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Review Article

# *Musa Paradisiaca* It's Phytochemistry, Traditional Uses And Pharmacological Activities

**Prakash Pralhad Sarwade[1], Kavita Narayan Gaisamudre (Sarwade)[2*], Kalpana Sonwani[3], Subhash Chand[4], Mamta Goswami[5], Harpreet Kaur[6], Navin Chandra Pant[5]**

[1]Associate Professor and Head, Department of Botany, Shikshan Maharshi Guruvarya R. G. Shinde Mahavidyalaya, Paranda Dist. Dharashiv (Osmanabad), 413502, Maharashtra, India.

[2**]Assistant Professor, Department of Botany, Shriman Bhausaheb Zadbuke Mahavidyalaya, Barshi Tal. Barshi, Dist- Solapur, 413401 Maharashtra, India.

[3]Head of Department, Department of Pharmacogy, G.S.R.M Memorial College of Pharmacy, Lucknow, India.

[4]Roorkee Business School of Pharmacy, Roorkee, Uttarakhand, India.

[5]Faculty of Pharmaceutical Sciences, Amrapali University, Haldwani, Uttarakhand, India.

[6]Surajmal College of Pharmacy, Surajmal University Kichha, Uttarakhand, India

## A B S T R A C T

*Musa paradisiaca* is a medicinally valuable and plentiful nutritious plant that has been popularly used in the traditional medicine systems of Asia, Africa and Latin America. The bioactive phytochemicals are very diverse in all parts of this plant such as the fruit, peel, leaves, pseudostem, and the flowers which contain phenolic acids, flavonoids, carotenoids, sterols, triterpenes, alkaloids and dietary fibers. A combination of all these constituents contributes to the plant possessing many pharmacological attributes. The review is an analytical study of the phytochemistry, ethnomedicinal use, mechanism of action, and therapeutic potential of *Musa paradisiaca*. It is established that the plant possesses great anti-inflammatory and antioxidant effects through Nrf2 activation, NF-kB and free radical scavenging. It possesses antidiabetic effects due to inhibition of a-amylase and a-glucosidase, enhancement of insulin sensitivity, and b-cells in the pancreas. The other drug effects are antimicrobial, anticancer, gastroprotective, hepatoprotective, cardioprotective, neuroprotective, nephroprotective, wound healing and reproductive health as shown in several preclinical studies. Despite the promising outlook of the bioactivity, some significant gaps in research include lack of standardization of the extracts, lack of sufficient mechanistic understanding, limited ability to carry out toxicological assessment and lack of well-designed clinical trials. Future studies should focus on the regions of additional phytochemical characterization, the isolation of the active molecules, nanotechnology-based delivery systems, and clinical validation as a form of therapeutic translation. Overall, *Musa paradisiaca* is a highly diverse plant that has huge potential of becoming useful in terms of being used as useful functional food, nutraceutical, and phytopharmaceutical. Scientific evidence will also need to be developed further and any research gaps will need to be addressed so as to ensure the full medicinal and industrial potential of it is unlocked.

**Keywords:** *Musa paradisiaca*; Phytochemistry; Ethnomedicinal uses; Pharmacological activities; Bioactive compounds.

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*Address for Correspondence:

Kavita Narayan Gaisamudre Sarwade, Assistant Professor, Department of Botany, Shriman Bhausaheb Zadbuke Mahavidyalaya, Barshi Tal. Barshi, Dist-Solapur, 413401 Maharashtra, India.

## INTRODUCTION

The banana plant (*Musa paradisiaca*) as it is popularly known in the region is one of the most popular food crops in the world, as well as most widely eaten and most widely culturally important crops in the world [1]. The species belongs to the family of Musaceae and has been a treasured commodity during the centuries as a source of food besides serving the medicinal purpose, with a large-scale potential

of therapy. The plant has been utilized as nutrition, medicine and industry all over as fruit, peel, pseudo stem, leaf, inflorescence and roots. With a high level of phytochemical composition, nutritional balance, and more than several centuries of ethnomedicinal practice, *Musa paradisiaca* has recently received considerable scientific interest in the recent decades [2]. With the growing attention to natural remedies and therapeutic agents of vegetal origin, the species has currently become the source of a useful object of pharmacological and nutraceutical research. It will be described in the following paragraphs as to its botanical name, taxonomical position, distribution around the world and ethnobotanical worth [3-5].

*Musa paradisiaca* is a giant, perennial, herbaceous, with its best attribute being its pseudostem, or solid mass of overlapping sheaths of leaves, forming the appearance of a strong trunk. The plant has an average height of between 2 and 7 meters depending on the cultivar and environmental factors. It is not a tree but possesses a pseudostem where the plant supports itself until it gets to the fruit. The leaves are oblong, thick and large and sometimes up to 2-3 meters long [6]. The reason they look so fringed is that their lamina is very tender, and torn after by the wind to which it is bright green. The leaves are formed in a spirally orientation and they grow out of an underground rhizome which is the major organ of storing the nutrients and vegetative reproduction. The banana heart is an inflorescence growing on a terminal location of the center of the pseudostem. It is a colossal, purple-red, tapered one of layers, a few of which envelop rows of tiny flowers. The grouping of the flowers is done with the female ones closer to the base of the infloescence and the male ones towards the end. It is only the female flowers which develop into fruits [7].

It is a curved and long berry, which grows in clusters of them, known as hands. The hand consists of several solitary fruits which are called fingers. The *musa paradisiaca* fruit is generally larger, starchy and more angular than the dessert bananas. When not quite ripe, it has a thick peel and hard pulp, becoming tender under cooking, or when quite ripe. *M. paradisiaca* have seedless, parthenocarpic fruits and are highly edible unlike Musa species they are grown wild. The fruiting period of the plant is 9-12 months after which the plant naturally senesces to produce suckers that maintain the perennial nature of the crop [8]. It has been regarded as being one of the most economically significant plants in the tropical areas through its structural features, easy proliferation as well as the quantity of biomass it generates.

**Figure1:** *Musa paradisiaca* plant

## Taxonomy and Classification

The family Musaceae is a group to which *Musa paradisiaca* belongs and has almost two genera including Musa and Ensete. The species of genus Musa are grouped into few sections basing on morphological and chromosome characteristics [9]. *M. paradisiaca* is a part of the genus Musa which contains edible bananas and plantains in the family. *Musa paradisiaca* is an intermediate species, which forms following natural crosses between *Musa acuminata* (genome A) and Musa balbisiana (genome B). Plantains, therefore, are more likely to have AAB form of genomic structure and this is one of the factors that make them possess characteristic starchy texture and cooking characteristics. This mixed descent is also applied to the reason why varieties of cultivars have been produced and the plant itself is modified to suit the weather conditions [10].

**Table 1:** Taxonomic classification

| | |
|---|---|
| Kingdom | Plantae |
| Clade | Angiosperms |
| Clade | Monocots |
| Order | Zingiberales |
| Family | Musaceae |
| Genus | *Musa* |
| Species | *Musa paradisiaca* L. |

Historically, there has been a taxonomic controversy between *Musa paradisiaca* (plantains) and *Musa sapientum*. In modern botanical nomenclature, many taxonomists use these names to refer to cultivated polyploid complexes, and not real species. But the name *Musa paradisiaca* is still currently used in scientific texts to

describe the kind of banana (plantains) that are consumed cooked and not raw. Such a hybrid and cultivar-based classification emphasizes the complexity of genetics of the plant making it exceptionally resilient, rich in nutrients, and phytochemicals [11].

## Geographical Distribution

*Musa paradisiaca* is a fast growing plant which can be grown in the tropical and subtropical climate when there is adequate humidity, temperature and good soil in the region. It is reported how the plant was first introduced in the Southeast of Asia particularly in the region of Indo-Malayan i.e. Malaysia, Indonesia and Philippines. It was introduced to India, Africa, Pacific Islands and eventually to the Americas through human migration and trade over the course of centuries. It has been able to establish a presence all over the globe due to its ability to spread out to different soils beginning with fertile alluvial plains to hilly soils [12]. The plant is also very sensitive to frosts but will be able to endure periodic droughts provided the soil is well moisturized. It is cultivated in places where the rainfall is over 1000mm each year and the temperature must be within the range of 20°C and 35°C. Plantains are also of key concern to Africa, as it is the center of food consumption and an excellent source of carbohydrates in the diet. Indian culinary, religious and traditional medicine include *Musa paradisiaca*.

## Ethnobotanical Significance

Ethnobotanical importance of Musa paradidiaca is broad-based, and it encompasses food, culture, and medicine. The practice of Ayurvedic and folk medicine has applied various parts of the plant in the treatment of various diseases. Unripe fruit is extracted to cure diarrhea, dysentery, and the gastrointestinal system whereas the ripe fruit is taken to sedate the digestive system. India and Southeast Asia use the flowers in traditional medicine to control the menstrual cycle, promote lactation, and treat diabetes. The traditional value of the pseudostem juice is in the treatment of kidney stones, UTI, and detoxification. Some cultures treat the skin and wounds with peel, which is used in the treatment of wounds and skin diseases due to its antioxidant and anti-inflammatory effect. The leaves are also applicable in culinary use and ritualistic use since people use them as natural wrappings to food [13].

The plant is culturally significant too on other accounts than medical. Banana plants are an indicator of prosperity as well and they are used during wedding ceremonies, festivals, and religious offerings in India and Sri Lanka. In Africa and Brazil, plantains are also central to the daily food, since they form the majority of the traditional foods. The ethnobotanical cultures highlight the value of the plant in terms of sustaining the local health systems long before the emergence of the modern pharmacology. These applications are compatible with the current scientific findings that confirmed the plant was antioxidant, antimicrobial, antidiabetic, gastroprotective and anti-inflammatory [14-16].

## Phytochemistry of Musa paradisiaca

Phytochemical abundance of the plant has given it a scientific basis on its nutritional and therapeutic uses. It is an intricate system of vegetation containing an enormous quantity of primary and secondary metabolites that are dispersed in the fruit, peel, leaves, pseudostem and flowers. All these constituents contribute to its antioxidant, anti-inflammatory, antidiabetic, anti-microbial, gastroprotective, and wound-healing. The following subsections will provide a descriptive and systematic review of the plant phytochemical composition although the emphasis will be placed on bioactive compounds present in different parts of the body [17].

It has been established that *musa paradisiaca* has a huge number of phytochemicals of nutritional and pharmacological classes. The plant has primary metabolites such as carbohydrates, proteins, amino acids, minerals, and dietary fibers as the nutritive backbone which makes the plant an important source of food in the tropical and subtropical regions. Coupled with them, the plant contains diverse categories of secondary metabolites that include phenolic acids, flavonoids, tannin, terpenoids, alkaloids and saponins that possess diverse bioactivities. Phytochemicals are highly selective regarding location. The pulp is composed of carbohydrates, minerals, vitamins, dietary fibers and phenolics. The peel contains rather more polyphenol, carotenoid and tannin compared to the pulp. The presence of leaves is characterized by strong antioxidant and antimicrobial molecules, whereas the presence of flowers is characterized by flavonoids, sterols, and lipophilic molecules associated with antidiabetic and hematological effects. The complex phytochemical comprising of this structure forms the foundation of the pharmacological activity of the plant [18].

## Primary Metabolites

### Carbohydrates

The largest primary metabolite is carbohydrates and is found in *Musa paradisiaca* fruit pulp in large amounts. Plantain in the immature phase contains a lot of resistant starch (amylose and amylopectin) that causes it to possess hard texture and low glycemic index. As it keeps on ripening, the starch is broken down by enzymes into simple sugars such as glucose, fructose and sucrose, which increase its digestibility and also its sweetness. The quantity of starch in the unripe fruits may reach 60-70 percent and in the ripe fruits it is far much more with a huge percentage of soluble sugars. These carbohydrates have also had significant application in energy metabolism and have been medically applied in dietary treatment of gastrointestinal problems, in the treatment of dehydration as well as in sustained release energy supplements. It also contains the resistant starch that assists in the maintenance of the healthy gut as a substrate of the colonic fermentation to produce the short-chain fatty acids [19].

### Proteins and Amino Acids

The content of proteins in the nutrition structure of the plant is less, although the qualitative picture of the protein is striking. These fruit consists of the essential amino acids that are leucine, lysine, isoleucine, lysine, valine and phenylalanine. The leaves and peel are relatively nutritious with a relatively high amount of protein thereby could be utilized as animal fodder and even as nutraceutical fodder. Plantain peel contains free amino acids that include arginine, glutamic acid and aspartic acid that are involved in wound healing and metabolism. Bioactive peptides have been found in different plant regions and this has attracted attention in food science and pharmacognosy since such peptides have antioxidant, antihypertensive, and antimicrobial effects [20].

### Dietary Fibers

*Musa paradisiaca* is a better source of dietary fibre particularly peel and unripe pulp. The fibers are cellulose, hemicellulose, pectin and lignin. The non-soluble fiber is in large proportions in the unripe fruits and is known to contribute to bowel regularity and reduced transit time in the intestine. Pectins and other soluble fibers assist in reduction of cholesterol and maintenance of glycemia. The peel contains nearly 40-50 percent fiber and this has been utilized in the manufacture of fiber based functional foods. The prebiotic effect, which is more conducive to the existence of beneficial intestinal flora, as well as the water-retaining and bulking effects, has helped it to be effective in the management of diarrhea and irritable bowel disorders [21].

### Secondary Metabolites

The bioactive constituents that cause the therapeutic applications of *Musa paradisiaca* are the secondary metabolites. Their density depends on parts of the plants, stage of maturity, and the environmental factors.

### Phenolics and Flavonoids

Some of the most typical secondary plantanoid compounds are phenolic. They are gallic acid, chlorogenic acid, caffeic acid, tannic acid, protocatechuic acid, ferulic acid and syringic acid and p-coumaric acid. Their free- radical scavenging and metal-chelating properties are high and are incorporated to the already existing antioxidant and anti-inflammatory activity of the plant. The flavonoids that were found in various parts of plants include quercetin, catechin, epicatechin, rutin, kaempferol, luteolin and naringenin. Their ability to control the oxidative stress-signaling and inhibit the activation of NF-kB and stabilize lipid membranes favor their pharmacological utility. Pulp possesses significantly lower amounts of polyphenols compared to plantain peel and therefore, it can be used as a source of polyphenols to be extracted and utilized as nutraceutical [22].

### Terpenoids and Steroids

Terpenoids and steroids are found in the peel of the plant, its leaves and flowers. B-sitosterol, stigmasterol, campesterol and lupeol among others, have been isolated. These molecules are anti-inflammatory, hepatoprotective and lipid-lowering molecules. The triterpenes in the peel assist in its healing effect to the wound by enhancing collagen and angiogenesis. The carotenoids, other important terpenoid family, can be traced in peels and are mostly present in ripe fruits. Antioxidant capacity B-carotene, lutein and zeaxanthin are compounds that have a protective effect on vision and immune functions, and they have antioxidant properties [23-25].

### Alkaloids

Although their levels are lower than in the phenolics, dopamine, norepinephrine and serotonin-like amines are alkaloids found in *Musa paradisiaca*. These include antioxidant, vasomodulatory and gastrointestinal regulatory substances. The anti-ulcer and cytoprotective properties of dopamine in the pulp and peel are that it enhances the mucosal protection and reduces the oxidative stress [26].

### Saponins

The saponin levels are not high with the saponin being present in the peel and leaves. These are surface active and contain antimicrobial, antiparasitic and cholesterol reducing properties. These cytotoxic and immunomodulatory effects include their membrane-modulating effects [27].

### Bioactive compounds identified in the pulp

*Musa paradisiaca* is a fruit with diverse array of bioactive phytochemicals in pulp which allows the fruit to possess both nutritional as well as therapeutic potential. It is currently rich in phenolic acid i.e. gallic acid, chlorogenic acid, vanillic acid and ferulic acid that have a cumulative impact of being essential in antioxidation and neutralizing the reactive oxygen species. They are also abundant in the flavanoid catechin, epicatechin and quercetin derivatives which have the purpose of vascular protection, anti-inflammatory control and hepatoprotection. Carotenoids b-carotene, a-carotene and lutein are also known to enhance antioxidant properties of the fruit, in addition, promote immune and eye functions [28]. Along with these compounds, physiologically important biogenic amines are also present in the pulp, in particular, dopamine, which has been associated with gastroprotective and anti-ulcer effects due to enhanced mucosal defence and reduced oxidative injury. Its nutrition value is also elevated with vitamins such as vitamin C, vitamin B6 and folate; electrolytes are observed to be maintained, such as potassium, magnesium and phosphorus [29]. Unripe pulp is especially rich in resistant starch and dietary fiber, that slow down the uptake of glucose and maintains the health of the gut and contributes to antidiarrheal effect, and are therefore valuable in managing diabetes and gastrointestinal diseases diets. When the fruit goes to maturity starch is enzymatically degraded to simple sugars rendering it palatable, despite still having high amounts of phenolic and flavonoid compounds that render it pharmacologically significant [30].

### Bioactive compounds in the peel

The *Musa paradidiaca* peel is an unusually excellent source of bioactive compounds that are highly antioxidative, antimicrobial and anti-inflammatory. Polyphenols, including gallic acid, tannic acid, protocatechuic acid,

caffeic acid, and epicatechin, which are not only the cause of strong free radical-scavenging and metal-chelating properties but also strong deprotonating properties, are also present in large quantities in the peel. Antioxidants, such as quercetin, rutin, and kaempferol also increase its antioxidant potential and anti-inflammatory and cytoprotective effect [31]. The peel is also a good source of sterols and triterpenes (b-sitosterol, stigmasterol and lupeol) that are associated with healing of wounds, lipid-lowering and anti-inflammatory effects. These carotenoids such as lutein, Zeaxanthin and b-carotene adopt its therapeutic effects profile by contributing to the regulation of oxidative stress and immune boosting. Also, the peel contains high concentrations of gastroprotective and anti-ulceric alkaloids, including dopamine and trace amines. The peel is composed of saponins and tannins, which are said to confer antimicrobial and antiseptic properties to the peel, and have been used in the traditional wound care and prevention of infection. The peel has been explored in functional foods, cholesterol-lowering interventions, compostable packaging and nutraceutical preparations as a result of its high dietary fiber content e.g. pectin, cellulose and hemicellulose. The mixture of these constituents makes the peel an untapped, powerful resource with high pharmacological and industrial potential [32].

## Bioactive compounds in leaves and flowers

*Musa paradisiaca* is a plant with numerous secondary metabolites and is typically utilized as a traditional medicine to treat metabolic and inflammatory conditions and are used as leaves and flowers. The leaves have the polyphenols, tannin, terpenoids, carotenoids and the chlorophyll derivatives. Their antioxidant properties are due to the presence of quercetin, kaempferol and gallic acid. Leaf extracts have antimicrobial, anti-inflammatory and hepatoprotective properties. They also contain sterols and triterpenes that result in wound-healing and anti-ulcer effects. The ethnomedicine also considers leaves as topical application in burns and inflammation of the skin since it has a cooling, soothing and antioxidant property. Their waxy coating contains phytol and b-sitosterol as well that serve the functions of anti-inflammatory and analgesic [33].

*Musa paradisiaca* flowers are rich in flavonoid, sterol, tannin and omega-3/ omega-6 fatty acids. They include quercetin, catechin, chlorogenic acid and b-sitosterol. These compounds have been associated with the effects of antidiabetes in the shape of regulating insulin secretions, pancreatic defense, and the inhibition of enzymes of carbohydrate breakdown. Flower extracts are also anti microbial, anti anemic and anti inflammatory. Their antioxidant effects and flavonoid properties respectively contribute to the reduction of the oxidative stress and preservation of cardiovascular and reproductive health. Traditional medicines are prepared using flowers in managing menstruation, lactation and cleansing of blood [34].

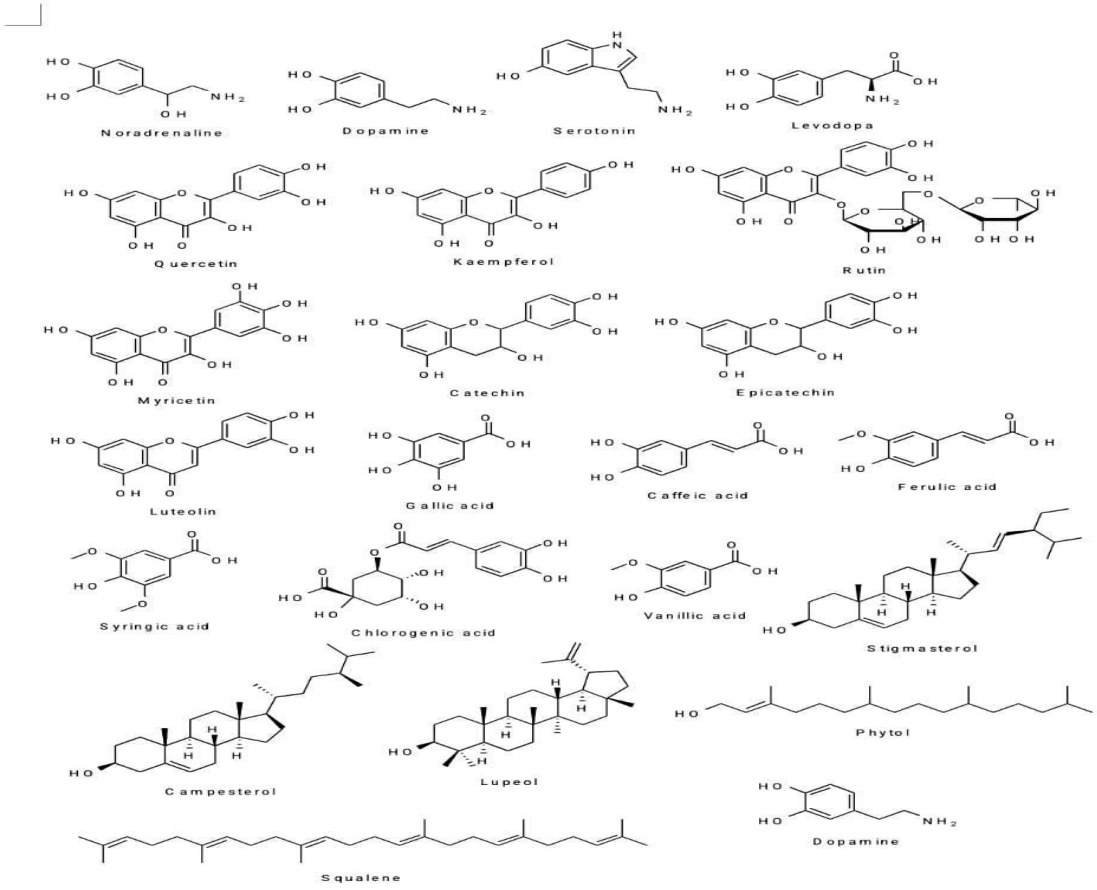


**Figure 2:** Bioactive compounds present in *Musa paradisiaca* plant

## 3. Traditional and ethnomedicinal uses

Musa paradisiaca possesses a rich and deep history of exploitation in the traditional medical systems, food and cultural activities, with its multitask significance as both a food and a medicine plant. The plant is considered a cooling, nutritional and restorative agent in Ayurveda and various parts of the plant are used to treat gastrointestinal malady, metabolic disorders, inflammation, and skin ailments [35]. The unripe fruits are typically used to treat diarrhea, dysentery, and peptic ulcers due to the high levels of starch and pectin, which form a protective layer of the mucosa and lower irritation of the intestine, as well as phenolic compounds that also help in the treatment of diarrhea, dysentery, and peptic ulcers. Instead, ripe fruit is appreciated due to its calming effect of the gastrointestinal tract and is suggested to be applied to problems like constipation, acid dyspepsia, and nutritional deficiencies. The pseudostem juice of the plant is also popular in Indian folk medicine, used in detoxifying, kidney stones, urinary tract infection, excessive acidity and is believed to have mild diuretic effect, and is believed to help clean up the urinary system. Banana flowers are considered to have special medicinal values in most traditional systems. The Southern Indian, Thai, and Sri Lankan folk medicines rely on flower preparations to control menstrual cycles, ease excessive bleeding, and stimulate lactation among the postpartum mothers. They are also known to be effective in terms of antidiabetic use wherein the flower extracts are considered to increase secretion of insulin, regulation of glucose levels, and oxidative stress related to diabetes. Banana leaves are not eaten but they are also significant in therapeutic and culinary [36]. They can be applied externally in traditional medicine to treat burns, wounds and skin inflammations because they have cooling, anti-inflammatory and antimicrobial properties. Food is in most cultures served on banana leaves because of its supposed digestive qualities and personal cleanliness, because the waxy phytochemical coating of the leaf is considered to possess mild antiseptic effect. The peel of Musa paradisiaca, which is usually wasted in the contemporary environment, was used topically to treat bruises, insect bites, minor trauma, and inflammatory skin conditions because it contains high quantities of tannin, phenol, and triterpenes, which are good wound healing agents and swelling reductions. African traditional medicine is in some cases prepared as plantain peels to make a poultice to cure infections and skin irritations, and as a decoction to cure hypertension and other metabolic disorders. In the Caribbean and Latin American regions, plantain is a foodstuff, as well as found in the management of anemia, fatigue and gastrointestinal ailment. The traditional uses are based on its high iron, mineral and antioxidant content [37]. Musa paradisiaca has cultural ritual value in various areas. In India, the plant is a symbol of prosperity and purity, stems and entire plants are adopted in festivals, marriage, and religious ceremonies as a symbol of fertility and good luck. Within the Polynesian and Southeast Asian, different components of the plant are used ceremonially and as part of dietary curative measures. Together, these ethnobotanical uses underscore the fact that the plant is widely used in the traditional health systems, its nutritional richness and phytochemical diversity of the plant have long been well known. Most of these uses are still confirmed through recent studies in pharmacology, and this adds support to the relevance of the plant both as a source of medicine and as a culturally important species [38].

## Pharmacological Activities

Musa paradisiaca (plantain/banana) is a highly grown medicinal plant due to its importance as a food crop as well as the medicinal effects it has in various ways. The plant has a long history of usage in Ayurveda, Unani, and folk systems of medicine with multiple parts of the plant, such as fruits, peels, leaves, flowers, and rhizomes, having a high pharmacological potential. Phytochemical studies have identified the presence of flavonoids, phenolic acids, tannins, alkaloids, sterols, and vitamins which are responsible in the wide range of biological actions. Recent experiments prove that M. paradisiaca has antioxidant activity, anti-inflammatory, antidiabetic, antimicrobial, wound-healing, antiulcer, nephroprotective, and anticancer properties. It was found to have the capacity to regulate oxidative stress, inflammatory mediators, glucose metabolism, and the process of repair of cells which accounts for these activities. Having a good safety profile, nutritional value and multidimensional therapeutic value, Musa paradisiaca remains a subject of scientific attention as a promising natural herbal agent in the prevention and treatment of several diseases.

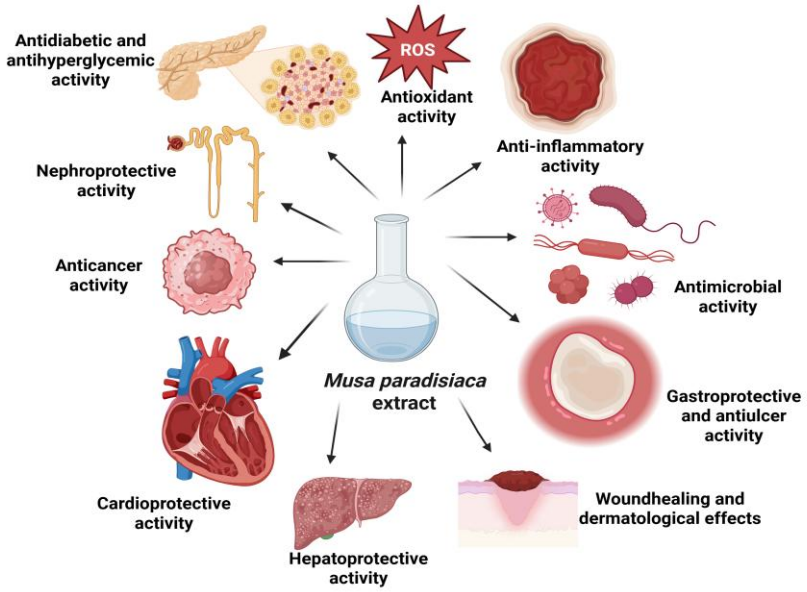


**Figure 3:** *Musa paradisiaca* pharmacological activities

## ANTIOXIDANT ACTIVITY

Due to the high concentration of phenolic acids, flavonoid, carotenoid and biogenic amines such as dopamine, Musa paradisiaca has a high antioxidant potential. The compounds are effective to neutralize reactive oxygen species and make sure that oxidative degradation of cellular macromolecules is avoided. Peel, pulp and leaf extracts show high abilities of radical-scavenging using DPPH and ABTS and FRAP. Amongst the edible plants, the peel in particular contains one of the highest concentrations of polyphenols that make the plant better than the others in regard to antioxidant properties. By regulating the oxidative stress, the plant helps in preventing the progression of chronic diseases such as diabetes, cardiovascular dysfunctions, neurodegenerative and inflammatory causes disorders. Its antioxidant property is also quite significant in wound healing, anti oxidant effect on the gastro intestinal tract and antioxidant agent on ageing [39].

## Anti-inflammatory activity

Musa paradisiaca is rich in flavonoids, tannins, triterpenes and sterols making it have anti-inflammatory properties. These components inhibit prominent inflammatory mediators such as prostaglandins, nitric oxide and cytokines by inhibiting such pathways as NF-kB and COX. The peel and pseudostem extracts prevent the formation of edema, stabilize the lysosomal membrane and inhibit the inflammatory cell invasion. Scientific justification of conventional application of the plant in the management of skin inflammation, burns and joint pain entails the potential of the plant to halt oxidative pressures, tissue edema and inflammatory communications. In addition, the fruit contains potassium that is known to reduce the inflammation of the system and improves cellular homeostasis [40].

## Antidiabetic and antihyperglycemic activity

Musa paradisiaca has a high antidiabetic property in many ways. Fruits that are not ready have high levels of resistant starch and soluble fibres which delay the absorption of carbohydrates, postprandial glucose spikes and increase insulin sensitivity. The occurrence of the phenolics and flavonoids in the peel and the flowers has an inhibitory effect in the enzymes of a-amylase and a-glucosidase, which inhibit the breakdown and absorption of the glucose. Extracts also increase antioxidant defences of pancreatic tissues which inhibits oxidative damage of b-cells. According to the modern research, there is better lipid profile, low-level glucose in the fasting period, and better insulin actions in a treated individual, and above all; the traditional purpose of using banana flowers is to control blood sugar levels. These effects support the suitability of the plant as a dietary and therapeutic supplement in the treatment of diabetes [41].

## Antimicrobial activity

The antimicrobial activity of *musa paradisiaca* leaves, peel and pseudostem is widely spread due to tannins, flavonoids, saponins and phenolic acids. Peel extracts prevent the growth of bacterial pathogens such as Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa and Salmonella. The membrane-disruptive terpenoids and tannins have been proposed to be the cause of membrane-disruptive antifungal activity in Candida albicans and dermatophytic fungi. Enteric viruses have also been reported to be meditated with viral-inhibitory effects by use of polyphenols through enteric viruses attaching and replicative inhibition. The properties render peel poultices conventional in infections and are

applicable in supporting potential application in natural antimicrobial preparations [42].

### Gastroprotective and anti-ulcer activity

*Musa paradisiaca* has gastroprotective properties which are well-established in the traditional medicine, as well as those supported by experimental studies. Unripened fruits are high in pectin, resistant starch and flavonoids that offer protective mucosal coating, reduce the acidity of the stomach and augment mucosal perfusion. Another way in which the dopamine concentration in the pulp and the peel improves cytoprotection is by the mucus secretion and reduction of the oxidative damage to gastric tissues. Plant extract inhibits the occurrence of ethanol, NSAIDs, and stress-induced ulcers by decreasing the activity of inflammatory factors and improving antioxidant effects. The natural antacid effect also contributes to the fruit to counter hyperacidity hence is also applied in diseases like gastritis, reflux and peptic ulcers [43].

### Wound healing and dermatological effects

*Musa paradisiaca* has been reported to contain wound-healing properties because of its high content of phenols, triterpene, saposins and vitamin which stimulate collagen production, angiogenesis and epithelial regeneration. The peel is especially known to promote contraction of the wounds, generate fibroblasts and reduce microbial contamination. It has anti-inflammatory and antioxidant properties that prevent secondary infection and oxidative tissue damage of the wound. The use of banana peel as a folk medicine in the management of burns, rashes, insect bites, and minor cuts are consistent with scientific findings of increased skin moistness, skin barrier repair, and reduced inflammation. Biogenic amines also help in reduction of pain and recovery [44].

### Hepatoprotective activity

*Musa paradisiaca* has hepatoprotective effects manifested as antioxidant stimulation, detoxification and in control of inflammation processes. The phenolic compounds prevent the lipid peroxidation of the liver tissues and stabilize the hepatocyte membranes. The presence of high levels of liver enzymes such as ALT, AST and ALP associated with the toxic damage is prevented by peel and leaf extracts. Flavonoid prevent the oxidative injury of chemicals, fatty and high-fat-based diets. In addition, dietary fibers found in fruits improve lipid metabolism as well as reducing the amount of fat accumulated in the liver. The effects of these effects identify the potential of the plant as natural hepatoprotective agent [45].

### Cardioprotective activity

The cardioprotective effect of *musa paradisiaca* is because it is highly composed of potassium and it can regulate oxidative stress, lipids metabolism and vascular inflammation. Potassium is used in the regulation of blood pressure, which enhances the level of vasodilation by reducing the sodium retention propensity. Flavonoids and phenolic acid inhibit the oxidation of LDL, endothelial dysfunction as well as the lipid profiles. It has been shown in experimental models that peel extracts possess cardioprotective effects, which encompass the prevention of the myocardial oxidative stress as well as the improvement of antioxidant enzymes. Low probability of hypertension, atherosclerosis, and ischemic injury are the results of these processes [46].

### Nephroprotective activity

*Musa paradisiaca* extracts avoid the injuries of the renal tissues under the influence of the oxidative and inflammatory processes. The phenolics and flavonoid block lipid peroxidation, maintain renal activity and avoid nephrotoxicity caused by drugs or chemicals. The pseudostem juice is folkishly remedial of kidney stones and urinary infection as well as the laxative effect plays tricks out to bring out metabolic wastes. Excess potassium keeps the body fluids and kidney in check. The low concentration of urea, creatinine and uric acid in the experimental models where the extracts of plantains were employed, are also indicated by research [47].

### Anticancer and antiproliferative activity

The presence of flavonoids, phenolic acids, triterpenes, and sterols makes *Musa paradisiaca* related to the anticancer potential, which causes the cancer cell death, inhibits cell growth, and disrupts the cancer-promoting pathways. Extracels have cytotoxic action on breast, liver, colon, and cervical cancerous cells. The cell cycle arrest, mitochondrial apoptosis and oxidative stress signaling are controlled by such compounds as quercetin, catechin, b-sitosterol and rutin. Resistant starch, along with dietary fibers also play an indirect role such that they regulate the gut microbiota and reduce carcinogenic metabolites [48].

### Mechanisms of action major bioactive compounds

*Musa paradisiaca* has contributed to the biological activities due to the abundance of phytochemical composition of phenolic acids, flavonoid, carotenoid, triterpenes, sterols, alkaloid, and dietary fibers. These compounds mediate via the functions of diverse molecular pathways, which regulate the oxidative balance, inflammation, glucose homeostasis, and cancer progression. The involvement of the pathways in the pharmacological action of the plant points to a combination of direct action on the cellular targets, and more global control of the metabolic and signaling pathways [49].

### Antioxidant pathways (Nrf2 activation and ROS scavenging)

The major antioxidants of *Musa paradisiaca* are phenolic acid (chlorogenic, gallic, ferulic, protocatechuic acid) and flavonoids (quercetin, catechin, rutin, epicatechin) and carotenoids (b- carotene, lutein) and biogenic amines (dopamine). Such substances are said to have two complementary actions that include: direct free radical neutralization action and endogenous antioxidant pathways modulation. Among the most important pathways, one can single out the Nrf2 (Nuclear factor erythroid 2-related factor 2) activation, which is one of the most significant pathways regulating the cellular defense [50]. Under oxidative stress Nrf2 dissociates with its suppressive protein Keap1, and translocates to the nucleus, where it can bind to antioxidant response

elements (AREs) and up-regulate detoxifying enzymes. Musa paradidiaca causes the synthesis of glutathione peroxidase, superoxide dismutase, catalase and phase-II detoxification enzymes by this activation with the help of bioactive compounds in Musa paradidiaca. By so doing, the plant enhances the possibility of the cell to counter the oxidative damage, reduce lipid peroxidation, and maintain the redox homeostasis. The compounds happen to be direct ROS scavengers neutralizing superoxide, hydroxyl radicals, hydrogen peroxide and peroxynitrite in addition to regulating Nrf2 [51]. The combats the Fenton reaction that is a significant source of reactive oxygen species by the metal-chelating properties of flavonoids. The carotenoids play a part in quenching the singlet oxygen and stabilizing the free radicules by its conjugated double-bonds. The high concentration of dopamine in the pulp and peel provides significant cytoprotective properties by the scavenging of reactive species, and at fortification of the gastric tissue mucosal barrier. These mechanisms combined are the basis of the protective effects of the plant against oxidative stress-linked diseases, including cancer, diabetes, cardiovascular diseases, neurodegeneration, and inflammation [52].

### Anti-inflammatory mediators (NF-κB suppression and COX inhibition)

The most significant sources of *Musa paradisiaca* anti-inflammatory power are flavonoids, tannin, b-sitosterol and triterpenic acid such as lupeol. The compounds exhibit multi-target effects on inflammatory signaling pathways with the most significant ones being the NF-kB, cyclooxygenase (COX) enzymes and proinflammatory cytokines. It is believed that NF-kB pathway plays a critical role in regulating inflammation as it has been found to regulate inflammatory cytokine and chemokine and adhesion molecule transcription, and inflammatory enzymes [53]. The bioactive compounds that are found in plants inhibit the IkBa phosphorylation and degradation which inhibits the NF-kB activation in the normal conditions. This leads to NF-kB to be retained in the cytoplasm hence blockage of the expression of proinflammatory cytokines and scramble of immune cells to inflammatory sites. Simultaneously, the COX-2 inhibitory effect of the phytochemicals of the plant is also exhibited, and it reduces the synthesis of the prostaglandin that causes pain, swelling, and inflammation. Trierpenes also control the COX expression and flavonoids competitive inhibitory characteristics of COX enzyme activity. This dual control is the one of analgesic, anti-inflammatory, and tissue-protective action. The other processes include inhibition of the formation of nitric oxide by inhibiting inducible nitric oxide synthase (iNOS), stability of lysosomal membranes and blocking the infiltration of leukocytes. Such concerted efforts verify the traditional use of the plant on the healing of wounds and burns, gastritis and arthritis, and inflammatory skin diseases [54].

### Antidiabetic mechanisms (α-amylase/α-glucosidase inhibition and insulin sensitization)

Nutritional (resistant starch, pectin, dietary fibers) and bioactive (phenolics, flavonoids, sterols) phytochemicals cause the antidiabetic effects of *Musa paradisiaca*. The net outcome of their concerted action is an influence on carbohydrate metabolism, insulin signaling and pathways, which involve oxidative stress, which enhances the development of diabetes. The key procedures are inhibition of the digestive enzyme a-amylase and a-glucosidase which decreases the degradation of complex carbohydrates into glucose. The phenolic compounds of peel and flower bind to the active sites of these enzymes that inhibit the hydrolysis of starch and lower the postprandial glucose peaks. It follows the same procedure as clinical drugs like acarbose having fewer side effects on the gastrointestinal system [55]. The plant also enhances the insulin sensitivity by stimulating the functioning of the insulin receptors and the glucose transporters. Flavonoid such as quercetin, rutin and catechin modulate PI3K/Akt signaling and lead to increased GLUT4 transporter translocation to the cell membrane and increased cell uptake of glucose. Unripe fruit resistant starch improves the insulin levels because it alters the gut microbiota structure as well as increase the production of short-chain fatty acids like butyrate, which influences metabolic processes. In addition, the insulin-secreting activity of pancreatic b-cells is preserved by *Musa paradisiaca* which prevents oxidative stress of the cells through its antioxidant constituents [56]. The flower extracts have resulted in the minimization of fasting glucose and the enhancement of lipid profiles as well as the normalization of inflammation, which are all linked to greater control over metabolism. This is based on such mechanisms that result in the recommendation of the use of plantain-based diets in the management of diabetes.

### Anticancer mechanisms (apoptosis induction and cell cycle arrest)

The mechanism of *Musa paradisiaca* cancer biology continues to work through a number of different pathways: apoptosis, cell cycle, oxidative stress, and inhibition of the metastatic progression. The large bioactive agents of flavonoids (quercetin, catechin, epicatechin), phenolics acids (ferulic, gallic, chlorogenic acids), triterpenoids (lupeol) and phytosterols (b-sitosterol) cause these effects. Apoptosis or programmed cell death is one of the key anticancer processes [57]. The outcome is the violation of mitochondrial membrane potential, the release of cytochrome c, and caspase-3 and caspase-9. Another mechanism that controls extrinsic apoptotic pathway is the activation of death receptors, which is involved in selective elimination of cancer cells. *Musa paradisiaca* compounds are known to have similar effects that lead to cell cycle arrest particularly in the G0/G1 and G2/M phases via modification of cyclins and cyclin dependent-kinases. Quercetin and rutin prevent the proliferation signals by blocking CDK2, CDK4, and cyclin D1 that prevents unlimited cell growth [58]. All these processes disrupt the development of cancer cells and inhibit the development of tumours. The other mechanism is significant and incorporates the prevention of carcinogenesis by oxidative stress. Phenolic antioxidants react with ROS and reduce the DNA damage, lipid peroxidation rate, and mutation rate. The carotenoids increase the redox balance and inhibit the

precancerous tissue alterations. Besides, triterpenes and sterols interfere with metastasis process as they prevent cancer cell invasion through inhibition of matrix metalloproteinases (MMPs) activities [59]. The antiangiogenic effects are also recorded in which the plant extracts reduce the expression of the vascular endothelial growth factor (VEGF) gene and limit the blood supply of the tumors. The current multi-targeted systems can be regarded as one of the positive signs of the potentiality of *Musa paradisiaca* as a source of natural chemopreventive and anticancer agents. The preclinical evidence is also good, but another research is required to determine clinical applications, dose-efficacy as well as drug interactions with conventional therapies [60].

## Limitations

Irrespective of the high-pharmacological potential of *Musa paradisiaca*, the scientific study of this species has certain severe constraints that restrict its full scientific validation and therapeutic translation. One of the best limitations is lack of standardization of the plants materials and the way the extraction processes are carried out [61]. The components of the plants used in investigations can be diverse, the stages of maturity are often used, and the use of different extracting solvents and unreliable drying or processing methods results in high levels of variability in phytochemical composition and the quality of biological performance. These differences make it difficult to compare the outcomes across studies or create reproducible therapeutic profiles. Moreover, the action of the environmental factors on the phytochemical composition of *Musa paradisiaca* strongly relies on the soil composition, climate, altitude, irrigation, and post-harvest treatment, which, nevertheless, are not reported in numerous studies, and the interpretation of the data is more challenging [62]. The other major limitation is that; the majority of the in vitro tests and small scale animal research, and little properly conducted human clinical research is performed to respond to the traditional allegations. Even though extracts are likely to exhibit the possible antioxidant, antidiabetic, antimicrobial and anticancer effects in laboratory setup, the same cannot be directly transferred to humans unless clinical evidence is discovered to be strong [63]. The absence of mechanistic research is also a major gap; although numerous reported biological processes have been reported, extremely little research has been conducted to determine the particularcy of the cellular and molecular pathways. Majority of the studies involve crude extracts and not individual compounds which means that it is not easy to establish the exact molecules that are responsible of the therapeutic effects or whether there exist any synergies or not [64].

The other limitation is linked to the impossibility of existence of complete toxicological data. Even though plantans are widely consumed, there has been no sufficient information on the safety of concentrated extracts, particularly those of peel, flowers and pseudostem that also contain high bioactivity compounds [65]. The reproductive safety, long-term toxicity, genotoxicity and dose-effect have not been sufficiently studied and as such they are restricting the regulatory acceptance of the medicinal or nutraceutical use. Pharmacokinetics and bioavailability have also not been examined appropriately with regard to polyphenols and flavonoids that have high metabolism and are not absorbed [66]. It is impossible to determine the right dosage and determine the therapeutic activity without the knowledge of absorption metabolism, tissue distribution and excretion profiles. Industrial application is as well limited with paucity of scalable technology of extracting or even not much standardized formulations or even stability assessments to encourage commercial manufacture of plant-derived products of *Musa paradisiaca*. The valorization of non-edible components like peel and pseudostem has not been developed due to the unavailability of the processing methods, preservative methods and quality assurance standards. Moreover, the majority of the existing research rely on a single part of the world and it is hardly possible to extrapolate it on the world and omit cultivar-specific differences [67]. Finally, the absence of interdisciplinary collaboration between botanists, pharmacologists, clinicians and food technologists is a drawback to the translation of clinical use and industrial application. Together, these limitations suggest that more stringent, standardized, and multidisciplinary research is needed to make the most of the therapeutic potential of *Musa paradisiacal* [68-70].

## Future prospective

The research on *Musa paradisiaca* has a lot of prospect and there are various avenues that can be pursued to advance the scientific knowledge, therapy development and industrial application of the multifaceted plant. One of the most important future directions is the standardization extracts through state of the art analysis techniques such as LC-MS/MS, UPLC, NMR spectroscopy and metabolomic profiling. Chemical fingerprint development and marker compounds determination will assist the researchers to establish uniform and reproducible formulations that may be applied in clinical evaluation. Another priority is isolation and characterization of individual bioactive compounds such as flavonoids, phenolic acids, sterols and triterpenes. As lead molecules in drug discovery, these compounds can be utilized and their mechanism of action can be described through the application of molecular docking, in silico modeling, and pathway-based studies. In addition, there is need to carry out sound clinical trials to license conventional usages and preclinical findings. Practicality of banana peel extracts in diabetes, flower extracts in menstrual regulation or pulp extracts in gastroprotection would be of good use to the evidence base and will aid to be included in the contemporary therapeutics. Increased bioavailability should also be introduced in the future since the majority of phytochemicals found in *Musa paradisiaca* are not absorbed or metabolized well. Nanoparticles-delivery systems, microencapsulation and phyto-systems can be helpful in achieving the stability and efficacy of the therapy. Another vast potential is the possibility of coming up with nutraceutical and functional foods using the previously little exploited portions of the plants such as peel and pseudostem which contain a lot of fiber, antioxidants and bioactive compounds. They may be

incorporated into dietary products, diabetic-friendly products, prebiotic products and natural colorants or preservatives. The second chance is that green extraction technologies, including enzyme-assisted extraction, the use of supercritical CO2 extraction, and fermentation-based technologies can be adopted and are capable of improving the yield, reducing the impact on the environment, and improving sustainability. Other interdisciplinary research may be directed to the use of biomaterial, such as packaging of peel fibers into biodegradable material, wound dressing or absorbent composite. Moreover, the agricultural and environmental sciences can be backed up by the research of the potential of the plants in soil rehabilitation, in the pests control in the nature and recycling the wastes. To clarify cultivar-specific variations in the profile of phytochemicals, genomic and transcriptomic analyses may be adopted, which would enable one to select high-value varieties that can be grown more specifically. The synergy of the pharmacology, food technology, biotechnology and agriculture would be significant in taking the full benefit of this plant. In general, the future of *Musa paradisiaca* is wide, and it is highly possible to transform it into the scientifically proven, sustainably exploited source of the natural medicine, functional foods, and industrial innovation.

## CONCLUSION

*Musa paradisiaca* is a highly valuable medicinal/nutritious plant that has a long and rich history of traditional application and accumulated scientific evidence base. A wide spectrum of pharmacological activities, including anti-oxidant, anti-inflammatory, anti-diabetic, anti-microbial, gastroprotective, hepatoprotective, cardioprotective, neuroprotective, and anticancer activity, is attributed to its diversity in phytochemical makeup including phenolic acids, flavonoids, carotenoids, sterols, triterpenes, alkaloids and dietary fibers. Asian, African, and Latin American traditional medicine traditions have long been employing different plant parts as gastrointestinal therapy, metabolic disorder, wound healing and reproductive health with more modern research starting to back up the claims with preclinical data and understanding of the mechanisms involved. In spite of the fact that this potential has been enriched, a lot of gaps still exist in the areas of extract standardization, toxicity profiling, pharmacokinetic analysis and high-quality clinical trials. Phytochemical composition is not reproducible because of variability in composition among cultivars, growing regions and processing conditions and makes it hard to establish standard formulations of therapy. The weaknesses are to be addressed by the necessity to transform laboratory findings into evidence-based clinical processes and regulatory acceptability. The potential of the plant is however high with respect to innovation. Analytical chemistry can be developed, green extraction can be developed, nanotechnology-based delivery systems can be developed, and functional foods can be developed and the portions that are not well exploited such as peel, pseudostem, and flowers can be utilized significantly. The integrative and multidisciplinary approaches to the research will also play a crucial role in realising its full therapeutic and industrial potential. In general, *Musa paradisiaca* holds a potential natural resource that can be used pharmacologically with an enormous level of usage and broad applicability in nutraceutical, pharmaceutical, and functional foods. It may contribute to establishment of a useful plant species in the future through the use of further scientific investigation and systematic validation in the health, wellness and development of sustainable bioproducts.

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