examined the combined effects of agavins (AV) and green banana flour (BF) on energy intake, body weight, metabolic markers, and gut short-chain fatty acid (SCFA) levels in obese mice. Mice fed a high-fat (HF) diet showed increased body weight and decreased SCFA levels. Those on a BF diet experienced reduced body weight and metabolic markers ($p < 0.05$). The combination of AV and BF provided synergistic protection against obesity-related metabolic issues, suggesting their potential as interventions for obesity-related disorders.

Rosado et al. (2021) studied the effects of green banana flour (GBF) on obesity-related conditions in mice on high-fat diets. Mice were divided into four groups: standard chow (SC), standard with 15% GBF (SB), high-fat diet (HF), and high-fat diet with 15% GBF (HFB). HFB mice had 21% less weight gain and reduced fat pad sizes compared to HF mice. Both SB and HFB groups showed smaller adipose tissue and changes in gut microbiota, with reduced Firmicutes and increased Bacteroidetes. The study concluded that GBF improved metabolism, reduced inflammation, and altered gut microbiota in obese mice.

Li et al. (2022) examined the effects of green banana flour (GBF) on restoring gut microbiota and intestinal barrier integrity after antibiotic disruption. Using a mouse model treated with ciprofloxacin and metronidazole, GBF (400 mg/kg) was found to accelerate recovery of gut permeability and barrier function compared to natural recovery (NR). GBF increased mucin secretion and enriched beneficial bacterial families, aiding in the rebalancing of gut microbiota. The study suggests GBF as a promising functional food for repairing antibiotic-induced gut disruptions.

De Andrade et al. (2021) investigated the impact of unripe banana flour (UBF), containing 48% resistant starch, on the serum concentrations of gut-derived uremic toxins, which are widely recognized as markers of disease burden in chronic kidney disease (CKD). in individuals undergoing peritoneal dialysis (PD). Conducting a randomized, double-blind, placebo-controlled, crossover trial with 43 PD patients, the study involved sequential treatments of UBF (21 g/day) and placebo (waxy corn starch—12 g/day) for 4 weeks each, with a 4-week washout. The results indicated that UBF did not significantly alter serum levels of these metabolites overall. However, a reduction in total serum indoxyl sulfate was observed in a subgroup of participants with daily UBF intake closer to the proposed amount.

Sugiharto et al. (2023) studied the effects of unripe banana flour (UBF) alone or with probiotics or multienzymes on broilers. Four groups were tested: CONT (control feed), UBF (5% UBF), UBFPRO (5% UBF + 0.05% probiotics), and UBFZYM (5% UBF + 0.05% multienzyme). Notable findings include improved growth performance in UBF, UBFPRO, and UBFZYM, with higher daily weight gain and feed efficiency compared to the control. UBFZYM exhibited enhanced hemoglobin levels, altered blood parameters, and improved intestinal morphology, suggesting positive effects of UBF in combination with probiotics or multienzymes on broiler health and performance.4

2.2.3. Glycemic Index and Glycemic Response of UBF-based Foods

The increasing prevalence of type 2 diabetes (T2D) worldwide calls for effective approaches to its management. Strategies for diabetes have generally focused on optimizing overall glycemic control as assessed by glycated hemoglobin (HbA1c) and fasting plasma glucose (FPG) values. In 2001, the American Diabetes Association established postprandial glucose (PPG) as an independent contributor to HbA1c and diabetes complications, and increasing evidence suggests that all three glycemic parameters of HbA1c, FPG, and postprandial glucose (PPG) are independently important. (Vlachos et al., 2020)

The Glycemic Index (GI) is a numerical measure indicating a carbohydrate food's impact on blood glucose levels. It represents the percentage of the incremental area under the glycemic response curve (AUC) for a food containing 50g of available carbohydrates compared to the AUC for a standard reference food (usually 50g of glucose or white bread) in the same individual. The lower the rate of carbohydrate absorption, the slower the rise in blood glucose, resulting in a lower GI value (Wolever et al., 1991; Jenkins, 2008)

According to the classification by Brand-Miller et al. (2003), foods are categorized based on their glycemic index (GI) as follows: low GI for values below 55, medium GI for values between 55 and 70, and high GI for values above 70. A GI value of ≥70 is considered high, 56–69 is medium, and ≤55 is low, with glucose serving as the reference point with a value of 100.

Glycemic response pertains to food's impact on blood glucose levels after being consumed. Glycemic Load (GL) extends beyond the Glycemic Index (GI), considering the type of carbohydrate and the total amount ingested. This concept emerged to address the combined influence of carbohydrate quantity and quality on blood glucose levels. GL assesses a food's carbohydrate content and how each gram affects blood glucose. It is categorized as low (< 10), intermediate (11–19), and high (> 20). This metric is employed as a foundation for objectives such as weight loss or diabetes management. Glycemic Load (GL) is calculated using the formula GL = GI × (total carbohydrate - dietary fiber) / 100. Here, "available carbohydrate" is determined by subtracting dietary fiber from the total carbohydrate content. Each unit of GL represents the glycemic impact equivalent to 1 gram of glucose. On average, diets consist of 60–180 GL units per day. It's essential to note that a diet with a high glycemic load may potentially contribute to an elevated risk of diabetes and obesity over time (Augustin et al., 2015).

In a crossover trial by Chang et al. (2019), altering nutrient breakfasts focused on glycemic load (GL) by reducing total carbohydrates, resulting in a low-carbohydrate breakfast (LCBF) where carbohydrates provided around 10% of energy. Participants, not on a low-carb or low-calorie diet, showed a 74% lower glucose response post-breakfast with LCBF, and a 32% ± 30% lower 24-hour incremental area under the curve (AUC) compared to the glycemic load breakfast (GLBF) group. Glycemic variability significantly improved in the LCBF group. No differences were found in postprandial responses after lunch and dinner between the two groups.

Kahraman et al. (2019) in their study, incorporating various resistant starch (RS) sources notably lowered the glycemic index (GI) of cookies. Cookies with commercial RS sources (Fibersym, Hylon VII, and Novelose 330) showed GIs of 81.7, 83.0, and 86.2, respectively. The cookies supplemented with lab-scale-produced cross-linked wheat and corn starches had the lowest GIs (77.2 and 78.8, respectively). The control cookie had the highest GI at 112.1, with no significant difference compared to cookies supplemented with native corn (GI: 111.2) and wheat (GI: 110.5) starches.

Njapndounké et al. (2021) studied the effects of an optimal biscuit made from composite flour of *Musa sapientum* L. ('banana cochon') and *Vigna unguiculata* L. (cowpea) on diabetic Wistar rats. The biscuit contained 9.4% dietary fiber, a low glycemic index (50.91%), and was rich in potassium, magnesium, and calcium. The biscuit significantly lowered blood glucose levels despite increased food intake. Treated diabetic rats showed significant improvements in hematological parameters, and biochemical markers like serum creatinine, urea, liver enzymes, and bilirubin were closer to non-diabetic levels.

Cahyana and Restiani (2017) replaced 60% of wheat flour with modified banana flour in cookies and reported a significantly reduced glycemic index (GI) from 77.1 to around 64 in mice. Further increasing the substitution to 90% resulted in a lower GI of approximately 57.1. However, the reduction was not significantly different from the GI observed with a 50% substitution of modified banana flour.

Onuoha et al. (2019) determined the glycemic indices of unripe red banana and unripe plantain flour meals. Both unripe plantain and red banana were processed into flour and subjected to proximate analysis. Twelve healthy normoglycemic adults consumed 50g of digestible carbohydrates from glucose drinks, unripe plantain, and unripe red banana meals. Blood glucose concentrations were measured at intervals. The calculated glycemic indices for unripe plantain and unripe red banana flour meals were 52.80 and 54.96, respectively.

Menezes et al. (2010) investigated the *in vitro* colonic fermentation profiles of unavailable carbohydrates in two types of unripe banana flour—unripe banana mass (UBM) from *Musa acuminata* and unripe banana starch (UBS) from *Musa paradisiaca*—and assessed their postprandial glycemic responses in rats. Colonic fermentation was substantial, reaching 98% for UBS and 75% for UBM, producing significant short-chain fatty acids (SCFAs). After ingestion, the increase in the glycemic response was notably lower, with a 90% reduction for UBS and a 40% reduction for UBM compared to bread.

Kouamé et al. (2017) determined the glycemic index (GI) and glycemic load (GL) of five local street dishes prepared from three varieties of plantain at different maturity stages. Following GI values were obtained: 44 for Klaclo (Ameletiha variety at all black stage), 39 for Aloco (Agnrin variety at full yellow stage), 39 for Aloco (Agnrin variety at full yellow with black spots stage), 45 for Chips (Ameletiha variety at green stage), and 89 for Banane braisée (Afoto variety at light green stage). GI values showed an inverse correlation with total sugar and carbohydrate content with no relationship observed with protein content. Except for Chips (GL = 12), the GLs of the other foods were high (G L > 20).

2.3. RTE and RTC Foods

In the 1980s, Professor Masayuki Yoshikawa from Japan introduced the concept of "3R food," encompassing "ready-to-eat," "ready-to-heat," and "ready-to-cook" options. The 3R food originated from the Home Meal Replacement (HMR) concept in the United States. During the 1960s, the growth of standardized meal enterprises in the U.S. catalyzed the industrialization of prepared dishes. Today, advanced global supply chains and shifting lifestyles have significantly diversified and expanded the reach of 3R foods, with the RTC food market experiencing rapid growth. (Temgire et al., 2021).

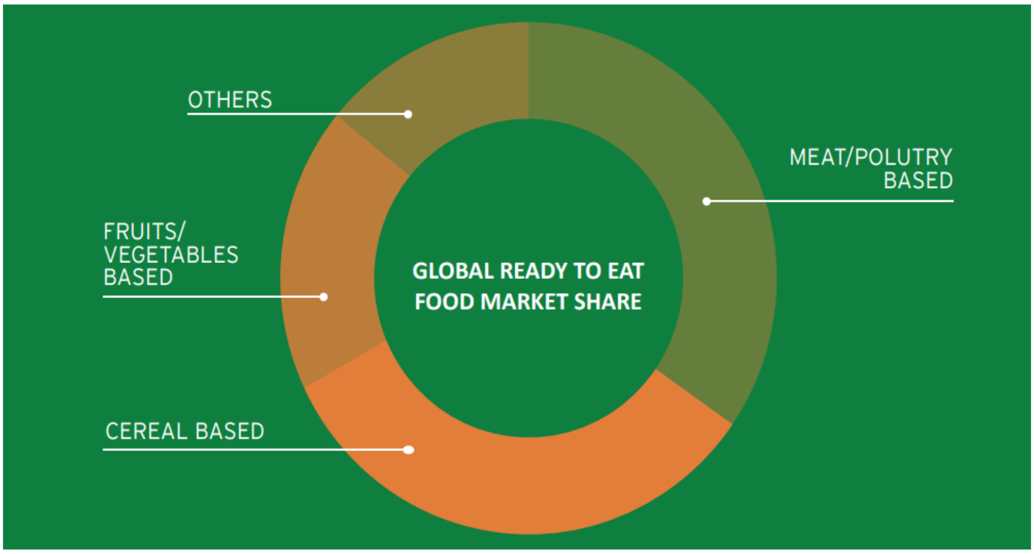


Figure 8: Global Ready-to-Eat Market Share

Adapted from the report - MOFPI,2023

The global RTE and RTC market is characterized by numerous players innovating to meet rising demand across segments such as frozen, chilled, vegetarian, and vegan meals. North America leads in market revenue, while the U.K. dominates Europe; together, Germany, the U.K., and France account for a significant share of Europe's RTE/RTC sales. Meanwhile, the Asia-Pacific region is projected to experience the highest growth rate in the coming years due to the increasing adoption of RTE products, rising consumption of ultra-processed foods, and expanding urbanization. Transnational food and beverage corporations are targeting Asia, attracted by open markets, shifting consumer preferences, a young and growing population, and strong economic growth (MOFPI,2023)

Globally, the demand for convenient foods, including instant pasta, rice, snacks, and meat products, continues to rise. This trend is fuelled by changing social and economic patterns, increased expenditure on food and beverages, heightened awareness of healthy eating, and evolving meal habits. Additional factors, such as a growing expatriate population and curiosity about new products, have contributed to this demand. The United States remains one of the largest markets for RTE foods, followed closely by Germany and the U.K., while emerging markets in Asia-Pacific, the Middle East, and Latin America are expected to see significant growth. In March 2021, General Mills expanded its product line by launching ready-to-eat Pillsbury Soft Baked Cookies in the U.S., available in four flavors (Mordor Intelligence, 2023).

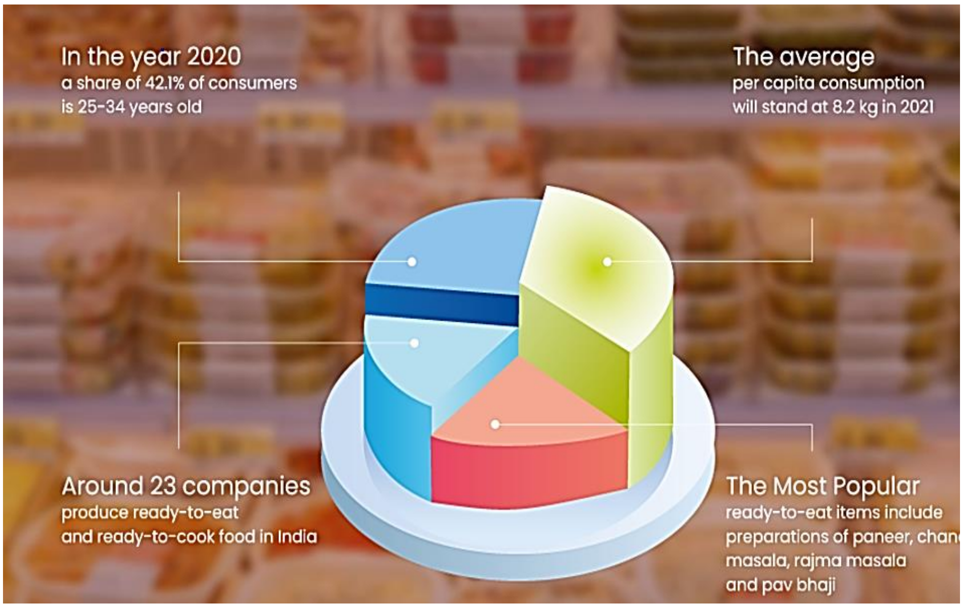
In February 2022, VegaBytz introduced a range of plant-based, 100% vegan meat products in India, including ready-to-eat meals and curry options that replicate meat, chicken, and tuna, all made entirely from plant-based ingredients. Companies in the RTE market are increasingly adopting strategic initiatives to strengthen their presence, further contributing to the sector's growth (Mordor Intelligence, 2023).

India boasts a rapidly expanding consumer market and a robust food sector. India is an attractive destination for international food companies aiming to tap into diverse consumer preferences. India ranks as the world's second-largest producer of rice, wheat, sugarcane, cotton, groundnuts, and various fruits and vegetables. As one of the fastest-growing economies in the Asia-Pacific region (MOFPI, 2023).

In 2023, India's food processing market reached INR 28,027.5 billion, with projections by the IMARC Group (2023) indicating growth to INR 61,327.5 billion by 2032, reflecting a compound annual growth rate (CAGR) of 8.8% from 2024 to 2032 (IMARC Group, 2023).

The key factors impacting the rise in the Food Processing Sector (MOFPI report 2023), are as given below:

- Changing demographics and the rise of disposable income among Indians
- Increasing urbanization and changing lifestyles
- Increased spending on food products
- Demand for functional foods/nutraceuticals
- Increasing awareness and spending on health
- Growth of organised retail and private labels penetration
- Quality standards and monitoring
- The internet has opened borders, and global food cuisines are now available in India
- Introduction of new manufacturing technologies and automation in the food processing sector



In the year 2020
a share of 42.1% of consumers
is 25-34 years old

The average
per capita consumption
will stand at 8.2 kg in 2021

Around 23 companies
produce ready-to-eat
and ready-to-cook food in India

The Most Popular
ready-to-eat items include
preparations of paneer, chan
masala, rajma masala
and pav bhaji

Figure 9: Key Statistics for RTE/RTC

adapted from https://www.foodprocessingindia.gov.in/sectors/RTE-RTC

The COVID-19 pandemic in 2020 led to a significant surge in the consumption of convenience foods such as ready-to-eat (RTE), ready-to-cook (RTC), and frozen products. Online grocery platform Grofers reported a 31% increase in purchases of readymade mixes and meals during this period. Similarly, MTR Foods recorded a 20% rise in sales within the same category. ID Fresh Foods experienced a remarkable 60% growth in paratha sales and a 20% increase in paneer and idly batter sales compared to the previous quarter. Additionally, research by Red Seer Consulting indicated a 61% rise in consumer spending on home-cooking products during this time (Ganapathiraju & Fernandes, 2022).

The ready-to-eat (RTE) functional food segment, incorporating traditional ingredients, holds significant potential, particularly with the growing health consciousness among consumers. Additionally, RTE processed foods enriched with medicinal plants possessing anti-inflammatory properties are gaining traction in the domestic market, driven by heightened awareness of preventive health following the COVID-19 pandemic.

Around 23 companies produce ready-to-eat and ready-to-cook food in India. The major players in the RTE/RTC food sector are listed below

- Bikanervala Foods Private Limited
- McCain Foods India Private Limited
- Haldiram Foods International Private Limited
- MTR Foods Private Limited
- ITC Limited
- Venky's (India) Limited
- Nestlé India Limited
- Gits Food Products Private Limited
- ADF Foods Limited
- Tasty Bite Eatables Limited

The evolving socio-economic environment in India has significantly influenced food consumption patterns. While the packaged food market shows strong potential, consumer behavior regarding ready-to-eat (RTE) and ready-to-cook (RTC) products remains underexplored. A deeper understanding of food consumption practices and socio-cultural preferences in specific regions can provide valuable insights for optimizing food product design and development (Rai, 2022).

The Indian government has actively promoted investment, strengthened regulatory oversight, and facilitated market access in the ready-to-eat, ready-to-cook, and ready-to-drink sectors through initiatives such as the Food Safety and Standards Authority of India (FSSAI) and various government schemes. These efforts focus on ensuring food safety, maintaining quality standards, and fostering innovation within the industry. The government's support, regulatory frameworks, and industry initiatives are poised to drive growth in India's ready-to-eat, ready-to-cook, and ready-to-drink sectors, ensuring sustainable growth while meeting the evolving demands of a dynamic market (MOPFI, 2023)

2.4. Research Gap

Based on the review of the literature, it was noticed that there is a notable gap in research on selected cultivars of unripe bananas, with limited comprehensive studies on their nutrient and phytonutrient profiles. Many banana cultivars remain underutilized, as existing research has largely focused on a few commercially available types. Moreover, current studies and nutrient databases often lack specificity regarding cultivar type and ripening stage. The functional attributes of unripe banana flour are not well explored, and there is limited research on its incorporation into product development, digestibility, glycemic impact, and prebiotic potential, particularly in the context of diabetes management and low glycemic index diets. Addressing these gaps could significantly enhance the understanding and utilization of unripe banana cultivars, potentially leading to innovative food products that cater to health-conscious consumers. There is a huge potential for RTE and RTC foods, which are wholesome, healthier, and provide health benefits.