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Nikita Shinde
M. Tech Research Scholar, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Vijaya Pawar
Professor, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Sakshi Jiwtode
M. Tech Research Scholar, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Monali Joshi
Ph.D. Research Scholar, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Ahmed Rayyan
M. Tech Research Scholar, Department of Food Safety and Microbiology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Corresponding Author:
Nikita Shinde
M. Tech Research Scholar, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Banana: A comprehensive review of its nutritional value, medicinal potential, antimicrobial properties and by-product utilization

Nikita Shinde, Vijaya Pawar, Sakshi Jiwtode, Monali Joshi and Ahmed Rayyan

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Abstract
Banana (*Musa spp.*) is one of the most widely consumed fruits globally, valued not only for its palatability and nutritional richness but also for its significant health-promoting properties and versatile by-product applications. This review provides a comprehensive analysis of banana from a multi-dimensional perspective, encompassing its nutritional composition, medicinal properties, antimicrobial activity, and sustainable utilization of its by-products. Nutritionally, bananas are a rich source of carbohydrates, dietary fiber, essential vitamins (especially vitamin B6 and vitamin C), minerals such as potassium and magnesium, and bioactive compounds including polyphenols and flavonoids. Medicinally, various parts of the banana plant have demonstrated anti-inflammatory, anti-diabetic, anti-ulcer, and wound-healing properties, widely recognized in traditional and modern therapeutic applications. Additionally, numerous studies highlight the antimicrobial activity of banana extracts against a range of bacterial and fungal pathogens, attributed to their phytochemical content. The review also explores the valorization of banana peels, pseudostems, and leaves in the development of biofuels, biodegradable packaging, animal feed, and other industrial products, contributing to waste reduction and circular bioeconomy. Overall, this multi-dimensional insight into bananas underscores their potential as a functional food and an important raw material for sustainable applications in food, pharmaceutical, and industrial sectors.

Keywords: Banana, nutritional profile, medicinal uses, by-product applications

Introduction
The banana plant, classified botanically as a large, evergreen, herbaceous monocot, is a perennial species belonging to the family *Musaceae* and the genus *Musa*. Over a thousand varieties are cultivated worldwide, with *Musa cavendishii*, *Musa paradisiaca*, and *Musa sapientum* being the most prominent in commercial agriculture. According to the Food and Agriculture Organization (FAO), India ranks as the top banana-producing country, contributing around 30.46 million tons per year, followed by China and Indonesia (Mostafa, 2021) [29].

Bananas, belonging to the *Musaceae* family, are among the most economically important tropical fruits in the global market. Highly favored across all age groups, bananas are consumed in both fresh and dried forms due to their palatability and versatility. They are not only one of the most affordable fruits but also highly nutritious, offering a rich source of readily available energy. Compared to other fruits such as apples which take approximately 210 minutes to digest bananas are easily digestible, with a digestion time of around 105 minutes. Bananas are widely appreciated for their soft texture, characteristic aroma, and ease of consumption, requiring no preparation for peeling or eating. The plant itself can grow to a height of 6-8 meters, with leaves arranged in a spiral pattern. Nutritionally, bananas are recognized as a rapid source of energy and an ideal means of potassium supplementation.

Beyond fresh consumption, bananas are processed into a variety of products at both small-scale and industrial levels, including chips, dried banana slices, banana bread, smoothies, ice cream, flour, and other functional food items. Owing to their nutritional profile, processed banana products are particularly suitable as weaning foods for infants or as nutritious

Snacks especially when combined with legume-based ingredients.

Bananas play a vital role in enhancing food security and serve as a significant source of export income in various countries (Siddiq *et al*., 2020) [38]. Historically, banana cultivation has contributed substantially to the economic stability of rural farming communities by creating employment opportunities for local farmers and reducing rural-to-urban migration in search of alternative livelihoods. As a cash crop, bananas have grown in importance, often serving as the primary income source for rural populations, thereby playing a key role in poverty alleviation. Furthermore, bananas are among the most cost-effective agricultural commodities to produce, making them particularly valuable for low-income households and communities. Given these factors, bananas represent a crucial agricultural resource with significant ecological, social, and economic importance.

Nutritional Composition of Banana

Bananas are highly nutritious fruits that support the absorption of essential nutrients while contributing minimal fat to the diet. They have been shown to help regulate plasma glucose levels and may enhance endurance during physical activity (Netshiheni *et al*., 2019) [30]. Due to their high moisture content, an average-sized banana contains approximately 88 grams of water (Ranjha *et al*., 2022) [36]. Ripe bananas have a low Glycaemic Index (GI), attributed to their moderate sugar content around 15 grams per fruit making them suitable for individuals managing blood sugar levels. The GI is a measure of how rapidly carbohydrates in food affect blood glucose. A typical banana contains roughly 26.95 grams of carbohydrates, accounting for about 12% of the recommended daily intake (Mateljan *et al*., 2007) [26]. In addition to carbohydrates, bananas are rich in dietary fiber, vitamins, and minerals. According to data from the U.S. Department of Agriculture, an average banana provides approximately 4 grams of dietary fiber (Ranjha *et al*., 2022) [36]. The fruit also contains important phytochemicals, such as sterols and unsaturated fatty acids, contributing to its functional food properties. Potassium is one of the most notable minerals in bananas; a medium-sized banana contains approximately 450-467 mg of potassium, which accounts for about 23% of the recommended daily intake (Kumar *et al*., 2012) [24]. Bananas also offer small but meaningful amounts of phosphorus (around 4% of the DRI per serving), though they contain minimal calcium (about 1% of the DRI) (Mateljan, 2007) [26]. Dhar *et al*. (2012) [16] reported that fresh bananas are a significant source of manganese, a mineral essential as a cofactor for antioxidant enzymes like manganese superoxide dismutase (MnSOD). While the values for vitamin C in bananas may vary due to limitations of earlier analytical techniques (such as calorimetry and titration), a 100-gram portion of a cooking banana (*Musa* × *paradisiaca*) contains approximately 18.4 mg of vitamin C. The Dietary Reference Intake (DRI) for vitamin C is 90 mg/day for adult males and 75 mg/day for adult females. Bananas also contain several B-complex vitamins, which are water-soluble and essential for cellular metabolism. In particular, a 100-gram serving of cooking banana provides measurable amounts of vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), and most significantly, vitamin B6 (pyridoxine), making bananas a valuable dietary component for maintaining metabolic health. The detailed nutritional composition of bananas is provided in Table 1.

Different Parts of banana plant

1. Root system
2. Rhizome
3. Pseudo stem
4. Stem
5. Leaves
6. Sucker
7. Inflorescence
8. Peduncle
9. Cluster

1. Root system

Roots are responsible for absorbing water and nutrients from the soil. It is formed by primary and secondary roots. All of them originate from the underground structure named rhizome. The primaries can reach up to 3 meters in length. However, the largest root mass is located in the first 60 cm of the soil.

2. Rhizome

It is commonly known as corm and grows by horizontal underground growth. This is the true banana stem found underground and consists of a flattened dome from which the offspring or offshoots are produced. In particular, they emerge through a vegetative bud from the mother plant. The outer or cortical part of the rhizome plays a protective role, while the central or active part gives rise to the air system, the radical system and the offshoots.

3. Pseudo stem

This is the part that looks like a trunk. It is made of "tightly packed overlapping leaf sheaths" *. This spiral assemblage can be arranged up to 25 leaf sheaths. When the pseudo stem grows, the leaves emerge one after the other reaching its maximum height (more than 2 m in many cases). At this moment, "the stem, which was developing inside the pseudo stem, emerges at the top of the plant".

4. Stem

The banana stem has three parts: the rhizome (previously mentioned), the aerial stem and the peduncle (described below). The aerial stem is the part of the plant that grows vertically, above the ground. "As it develops, it carries the inflorescence and the leaf bases upwards inside the pseudo stem. When the aerial stem emerges at the top of the plant, it is called the peduncle".

A particular feature of the banana plant is that the rhizome is a stem modification which grows laterally and has many nodes on it, so that it can be cut and grown into new plants.

5. Leaf

Photosynthesis takes place in the leaves. They originate in the apical meristem (a part of the rhizome). They emerge from the centre of the pseudo stem as cigar leaves (like a rolled cigar). In other words, a cigar leaf is a recently emerged leaf.

The curious thing is that the pods of the leaves are arranged in helical form inside the rhizome, so that when growing, they form the pseudo stem.

It is worth mentioning here a type of leaf that covers the cluster when it is growing. It is known as the placenta or

bracteal leaf and is transient. In some parts of the world, it is also known as *Capote Leaf*.

6. Sucker

A sucker is a shoot that grows from the base of the banana plant. Specifically, it grows from a lateral bud on a rhizome. When a sucker emerges through the soil, it is called a peeper. When it has grown and has true leaves it is called maiden sucker. There are different types of suckers, but only sword suckers (those with narrow leaves and a well-developed root system) grow into thriving banana plants.

A good management of suckers is crucial for obtaining quality bananas. If you remove a sucker from the main stem and replant it, it can develop into a new banana plant.

7. Inflorescence

An inflorescence is a complex structure, containing flowers that will develop into fruits. It is produced by the terminal growth point of the rhizome, grows through the pseudo stem and emerges at the top of the plant once the last cigarette leaf has sprouted.

Firstly, female flowers appear. These will develop the hands of fruits. While the female flowers develop into fruits, "the distal portion of the inflorescence elongates and produces clusters of males (staminate) flowers, each under a bract. These flowers usually do not develop as fruits and their stamens do not produce pollen".

8. Peduncle

The peduncle is the stem that supports the inflorescence and fixes it to the rhizome. And, more specifically, the part that supports the female and male flowers is known as *rachis*.

9. Cluster

The cluster or bunch is the group of fruits that appear along the *rachis*. The individual fruits are grouped in hands. By analogy, each individual banana in a hand is called a finger

Table 1: Nutritional Composition of Banana

Components	Banana
Moisture	77.19
Protein	0.3
Ash	0.1
Fat	0.1
Carbohydrates	22.12
Minerals	
potassium	308-426
phosphorus	15-29
Calcium	4-7
Copper	0.025-0.186
Zinc	0.11-0.24
Iron	0.19-0.41
Manganese	0.116-0.829
Vitamins	
Vit .B1	0.062
Vit.B2	0.072
Vit .B6	0.0242
Vit.C	18.4

References Ranjha *et al*. (2022) [36]

Medicinal Importance

1. Reduced risk of high blood pressure

Bananas are one of the best sources of potassium, an essential mineral for maintaining normal blood pressure and heart function. A medium-sized banana provides 350 mg of potassium. The effectiveness of potassium-rich foods in lowering blood pressure has been demonstrated by a number of studies. The US Food and Drug Administration have allowed the banana industry to make official claims for the fruit's ability to reduce the risk of blood pressure and stroke. According to the FDA, "Diets containing foods that are good sources of potassium and low in sodium may reduce the risk of high blood pressure and stroke." Plus, potassium helps your body maintain normal fluid and electrolyte balances in the cells. Scientists report that natural compounds in bananas act in a manner similar to antihypertensive drugs. The team studied six popular banana varieties and found that all had ACE inhibiting properties, though the ripened bananas had a stronger action than unripe ones. Researchers have reported that blood pressure fell by 10% in people who ate two bananas daily for a week.

2 Reduced Risk of Stroke

Scientists suggest that people with a low amount of potassium in their diet may have an increased risk of stroke. A study of 5,600 people aged over 65 found that those with the lowest intake of the potassium were 50% more likely to suffer a stroke. High-potassium foods, like bananas, may lower the risk of stroke, but researchers say that more studies are needed to confirm whether increasing potassium in the diet can prevent strokes.

3. Restore normal bowel Activity

Because the banana is rich in nondigestible fibers (including cellulose, hemicellulose, and alpha glucans) it can help restore normal bowel activity and help with both constipation and diarrhoea. Bananas normalize the colon's function to absorb large amounts of water for regular bowel movements. Their usefulness is due to their richness in pectin, which is water-absorbent and this gives them a bulk producing ability. Bananas are an exceptionally rich source of fructooligosaccharide, a compound called a prebiotic because it nourishes probiotic (friendly) bacteria in the colon. These beneficial bacteria produce vitamins and digestive enzymes that improve our ability to absorb nutrients, plus compounds that protect us against unfriendly microorganisms. When fructooligosaccharides are fermented by these friendly bacteria, not only do numbers of probiotic bacteria increase, but so does the body's ability to absorb calcium. For this reason, ingesting antibiotics harm these beneficial bacteria.

Research published in Digestive Diseases and Sciences underscores just how much bananas can improve nutrient absorption. In this study, 57 babies (5-12 months) with persistent diarrhea of at least 14 days duration were given a week's treatment with a rice-based diet containing either green banana, apple pectin or the rice di*et al*one. Treatment with both green banana and apple pectin resulted in a 50% reduction in stool weights, indicating that the babies were absorbing significantly more nutrients.

4. Protection from ulcers & Heartburn remedy

Bananas have long been recognized for their antacid effects that protect against stomach ulcers and ulcer damage. A flavonoid in the banana, leucocyanidin, has been found to significantly increase the thickness of the mucous membrane layer of the stomach. Since bananas help to neutralize acidity, they are also a great way to get rid of

heartburn. In an animal study, a simple mixture of banana and milk significantly suppressed acid secretion.

5. Protection against neurodegenerative diseases (Alzheimer's disease)

Researchers at Cornell University investigated the effects of apple, banana, and orange extracts on neuron cells and found that the phenolic phytochemicals of the fruits prevented neurotoxicity on the cells. Among the three fruits, apples contained the highest content of protective antioxidants, followed by bananas then oranges. These results suggest that fresh apples, banana, and orange in our daily di*et al*ong with other fruits may protect neuron cells against oxidative stress-induced neurotoxicity and may play an important role in reducing the risk of neurodegenerative disorders such as Alzheimer's disease

6. Kidney Health

Bananas promote an overall improvement of the functional efficiency of kidneys. Benefits to the kidneys are again due to the high potassium content of bananas. A normal intake of potassium suppresses calcium excretion in the urine and minimizes the risk of kidney stones. The results of the Swedish population based prospective study (13.4 years) of 61,000 women aged 40-76, show that women eating more than 75 servings of fruits and vegetables per month (which translates into 2.5 per day) cut their risk of kidney cancer 40%. Among the fruits, bananas were especially protective. Women eating bananas four to six times a week halved their risk of developing the disease compared to those who did not eat this fruit.

7. Energy booster

Bananas contain three natural sugars - sucrose, fructose and glucose combined with fiber. Potassium is also essential for helping muscles to contract properly during exercise and reduces cramping up. A banana gives an instant, sustained and substantial boost of energy. Research has proven that just two bananas provide enough energy for a strenuous 90-minute workout.

8. Immunity booster

Bananas contain 25 percent of the recommended daily allowance (RDA) for vitamin B6, necessary for producing antibodies and red blood cells as well as aiding in the metabolism of fat. In addition, vitamin B6 serves as an immunity booster. So, this fruit strengthens your Armor against infectious diseases. With each average sized banana, you ingest about 15% of the RDA for vitamin C, one of the strongest antioxidants.

9. Cardiovascular Protection

Banana is a good source of potassium. Potassium maintains normal blood pressure and heart function. One serving of banana contains 467 mg of potassium, this makes people to believe that one banana a day may help to prevent hypertension or even atherosclerosis. A number of studies have demonstrated this banana nutrition benefit. Potassium may further promote bone health. As potassium may prevent the calcium loss in urine, which is caused by high salt diets.

10. Food Uses

All banana plants can produce edible fruit, but the fruit taste, seediness, color, size and other characteristics depend on the species or variety. Bananas can be peeled and eaten raw, baked peeled or unpeeled, made into a puree suitable for infants and used in many other ways. In addition to this plant's highly versatile fruit, peeled stems can be chopped and added to salads or steamed with other vegetables.

11. Non-Food Uses

Banana leaves are commonly used as plants, for wrapping food and as an eye-shade or for protection from rain. The banana pseudo stem can be utilized for its fiber. The pulp can be used to manufacture rope, paper, place mats and other goods, but the pseudo stem is often most valuable economically if it is chopped and left in a field for its organic matter content. All parts of the banana have medicinal value. For example, flowers can be cooked and eaten by diabetics or used for bronchitis, dysentery and ulcers. Plant sap can be taken internally or applied externally to stings and bites. The young leaves can be used as a poultice for skin irritations. The roots, ashes of peels and leaves and seed mucilage also serve medicinal purposes in some regions and cultures.

Antimicrobial Activity of the Banana Plant

Various traditional plants are used worldwide as the main health care therapy to treat diverse diseases and infections. Banana is one of the eldest medicinal plants, and many studies have aimed to elucidate the efficiency of its naturally active ingredients, such as antimicrobial agents (Al-Mqbali & Hossain, 2019) [5]. These studies have used common *in vitro* tests, such as disc and well diffusion methods or minimum inhibitory concentration (MIC) assay.

Antibacterial Activity

The susceptibility of microorganisms to antimicrobial agents varies considerably depending on several factors (Ismail *et al*., 2018) [21]. Key determinants include the polarity, solubility, and chemical stability of the extracts, as well as the concentration and composition of active compounds within the extract all of which influence the rate at which these agents diffuse through the agar medium (Karuppiah & Mustaffa, 2013) [22]. Additionally, the type of microorganism particularly its species and Gram classification can significantly affect the antimicrobial response, thereby altering the size of the observed inhibition zone (Norfaradhiah & Rapeah, 2017) [31].

Two widely employed qualitative methods for evaluating antibacterial potential are the agar disc diffusion and well diffusion assays. These techniques assess antimicrobial activity based on the diameter of the inhibition zone formed around the agent.

In the disc diffusion method, agar plates are first inoculated with a standardized volume of microbial culture. A sterile filter paper disc (typically 6 mm in diameter) impregnated with the test extract at a specified concentration is then placed on the surface of the agar. In contrast, the well diffusion assay involves using a sterile cork borer to create a well (6-8 mm in diameter) in the solidified agar medium, which is then filled with a measured volume (usually 20-100 µL) of the test extract.

During incubation, the extract diffuses into the surrounding agar and inhibits the growth of the microorganism if antimicrobial activity is present. The extent of inhibition is determined by measuring the diameter of the clear zone

surrounding the disc or well, with larger zones indicating stronger antibacterial effects (Balouiri *et al*., 2016) [9].

Antifungal Activity

Fungi are ubiquitous in the environment, and fungal-induced spoilage of food products has become increasingly common (Kumar *et al*., 2014) [25]. While limited research has explored the antifungal properties of various parts of the banana plant, the findings to date are summarized in Table 5. One of the most straightforward and widely used methods to evaluate antifungal activity is the agar diffusion assay, which enables uniform distribution of the test extract through the agar medium (Balouiri *et al*., 2016) [9].

Although extracts from the banana pseudo-stem have demonstrated limited or no inhibitory effect against several fungal strains (Kumar *et al*., 2014) [25], other plant parts particularly banana leaves have shown significant antifungal activity. Notably, large zones of inhibition were observed against species such as *Penicillium*, *Candida*, and *Alternaria* (Bankar & Dole, 2016; Bisht *et al*., 2016; Harith *et al*., 2018) [10, 11, 19].

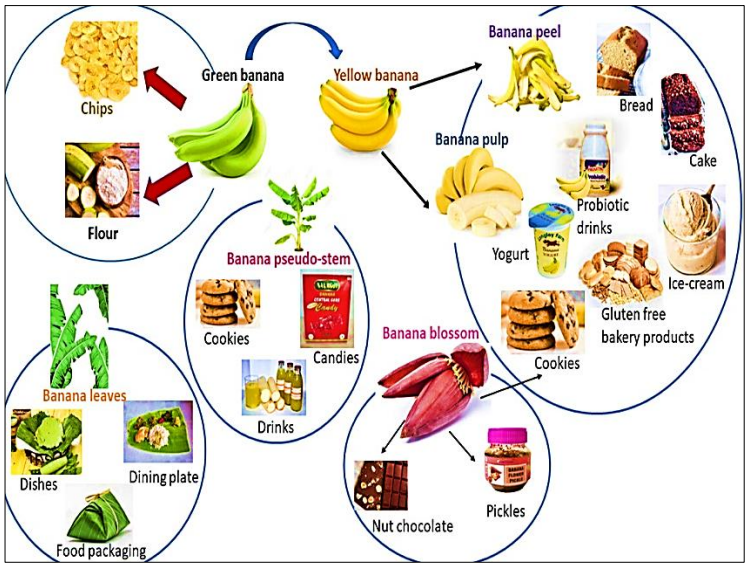
Among the solvents used for extraction, methanol-based extracts generally produced the highest levels of fungal growth inhibition, followed by ethanol and then ethyl acetate. This enhanced antifungal efficacy may be attributed to methanol's higher volatility and its ability to extract a broader range of bioactive phytochemicals with antifungal properties

Antimicrobial compounds and their actions

Banana plants contain a wide variety of phenolic compounds with different polarities. Their abundance of hydroxyl groups makes these compounds essential due to their scavenging abilities and potential for multiple biological effects, including antimicrobial activity. The recognized compounds and their antimicrobial action vary depending on the banana part and the chemical structure of these compounds, as well as the tested strain of bacteria and fungi. Some of their actions have already been well defined. For example, lupeol (Gallo & Sarachine, 2009) [18] and 1, 3-dioxalane (Kucuk *et al*., 2011) [23] have antimicrobial properties, while gentisic acid has antifungal effects (Vandal *et al*., 2015). β-Caryophyllene showed selective antibacterial action against *S. aureus* and stronger antifungal activity than kanamycin (Dahham *et al*., 2015) [15], whereas epicatechin (+-catechin) exhibited antimicrobial effects against *Helicobacter pylori in vitro* (Escandon *et al*., 2016) [17].

Applications of Banana and its by-Products in Food Industry

A) Banana



1. Banana Chips

Banana chips are widely consumed globally and are recognized as a high-quality nutritional snack due to their relatively low fat and calorie content. Their classification typically depends on factors such as ingredients, texture, and colour (Ranjha *et al*., 2022) [36]. In addition to being a convenient snack, banana chips are considered a healthy source of energy and essential minerals, particularly phosphorus and potassium. Their preparation is both simple and environmentally sustainable (Abd Elmoneim *et al*., 2014) [1].

Research by Wani *et al*. (2017) [43] indicated that extended frying durations lead to a deeper yellow coloration in banana chips, largely attributable to Maillard browning reactions. Optimal production parameters identified as a frying temperature of 160°C, duration of 2.69 minutes, and slice thickness of 1.5 mm were found to yield banana chips of superior quality with improved shelf stability.

Moreover, consumption of vacuum-fried banana chips, noted for their enhanced nutritional profile, was associated with reduced fatigue levels among workers (Christi *et al*., 2019) [14]. Further improvements in chip quality were observed through the addition of 0.02% dried curry leaf and 0.01% natural antioxidants, such as tocopherol acetate and sodium ascorbate, which significantly enhanced both chemical stability and physical properties compared to untreated samples (Adrika *et al*., 2015) [2].

2. Banana Flour

The use of banana flour as a functional food ingredient has garnered increasing interest due to its richness in dietary fiber, resistant starch, and potassium (Pragati *et al*., 2014) [34]. Banana has also been associated with various health

benefits, including improved digestive health, kidney protection, enhanced muscle function, and the prevention of muscle cramps and depression (Christi *et al*., 2019) [14]. Consequently, banana flour has been recommended for incorporation into a range of bakery products such as cookies, bread, and pasta. Incorporating 10% banana flour as a substitute for wheat flour in cookies yielded highly acceptable results across all quality parameters. The substitution notably increased the crude fiber and ash contents by 197.56% and 93.25%, respectively (Alam *et al*., 2020) [4]. Similarly, the use of whole green banana flour (WGBF) in bread formulation significantly enhanced macro minerals including calcium, phosphorus, sodium, and magnesium without causing notable changes in micro minerals such as iron, zinc, and manganese (Khoozani *et al*., 2020) [6].

Gluten-free pasta produced using raw banana flour combined with protein and vegetable gums demonstrated greater resistance to α-amylase digestion compared to traditional wheat-based pasta. According to Segundo *et al*. (2017) [37], the inclusion of banana flour in cakes substantially improved their nutritional profile, especially by increasing polyphenol content, antioxidant activity, and dietary fiber achieving up to a threefold enhancement in antioxidant capacity.

In another study, Yangılar (2015) [44] evaluated the impact of green banana flour on the physical, sensory, and chemical properties of ice cream. The results indicated a decrease in calcium content and an increase in sulphur content. Sensory analysis revealed that ice cream containing 2% banana flour was rated highly acceptable by panelists.

3. Banana Biscuits

Banana biscuits are made by mixing 60% banana flour and 30% maida. The dough is made using flour mixture and suitable proportions of sugar, saturated fat, baking powder, milk powder and essence. These biscuits are very tasty and highly nutritious.

4. Banana Bread

Breads produced with varying levels of banana flour substitution (5%, 10%, and 15%) demonstrated a reduction in loaf volume alongside increases in moisture content, ash levels, and overall weight, correlating with the percentage of banana flour added. Despite these changes, banana flour remains a promising ingredient for the bakery industry, offering enhanced dietary fiber without significantly compromising sensory attributes (Rahman *et al*., 2021) [35].

Similarly, the incorporation of air-oven dried (OD) and freeze-dried (FD) whole green banana flour (WGBF) at 30% substitution with wheat flour resulted in doughs exhibiting greater elasticity, loss modulus, and complex viscosity compared to those made from 100% wheat flour ($p < 0.05$). However, increasing the proportion of WGBF led to the production of bread with a harder texture, darker coloration, and increased chewiness (Amini Khoozani *et al*., 2020) [6].

Hernández-Aguirre *et al*. (2019) [20] further found that the inclusion of both water and pregelatinized banana flour in bread formulations influenced the formation and diffusion of gas bubbles (alveoli), increasing their size. These structural changes directly affected the texture and physical characteristics of the bread. Therefore, unripe banana flour presents itself as a viable substitute ingredient for producing high-quality gluten-free bread.

5. Fermented banana beverages

Bananas are also utilized in the production of fermented beverages such as wine and beer. Clarified banana juice, characterized by its low acidity and high concentrations of sugars and minerals, serves as a suitable substrate for fermentation (Mohapatra *et al*., 2011) [27]. Research indicates that banana wine produced after secondary fermentation exhibits superior sensory attributes specifically in taste, appearance, and aroma compared to that produced through primary fermentation. Additionally, it demonstrates higher °Brix, increased total acidity, elevated alcohol content, greater levels of residual sugars, and lower pH (Chen *et al*., 2020) [13]. The predominant volatile compounds identified in banana wine are esters and alcohols.

As fermentation progresses, both alcohol content and titratable acidity increase steadily (Nwobodo, 2013) [32]. Bananas may also be incorporated as a supplementary ingredient in beer production, particularly in all malt-wort beer, to enhance ethanol yield. Their inclusion contributes to a darker coloration of the beer, primarily due to the activity of browning enzymes. In traditional brewing practices, crushed bananas are combined with sorghum and water, then fermented for approximately three days to produce a light beer with a relatively low alcohol concentration ranging from 2% to 5% (Shandilya & Siddiq, 2020) [38].

6. Banana Fruit Bar

Banana Fruit Bar is confectionary item prepared from ripe banana fruit of any variety. It is made by homogenizing banana pulp, sugar, citric acid and pectin in suitable proportions and dehydrating the mass in ghee coated ray at 70° C in an oven till sets into a sheet. It is then cut into suitable size and packed in polyethylene pouches. #

B) Banana peel

Extracts of BP may be used in food products as a natural preservative agent to increase the quality and shelf life of food due to their strong antioxidant and antibacterial characteristics. Different kinds of foods have been successfully fortified using BP extracts such as cookies and yogurt (Vu *et al*., 2019) [42].

1. Cookies

According to the findings of Oguntoyinbo *et al*. (2021), incorporating banana peel (BP) flour into cookie formulations led to increased levels of ash, crude fiber, and fat rising from 2.26%, 1.03%, and 12.00% to 2.73%, 1.33%, and 12.20%, respectively. Additionally, the supplementation enhanced antioxidant properties, mineral content, total phenolic content, and even anti-nutritional factors, while having no significant impact on the cookies' physical attributes.

Alam *et al*. (2020) [4] reported that BP flour exhibits a greater water-holding capacity (4.58 g/g dry sample) compared to wheat flour (3.19 g/g dry sample), contributing to improved textural and functional properties. Similarly, a study by Arun *et al*. (2015) [7] highlighted that cookies fortified with BP flour are a rich source of total dietary fiber. Shafi *et al*. observed that increasing the concentration of BP flour in cookies correlated with greater hardness and enhanced antioxidant activity. Specifically, DPPH radical scavenging activity ranged from 47.761 to 70.298, total phenolic content from 0.282 to 0.921 mg GAE/g, and lipid peroxidation inhibition from 36.74% to 71.84%. However,

these antioxidant indicators were found to decrease over the storage period .Overall, the studies confirm that fortifying cookies with BP flour significantly improves their nutritional value particularly antioxidant and phenolic content without compromising physical or sensory qualities.

2. Cakes

Gluten-free and nutrient-enriched cakes have been successfully developed by incorporating green banana peel (BP) flour into rice flour at various levels (5%, 10%, 15%, and 20%). According to Turker *et al*, the addition of 5% and 10% BP flour did not significantly affect key baking characteristics such as specific volume, density, overall volume, or baking loss. This suggests that BP flour can be effectively used to formulate gluten-free cakes, offering a nutritious alternative particularly beneficial for individuals with celiac disease.

Ahmed *et al*. (2021) [3] further reported that replacing wheat flour with BP flour in cake formulations enhanced antioxidant activity, particularly at substitution levels of 12% and 15%. Based on these findings, the use of up to 15% BP flour is recommended to improve both the nutritional profile and overall quality of cakes.

In a related study, Balakrishnan (2021) [8] demonstrated that cakes enriched with banana peel extract showed higher fiber and carbohydrate content compared to control samples without BP flour, further supporting the nutritional benefits of its incorporation in bakery products.

3. Meat Products

Banana peel powder (BPP) has been identified as a functional ingredient in meat processing due to its rich nutritional composition. Mohd Zaini *et al*. (2022) [28] found that BPP supplementation in sausages led to increased dietary fiber content, improved water-holding capacity, and higher cooking yields, while simultaneously reducing fat levels.

Similarly, Chappalwar *et al*. (2021) [12] evaluated the development of very low-fat chicken patties fortified with BPP. The results revealed improvements in moisture retention, ash content, and cooking yield. At the same time, there were reductions in emulsion stability, pH, water activity, fat content, and cholesterol levels when compared to control patties.

Further analysis of chicken sausages prepared with two varieties of BP flour showed that Saba BP flour had lower water and oil retention but better swelling capacity compared to Berangan BP flour. These variations highlight the potential of different BP flour types for tailoring the textural and functional properties of meat products.

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