Review
Sciences of Phytochemistry

A Comprehensive Review on Nutrient Profile and Pharmacological Benefits of *Musa paradisiaca*

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[The author informations are in the declarations section. This article is published by ETFLIN in Sciences of Phytochemistry, Volume 3, Issue 2, 2024, Page 123-143. https://doi.org/10.58920/sciphy0302254]

Received: 01 June 2024
Revised: 05 November 2024
Accepted: 13 November 2024
Published: 27 November 2024

Editor: Samir Chtita

Keywords: Musa paradisiaca, phytochemicals, anti-cancer, antidiabetic, antibacterial, antiviral, antifungal, depression, urolithiasis, hypertension.

Abstract: The Banana (*Musa paradisiaca* Linn., Family: Musaceae) is one of the oldest and most widely cultivated fruit plants, dating back to prehistoric times. Bananas are rich in minerals and phytochemicals, contributing to their significant culinary, nutritional, and medicinal properties. This review analyzes 191 peer-reviewed articles published between 1981 and July 2023 to comprehensively assess the health benefits of bananas. Studies highlight their effectiveness in reducing inflammation, cancer, diabetes, depression, diarrhea, urolithiasis, and ulcers. Additionally, bananas exhibit antibacterial, antiviral, antihyperlipidemic, antiatherosclerotic, hepatoprotective, hair-growing, wound-healing, and antihypertensive properties. The articles were sourced from databases such as PubMed, Scopus, and Google Scholar using keywords like *Musa paradisiaca*, health benefits, inflammation, cancer, diabetes, and phytochemicals. Inclusion criteria included original research, clinical trials, in vitro and in vivo studies, and reviews focused on banana's medicinal properties, while non-peer-reviewed papers and studies not directly related to *Musa paradisiaca* were excluded. This review reinforces the comprehensive health-promoting benefits of bananas and sets the stage for future research, which should focus on large-scale clinical trials, phytochemical standardization, and sustainable utilization of banana plant components. Bananas hold immense potential as both a functional food and a medicinal plant, making them a promising subject for future studies in nutraceuticals and sustainable agriculture.

Introduction

Banana (family Musaceae) is one of the world's most widely cultivated fruit crops and has been a staple for humanity since 600 BC. Known for its accessibility, year-round availability, and exceptional nutritional value, the banana is often referred to as the "plant of virtues" (Kalpataru) due to its extensive applications and economic importance. This complex hybrid, derived from *Musa acuminata* and *Musa balbisiana*, is native to Asia but widely distributed across tropical regions worldwide, particularly in South and Southeast Asia and the western tropical Pacific Ocean (1-3). Bananas offer unique nutritional and medicinal properties, with all parts, including flesh and peel, usable in products like chips, powder, biscuits, and juice (4). Bananas are an affordable, nutrient-dense food source, rich in carbohydrates, dietary fiber, essential minerals, and vitamins that support human health (5). Furthermore, bananas contain numerous bioactive phytochemicals, including plant sterols, carotenoids, biogenic amines, and phenolic compounds, all playing significant roles in health by combating inflammation, cancer, and diabetes and serving as antioxidants (6). The banana peel extracts have demonstrated wound-healing properties by enhancing mucosal cell proliferation and DNA synthesis (7).

Despite these notable benefits, a comprehensive review of bananas' dietary and phytochemical profiles is essential to better understand their wide-reaching pharmacological potential. Given the diversity in banana cultivars, this review addresses the challenges in standardizing banana-derived products and examines the phytochemicals' specific roles in preventing chronic diseases and enhancing well-being. Additionally, it seeks to evaluate gaps in current

knowledge, emphasizing the need for more research into optimal processing and formulation methods to retain and maximize the pharmacological efficacy of banana-based treatments. This review highlights the enormous potential of bananas and considers future research avenues to fully utilize their therapeutic power for human health at a time when the demand for easily accessible and natural nutraceuticals is rising.

Methodology

A comprehensive review of 191 research papers published between 1981 and July 2023 was conducted to examine the health benefits of *Musa paradisiaca* (banana). The literature search was carried out using databases like PubMed, Scopus, and Google Scholar, focusing on studies exploring bananas' nutritional, medicinal, and therapeutic properties. Inclusion criteria encompassed original research, clinical trials, in vitro and in vivo studies, and reviews on bananas' bioactive compounds and health effects, explicitly addressing conditions such as cancer, diabetes, inflammation, and hypertension. Exclusion criteria included non-peer-reviewed articles, conference abstracts, papers unrelated to *M. paradisiaca*, and studies unavailable in English or lacking data on banana-specific effects. Data extraction focused on study types, health outcomes, and phytochemicals, followed by a synthesis of trends in efficacy and a qualitative assessment of study methodologies. Limitations related to study designs and phytochemical standardization were also addressed, suggesting future research directions.

Nutrient Profile of Banana

In addition to routine contents like carbohydrates, dietary fiber, minerals, and vitamins, bananas also contain several health-promoting bioactive phytochemicals, including antioxidants, carotenoids, and phenolic compounds (5). Phytochemical analysis of *M. paradisiaca* showed that along with the usual carbohydrates and reducing sugars, different parts of the banana also contain alkaloids, glycosides, phenols, tannins, steroids, terpenoids, saponins, flavonoids, and several secondary metabolites (8). The ripe banana peel of *M. paradisiaca* contains various minerals like Na, Mn, Ca, Zn, Cu, N, K, and Fe with concentrations in ppm of 84.53, 18.82, 2.41, 1.01, 1.89, 1.15, 3.96, and 27.83 respectively (9). Ripe peel also contains proteins, carbohydrates, fat, fiber, and ash at concentrations (in percentage) of 7.18, 42.95, 6.22, 14.31, and 22.30, respectively (9). An average-sized banana fruit contains approximately 6 g of fiber and 450-467 mg of potassium, and its pulp is high in cellulose, sugars, fiber, and starch and is a good source of vitamins like vitamins A and C (10). The pulp of the banana fruit, *Musa paradisiaca* var. *sapientum*, is also reported to contain several bioactive nitrogen-containing compounds like serotonin, tryptophan, norepinephrine, indole compounds, stearyl acyl glycosides, sitosterol, acyl stearyl glycosides, myoinositol β-D-glucoside, cyclomusalenol, cyclomusalenone, 24-methylene cycloartenol, stigmast-7-methylenecycloartanol, stigmast-7-en-3-ol, lanosterol, and β-amyrin (11, 12). In *M. cavendish*, antioxidant gallocatechin was reported and was more abundant in the banana peel than in the pulp (13). Flavanoid intake protects against coronary heart diseases (14). Furthermore, the flower has yielded hemi terpenoid glucoside (1,1-dimethylallyl alcohol β-glucoside), syringin, (6S,9R)-roseoside, and benzyl alcohol glucoside (15). In addition to the pulp, the banana peel is also a rich source of phytochemicals. Studies on the nutrient content of six varieties of banana peel reported 40-50% dietary fiber with a high protein content of 8-11%, along with essential amino acids like phenylalanine, leucine, valine, and threonine. Among the minerals, potassium was present in significant amounts (16).

Banana peel is valued for its bioactive components, including phenolic compounds such as flavonols, hydroxycinnamic acids, flavan-3-ols, and catecholamines, and is also a potential source of pectins and dietary fibers (17, 18). The pulp and the banana peel are also a rich source of bioactive compounds like carotenoids, flavonoids, phenolics, vitamins like C and E, and amines (19, 2). As the fruit ripens, the starch present in the banana is converted into glucose, sucrose, and fructose (20). Unripe bananas have a lot of digestible starch, while ripe bananas have more resistant starch (21). Chitinase, a transient Vegetative Storage Protein, is common in unripe bananas (22). Also, as the banana ripens, a large increase in fructose, glucose, and total sugar is noted (23). Comparison of phytochemicals and mineral compositions of ripened and unripe banana flours revealed that the total amount of soluble sugars present in unripened bananas ranged between 1.70 to 2.15 mg/100 g, while those in ripened bananas ranged from 37.5 to 43.8 mg/100 g (24). Its inflorescence is edible and is used as food and in medicine (24, 25). Banana is a good and easy source of macronutrients such as carbohydrates, protein, unsaturated fatty acids, vitamins, and various minerals. Soluble solids (17.9%), vitamin A (12.4 mg/100 g), and vitamin C (12.7 mg/100 g) were also observed in bananas by researchers. The nutrient and phytochemical composition of banana fruit (as per 100 g) is given in Figures 1 and 2 (26). Bananas contain various bioactive compounds rich in antioxidants, including carotenoids, flavonoids, phenolics, amines, and vitamins C and E, which offer numerous health advantages (2). The peel is rich in flavonoids, flavan-3-ols, hydroxycinnamic acids, and catecholamines (18). Additionally, *Musa cavendishii* is notable for its antioxidant dopamine, present in both the peel (80-560 mg/100 g) and pulp (2.5 to 10 mg) (27).

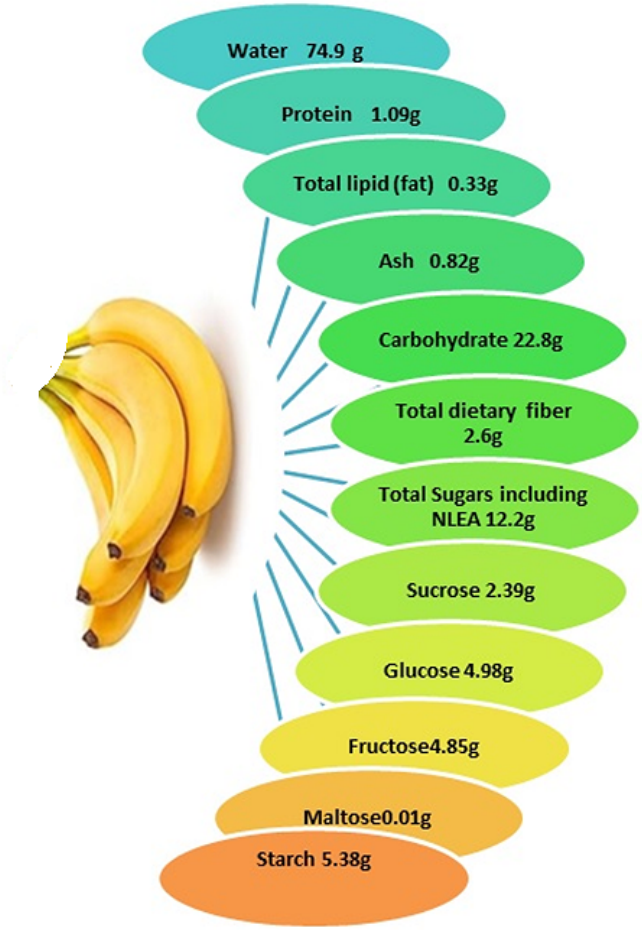

Figure 1. Nutrients of banana fruit.

The significant presence of phenolics, biogenic amines, flavonoids, carotenoids, sterols, and various antimicrobial agents makes bananas suitable for enhancing health (29). They contain phenolic acids like ferulic, gallic, vanillic, salicylic, sinapic, p-hydroxybenzoic, syringic, gentisic, and p-coumaric acids (30). Ferulic acid, in particular, has antimicrobial, anticarcinogenic, anti-inflammatory, and vasodilatory properties (31).

An assessment using LC-MS-ESI revealed the presence of flavonoids such as epicatechin and 3-O-rhamnosyl-glucoside. Potassium was the most abundant mineral at 14,746.73 mg/Kg, while zinc concentration was 3.55 mg/Kg in unripe banana flour (32). Key bioactive compounds with antioxidant properties in banana fruit include gallic acid, tannins, catechin, epicatechin, and anthocyanins. Plantain pulp is rich in hydroxycinnamic derivatives like ferulic acid-hexoside, while banana peel contains high levels of rutin (5). The flavonoids identified from bananas, such as quercetin, myricetin, kaempferol, and cyanidine, are free radical scavengers (33). Carotenoids in bananas include lutein, lycopene, and zeaxanthin (34), with orange and yellow-fleshed varieties having higher trans-carotene content (35). Biogenic amines like dopamine, norepinephrine, and serotonin are prevalent in banana peel and pulp, with serotonin levels ranging from 8 to 50 µg/g and varying dopamine levels in different banana pulps (36). Dopamine in bananas improves LDL resistance to oxidation and reduces plasma oxidative stress, leading to decreased oxidative modification of low-density lipoprotein (37).

Health Benefits of Banana

Researchers have uncovered numerous health benefits of bananas (Figure 3). Sitosterol in bananas may alleviate benign prostatic hyperplasia symptoms and lower cholesterol levels (38). Banana ethanol fiber extract reduces cholesterol in obese male mice (39), while gallocatechin gallate aids cholesterol reduction and offers hepatoprotective effects (40, 41). Serum α-carotene levels inversely correlate with CVD and cancer mortality risk (42). Plant sterols like campesterol and stigmasterol in bananas lower cholesterol absorption by replacing LDL in the intestine (43). Additionally, cinnamic acid serves as an aspartame precursor (44), and cycloartenol supports plant steroid biosynthesis (45). Catechins enhance plasma antioxidants, reduce lipid peroxides, and improve LDL oxidation resistance (46).

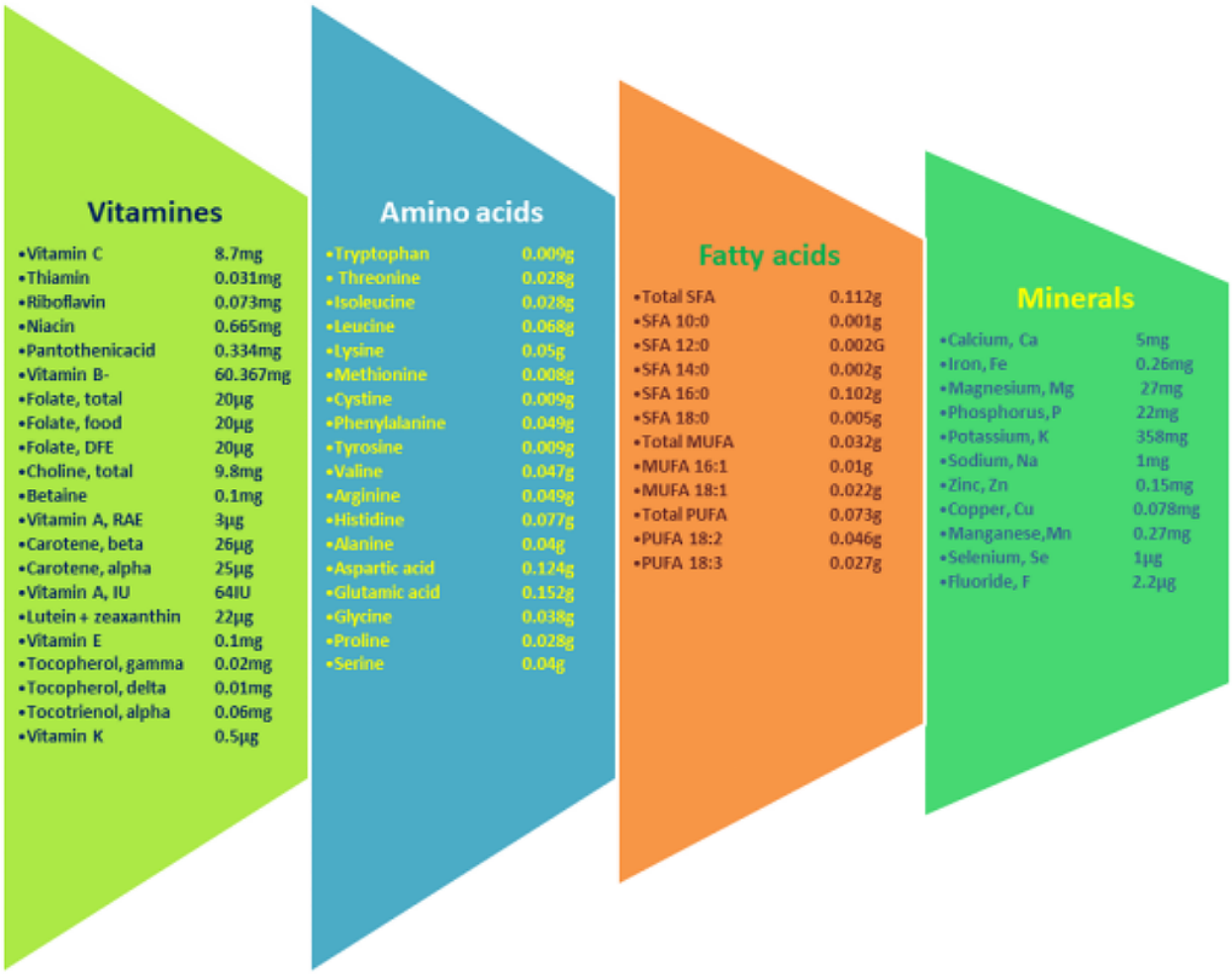

Figure 2. Phytochemical composition of banana fruit (as per 100 g).

Figure 3. Various health benefits of banana.

The serotonin content in bananas has been linked to feelings of well-being and happiness. Although bananas contain serotonin, they do not cross the blood-brain barrier (47). Banana lectin (BanLec-1) isolated from *Musa paradisiaca* showed binding specificity for oligomannosidic. It has been shown to stimulate T-cell proliferation (48). Catecholamines are neurotransmitters and are precursors of benzophenanthridine alkaloids (49). The tannic acid from bananas has been utilized in burn treatment (50).

Anticancer Properties

An anticancer polyphenol, protocatechuic aldehyde (PCA), was identified in green Cavendish bananas (51). PCA increases activating transcription factor 3 (ATF3) expression and shows anticancer properties in leukemia, colorectal, and breast cancer cells (52). A higher incidence of esophageal cancer has been reported in males consuming fewer or no bananas (53). Daily consumption of 2 g of banana in Swiss albino mice with Ehrlich ascites carcinoma cells resulted in growth suppression, allowing 30% of the animals to survive longer (54). A diet with 10% green banana flour in colon cancer mice reduced the number of aberrant crypt foci (a colorectal cancer biomarker) reported in colorectal mucosa (55). A high intake of certain vegetables and fruits reduces the risk of breast cancer (56). Research indicated that 2-pentanone, a compound found in bananas, can inhibit the production of prostaglandin and COX-2 protein expression in colon cancer cells (57). The banana peel methanol fraction inhibited testosterone-induced cell growth in the androgen-responsive LNCaP prostate carcinoma cell line, which may aid in controlling benign prostate hyperplasia (58). Anthocyanin from the bract of *M. acuminata* regulated the human breast cancer cell line (MCF-7) by inducing apoptosis (59). Protocatechualdehyde showed antiproliferative activity on human colorectal carcinoma cells in a dose-dependent manner by reducing the expression of enzyme histone deacetylase 2 mediated by cyclin-D1suppression (60). Ethanol extract from banana flower demonstrated anticancer properties on HeLa cells, activating apoptosis and increasing caspase-9 enzyme activity by blocking the cell cycle at the G0/G1 phase (61). The hexane fraction of banana pulp and peel has shown in vitro anticancer activity against HCT-116 cells (62) and high toxicity against MCF-7 and HCT-116 tumor cell lines (63). Extracts from banana pseudostems and rhizomes have demonstrated excellent cytotoxicity against HepG2 liver cancer cells (64). Ferulic acid from banana peels activated DNA fragmentation in HeLa cervical cancer cells (65). Three phytochemicals from pseudo stem of a banana can arrest mitotic cell division via proteins, cyclin-dependent kinase 2 and tubulin (66). Banana flower extract (aqueous) exhibited anticancer activity against benign prostatic hyperplasia by inducing cell cycle arrest at the G1 phase (67). Ethyl acetate sub-fraction collected from soft piths of banana (*M. paradisiaca*) is found to exhibit excellent antiproliferative and cytotoxic activity on human tongue squamous cell carcinoma (HSC-4) (68). Banana peel methanol extract collected from the Nendran variety showed excellent antitumor activity against the MCF-7 breast cancer cell line. Treated cell lines showed condensed nuclei and apoptosis, which showed their efficiency against breast cancer (69). Studies showed that *M. cavendish* green peel extract has antiproliferative properties on HepG2, A-375, MCF-7, and Caco-2 cancer cells. The extract showed an antiproliferative effect in all cell lines at a concentration of 100 µg/mL. Also, HepG2 induced changes in cell morphology and necrosis related to cell death. The authors suggested that MHE can be considered for developing new drugs with anticancer properties (70). Hyperpigmentation of the cell is considered due to over expression of pigment melanin. Sucrier banana peel (Methanolic) extract inhibits melanogenesis via the p38 signaling pathway in B16F10 mouse melanoma cells (71). Mannose-specific lectin from bananas exhibited antiproliferative activity and induced cell cycle arrest in different cancer cell lines (72). *M. acuminata* flower methanol extract showed cytotoxic and antiproliferative properties on HeLa cells (73). The ethyl acetate fraction from *M. paradisiaca* leaves displayed potential anticancer activity against HeLa and A375 cervical cancer cell lines (74).

Antidiabetic Properties

Bananas have a low glycemic index, effectively reducing immediate blood glucose levels. Studies show that methanolic extract from green M. paradisiaca fruits exhibits significant hypoglycemic properties in both healthy and diabetic-induced mice (75). A pectin-type polysaccharide from banana peel demonstrated antidiabetic effects by activating insulin production (76). Alcoholic extracts from M. paradisiaca flowers have also shown excellent antihyperglycemic properties (77). Banana flower has several bioactive compounds and shows antidiabetic properties (78). Consumption of *M. paradisiaca* inflorescence extracts normalized blood glucose and lipid peroxidation levels in diabetic rats (79).

Malaysian banana flower extracts have been identified as a potent source of antioxidants and postprandial regulators to combat hypoglycemia (80). Insulin tolerance tests indicated that extracts from *M. cavendish* and *M. acuminata* had the highest hypoglycemic activity compared to *M. sapientum* and *M.paradisica* (81). Methanol and hydroalcoholic extracts from the pseudostem effectively inhibited α-amylase and α-glucosidase enzymes, demonstrating antidiabetic activity (82). Ethanol extracts from *M. balbisiana* flowers exhibited significant antidiabetic,

antihyperlipidemic, and antioxidant effects in diabetic rats. The serum insulin level increases, and glucose absorption from the intestine is reduced considerably (83). *M. paradisiaca* inflorescence is also an excellent source of soluble dietary fiber, which can enhance glucose and cholesterol adsorption and increase glucose uptake in myoblasts (84). Streptozotocin-induced diabetic rats, when given with aqueous extracts of *M.paradisiaca* inflorescence showed that the inflorescence could be used as an alternative therapy for treating type 2 diabetes mellitus with promising hypoglycemic effect (85) .M. Type 2 diabetic rats (induced by STZ) showed reduced food intake, also the fasting insulin and GLP-1 levels are increased, after the ingestion of banana peel dietary fibres to such rats. Thus, banana peel soluble dietary fiber can be used to treat type 2 diabetes mellitus (86).

Chloroform extracts from banana flowers have shown antidiabetic properties (1). Consumption of resistant starch from green bananas can reduce fasting glucose and body weight, making it a good option for prediabetics (87). An extensive review recommends standardizing dosage and considering the banana variety and ripening level for different age groups (88).

Antibacterial Properties

Different parts of bananas also show potent antibacterial properties. The threshold of inhibitory concentration (ic 50) against *Staphylococcus* and *Pseudomonas* with *M.paradisiaca* bark/peel aqueous extract were 143.5 and 183.1 µg/mL, respectively. The banana peel extract was more active than the leaf extract against both bacteria. Also, the extract was more active against *Staphylococcus* bacteria than the *Pseudomonas* species (89). In the laboratory study, ethyl alcohol extracts of banana flowers of *Musa sapientum* have been shown to inhibit the growth of several pathogenic bacteria like *B. subtilis*, *B. cereus*, and *E. coli*. Of the different bioactive compounds isolated (which include β-sitosterol, 12-hydroxy stearic acid, palmitic acid, and d-malic acid), β-sitosterol and malic acid were the active compounds responsible for antibacterial activity. The study may aid in wound healing and infection prevention (90). The antimicrobial property of M. paradisiaca and Cocos nucifera crude extracts on bacteria was studied using the agar disc diffusion method. Both plant extracts hindered the growth of test organisms. The methanol extract of *M. paradisiaca* fruit peels exhibited pronounced antibacterial activity against bacteria such as *Staphylococcus aureus*, *Bacillus subtilis*, *E. coli*, and *Pseudomonas aeruginosa* (91). The flower extracts (ethyl alcohol and ethyl alcohol: water extracts) of *M. paradisiaca* showed antibacterial and antifungal activity against *E. coli*, *B. subtilis*, *B. cereus*, *Klebsiella pneumoniae*, *P. aeruginosa*, *P. mirabilis*, *S. aureus*, *S. pneumoniae, S. typhimurium*, *C. albidus* and *C. albicans* with minimum inhibitory concentrations that ranged from 5.62-25.81 and 7.60-31.50 µg/mL, respectively (77). Studies also showed that the ethanol extract of unripe banana peel inhibited the microorganism like *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Proteus mirabilis*, *Bacillus subtilis*, *Aspergillus niger* at a concentration of 100 mg/mL with the inhibition zones of 8.2, 7.8, 8.3, 5.4, 4.6 respectively (9). Ethyl acetate extract of *M. paradisiaca* demonstrated effective antibacterial properties against multidrug-resistant strains of nosocomial pathogens *P. aeruginosa*, *E. coli* and *Citrobacter sp* (92).

The antibacterial activity of the banana extract was highest against *M. catarrhalis* and *S. aureus* (inhibition zone 30 mm), followed by *S. pyogenes*, *E. aerogenes,* and *K. pneumoniae* (93). Alcoholic extract of banana peel has antimicrobial properties against pathogens causing aggressive periodontitis *P. gingivalis* and *A. actinomycetemcomitans* (94). Antibacterial potentials of leaf ethanol and aqueous extract of *M. paradisiaca* against bacteria of clinical importance like *S. aureus*, *B. subtilis*, *P. aeruginosa*, *V. cholerae*, and *S. dysenteriae* showed that aqueous fraction has a minimum inhibitory concentration that ranged from 3.125 to 25 mg/mL. The aqueous fraction outperformed the ethanol extract regarding antibacterial activity (95). Methanol extract is reported to have more inhibition than ethanol extract in controlling *E. coli*, *P. aeruginosa*, Staphylococcus aureus, and Salmonella typhi (96). Also, the methanol fraction of *M. paradisiaca* exhibited greater wound-healing activity in albino rats (97). *Streptococcus mutans* is reported as the most susceptible bacteria with banana peel ethanol extract, and the inhibition zone ranged from 8 mm at 3.125 mg/mL to 25 mm at 100 mg/mL. It was followed by *P. aeruginosa* and *E. coli*. Also, the sensibility of the multidrug-resistant bacteria to the ethanolic peel extract is of great significance in future work (98). The peel extract in methanol had strong antibacterial action on *S. aureus* and *E. coli,* and the activity was suggested to be associated with the total flavonoid and the phenolic compounds. The leaf stalk extract of *M. acuminata*collected in acetone showed antimicrobial properties against the disease-causing bacteria, *P. aeruginosa* and *E. coli*, and therefore, it can be recommended for infections caused by these microorganisms (99). *M. acuminata* and *M. paradisiaca* ethanolic leaf extracts act as antibacterial agents for methicillin-resistant strains of *S. aureus* (100).

Antiviral Properties

Banana lectin was discovered in 1990 in M. paradisiaca (48); however, no significant further work was reported for a long time. The crystal structure of methyl αD-monoxide with banana lectin (from *M. paradisiaca*) has exposed two primary binding sites for banana lectin

(101). Lectins are homodimeric natural proteins capable of binding reversibly with carbohydrates on the cell surface. So, lectin can bind with the surface of pathogens and can damage their structure, preventing the host infection. Studies showed that lectin can bind with mannose and mannose-containing oligosaccharides and is an effective T-cell mitogen. BanLec or banana lectin is extracted from the fruit of *M. acuminata.* The lectin has high affinity and can bind to mannose structures, especially those located on the glycosylated envelope of viruses like HIV-1, by binding to glycosylated envelope protein gp120 and preventing its further entry into the cell and showing potent anti-HIV properties (103). Substituting a single amino acid, histidine, with threonine in banana lectin (H84T) can reduce mitogenicity and maintain its antiviral properties. It can bind to mannose N-glycans and showed antiviral properties on several high-mannose expressing viruses, like HIV-1, HIV-2, hepatitis C, and influenza A and B. BanLec H84T can inhibit both virus-like particles as well as entry and replication of the Ebola virus mini-genome in cells (103, 104). Ethanol/acetone extract of banana leaf isolated from many cultivars showed excellent anti-Chikungunya virus properties (EC50 around 10 µg/mL) (105). 25 µg/mL BanLec has exhibited an increased rate of inhibition on Bovine Viral Diarrhea 1 (BVDV-1) (of 99.98%) and on Bovine α Herpes Virus (BoHV-1) (of 99.68%) without showing any cell viability (106).

Antifungal Properties

Peel and stalk extract of banana (*M. paradisiaca*) exhibited antifungal actions, and the activities were studied using the percentage inhibition test. A stalk extract of 1.0 mg/mL showed 100% inhibition of growth against fungi like *Aspergillus oryzae*, *Aspergillus niger*, and *Rhizopus stolonifer*. Peel extract inhibition was 100% on A. niger, 76.67% on A. oryzae, and 56.67% on *R. stolonifer* at the concentration of 1 mg/mL (107). Banana leaves also exhibited significant antifungal activity. In another M. acuminata leaf extract experiment, the largest inhibition zone diameters were shown against *Candida albicans* (108). Similar antifungal activities of banana leaves were observed against *Penicillium oxalicum* (with inhibition of 40%) and *Alternaria alternate* (109). Kadali banana dried peel powder and ash extract showed antifungal properties against *Aspergillus niger* (110).

The antimicrobial property of extracts collected from *M. paradisiaca* and Cocos nucifera on fungi *Candid* sp (*Candida tropicalis* and *Candida albicans*) and Aspergillus niger was studied using the agar disc diffusion method. Both plant extracts hindered the growth of test organisms. Also, *M. paradisiaca* extract suppressed *Candida albicans* more effectively than *Cocos nucifera* crude extract with a wider zone of inhibition (91). When compared to nystatin, the extract of *M. acuminata* leaves in methanol demonstrated superior antifungal actions on *Staphylococcus* epidermidis at a dose of 60 mg/mL and on *Trichophyton mentagrophytes* at a concentration of 40 mg/mL. The capacity points out that the methanol extract collected from the leaves of *M. acuminata* served as a powerful antifungal agent (111).

Antiurolithiasis Properties

The impact of *M. paradisiaca* stem juice on the formation of crystalline substances (stones) and the anti-lithic properties was studied on urolithiasis rats. Oxalate synthesizing enzymes, Glycollic acid oxidase, and Lactate dehydrogenase (LDH) were significantly active in such rats. The extract treatment lowered the enzyme activity, such as glycollic acid oxidase and urinary alkaline phosphatase, reducing oxalate synthesis. There was a reduction in other enzymes like LDH, inorganic pyrophosphatase, and -glucuronidase. There was a lowering in the level of oxalate in the urine. Thus, the *M. paradisiaca* extract lowers the crystalline component formation (112). In a study, *M. paradisiaca* and *M. sapientum* pseudostem core were used to treat urinary stones for two weeks. Results indicated the effectiveness of plant material in treating urolithiasis, mostly that of calcium oxalate stones. Out of the 71 patients treated for 4 weeks, 20 had a complete cure, 43 patients had passed the different-sized stones and 4 patients had reduced the number of calculi (113).

In a review, 103 plants have been reported to show potent litholytic properties, of which *M. bulbisiana* roots and *M. paradisiaca* ripe juice (kernel or the pulp) have been listed to have litholytic properties (114). The role of ethanol extract of the banana corm *Musa* (cultivar monthan) on urolithiasis rats (induced by ethylene glycol and ammonium chloride) was studied concerning kidney stone crystal formation and inhibition. The stone was analyzed spectrophotometrically, and the result showed its efficiency in diuresis and promoting crystallization inhibition (115). In vitro studies in calculi-induced albino rats using *Musa* formulations (AAB) for treating renal calculi are well studied. The administration of liquid *Musa* formulations reduced the size of kidney stones significantly, as it contains organic constituents such as β-sitosterol, saponins, quercetin, tannins, and several inorganic contents such as magnesium, potassium, and nitrate. Also, it is suggested that *Musa* AAB liquid formulations may help overcome the disadvantage of several surgical procedures that may follow due to stone recurrence (116). The efficacy of *Musa* (banana) pseudostem ethanol extract used in regulating ethylene glycol-induced urolithiasis in rats may be by inhibiting various biochemical pathways associated with renal calcium oxalate metabolism (formation), as well as its antioxidant property and the

ability to inhibit biochemical markers of renal impairment (117). Both aqueous and methanol extracts from the fruit peel of *Musa sapientum* (as well as other plants like *Malus pumila*, and *Punica granatum*) showed anti-urolithiatic activity in experiments. The result is significant and can be used for treating lithiasis (118). The anti-urolithiasis property of extract in methanol collected from pseudostem of *M. acuminate* was studied using a spectrophotometer in vitro nucleation and aggregation experiment and by subsequent microscopic examination, showing its efficacy as an alternative medication for kidney stones (119).

Antidepressant Properties

Depression is a mental disorder that affects the mood and thoughts of more than 10% of the population (120) and shows a severe complication of suicidal behavior. Banana peel contains several phytochemicals that can reduce depression. In an experiment to study the antidepressant activity of bananas, fruit paste was administered at concentrations of 5%, 10%, and 20% once daily to Swiss mice for 15 days, and subsequently, the antidepressant property was measured by the methods of Tail Suspension Test and Forced Swim Test. The experiment indicated that the fruit paste could remarkably lower the time for immobility in both tests. *M. paradisiaca* paste inhibited the malondialdehyde and the Monoamine oxidase enzyme (121). Studies carried out in Swiss albino mice showed that intake of extracts orally from green or yellow banana peel (at 200 and 400 mg per kg, respectively) can be recommended for treating depression (122). In a study with pulp and the banana peel extract (at a dose of 600 mg per kg and 400 mg per kg, respectively) of *Musa sapientum* on male albino mice for 14 days through oral administration, and further assessment of its performance through forced swimming test, light and dark activity and maze activity tests, it showed antianxiety, antidepressant, and memory enhancement properties, possibly through phyto-antioxidants (123). Though banana leaf extracts (*M.sapientum*) showed antidepressant activity that may be mediated by α1-adrenergic and D2 dopaminergic receptors, no significant anxiolytic effects were reported (124). The essential amino acid tryptophan for synthesizing serotonin is very supportive in relaxing people, improving their mood, and making them happy. Thus it can be used to treat depression (1, 125). Bananas can be recommended for managing depression based on the 2:1 ratio of ώ 6 to ώ 3 fatty acids (126).

Hepatoprotective Properties

The role of *M.paradisiaca* in supplementing hepatotoxic rats and the biochemical and histological effects were studied in detail, including transaminase enzymes. Histological examination of liver tissue sections revealed necrosis in hepatotoxic rats; however, varying degrees of regeneration were noted in rats given *M. paradisiaca* supplements (127). The alcoholic extract of *M. paradisiaca* stem at dosages of 500 mg/kg, per organism. To a lesser extent, the aqueous extract at a concentration of 500 mg/kg, per organism has a substantial recovery on the liver of carbon tetra chloride and paracetamol caused hepatotoxic damage in rats. The hepatic damage was reversed in these test organisms. It reduced increased levels of various enzymes like serum glutamic oxaloacetic transaminase and serum glutamic pyruvic transaminase (128). Banana contains ferulic acid (30). It acts as a strong hepatoprotective phytochemical and shows no side effects (129, 31). The root extract (aqueous) of *M. paradisiaca* contains bioactive compounds that can protect the liver and kidney from arsenic-caused damage in albino rats (130).

Methanolic extract of *Musa sapientum* treated for 7 days in albino rats exhibited a considerable lowering of ulcer index, and its ulcer protective effect is similar to omeprazole and ranitidine even though more work is essential to determine the true nature of the therapeutic of the plant (131).

Antiulcerative Properties

Leucocyanidin, an active antiulcer compound from the banana, *M. paradisiaca* protects aspirin-induced ulcers. This natural flavonoid protects against aspirin-induced damage to the gastric mucosa (132). The antiulcer activity of banana peel water extract on male albino rats is due to the flavonoids (leucocyanidin), tannins, and saponins. Plantain peel extract of 200 mg/Kg body weight showed the lowest mean ulcer index and concluded that the peel extract could be used in ethnomedicine (133). Several banana varieties from northeast Thailand are reported to have a gastrointestinal protective effect against peptic ulcers, with Palo and Hom varieties showing a pronounced effect (134). The ethanolic extract of plantain elevated eicosanoid accumulation in the stomach and colonic mucosa in a concentration-dependent manner, and the banana might have acted possibly by making arachidonate available (135). The ulcer-curing actions of unripe bananas, *Musa sapientum,* were investigated by many (136, 137) and reported a flavonoid leucocyanidin that showed antiulcerogenic properties. Administration of *Musa sapientum* aqueous extract in the prescribed dosage helps to alleviate ulcers (137). It is almost a fact that banana juice can help heal wounds and burns and relieve the pain of ulcers and other gastrointestinal disorders, including acid secretion. The flavonoid leucocyandine increases the mucosal membrane thickness of the stomach (1). A pylorus ligation technique revealed that the methanol extract from *M. paradisiaca* shows cytoprotective action on peptic ulcers caused by indomethacin (138).

Chloroform and ethanol extracts from the leaves of *Musa sapientum* lowered the ulcer and ulcer index in ulcer-induced rats (139). The banana tepal and peel extracts worked against ulcers by strengthening the stomach mucosa and reducing gastric secretion acidity in ulcer-induced albino mice (140). When treated with M. sapientum methanol extract, ulcer-induced rats showed regeneration of epithelial tissues of the stomach from the third day. By the twelfth day, the regeneration became almost complete. The healing of the ulcer is attributed to the basic fibroblast growth factors (141). The banana flower has several bioactive compounds and shows antiulcer properties (78).

Antidiarrhoeal Properties

Green bananas were used by the public to treat a number of digestive issues, like childhood diarrhoea. Providing a solution with 50 g/L of plantain flour and 3.5 g/L of sodium chloride to children suffering from acute diarrhoeal diseases indicated good rehydration and antidiarrhoeal activity. However, some children have noted decreases in blood sodium and potassium levels (142). Also, in the same year, a comparative study of standard medical care with banana flakes was found to be more effective in treating diarrhoea in enterally fed patients. Banana's antidiarrheal activity might be due to its pectin and other soluble fibers that serve as active antidiarrhoeal substances (143). Children having persistent diarrhoea for 14 days showed that including green bananas in the diet can increase the permeability of the intestine. The increased permeability was proved with lactulose-mannitol drink given to children and by subsequent recovery (after 5 hours) of increased urinary mannitol and reduced lactulose content. Recovery of stool weight was reduced by 50%, and there was a drastic acceleration in the clinical recovery. Thus, the green banana and the pectin's antidiarrhoeal effects are mediated by the increased rate of the permeability of the small intestine, along with the known colonotrophic properties (144). Green banana's antidiarrheal action is believed to be due to its high starch content resistant to amylase, which gets fermented to yield several short-chain fatty acids (SCF) in the colon that stimulate the absorption of salt and water from the colon. The SCF thus produced is an adaptive process as these fatty acids get absorbed in the epithelial cells of the colon, which subsequently helps in the absorption and conservation of fluid and electrolytes. Thus, adding resistant starch that produces SCF in the colon to oral rehydration solution (ORS) might improve the efficiency of the ORS given to children under 5 years suffering from acute diarrhea (145).

The antidiarrheal property of *M. paradisiaca* sap is considered to be due to the presence of phytochemicals like alkaloids, flavonoids, phenolics, and saponins of the sap that is responsible for the increased absorption of fluid and electrolytes via de novo synthesis of Na-K-ATPase pump (146). Unripe banana (*M.paradisiaca*) ethanol extract has antidiarrheal activity (147). Studies showed castor oil-induced diarrhea of rats' stool consistency can be improved with unripe banana peel extract (BPE) containing pectin and other active substances (148).

Wound-Healing Activity

Banana extracts have wonderful wound-healing capacity with its antioxidant effect as well as due to the various wound healing biochemical parameters (like enzyme activity of superoxide dismutase, reduced glutathione, and lipid peroxidation as well as that related to connective tissue development (like hexuronic acid, and quantity of hexosamine and hydroxyproline), it showed that plantain banana extracts have significant healing capacity (149). It was reported that the *M. paradisiaca* stem exhibits a hemostatic effect. A 10% juice of plantain stem extract was formulated to prepare an ointment and tried for the healing properties of rats. It confirmed a prominent ($p<0.05$) enhancement in the healing process. When the wound area closure (in %) was compared between plantain stem juice and silver sulphadoxine, the plantain-based ointment showed 98.9±0.7% closure area, and for the silver sulphadoxine was 100±0.00%. The results conclude the efficiency of plantain-based ointment in healing wounds (150). The dermal application of banana peel extract augments healing through vascular endothelial growth factor (VEGF), which is released from degranulating platelets in large amounts, and new capillary development occurs in the area. An increased collagen concentration occurred in the wound area due to the synthesis and deposition of new collagen (151), aiding in wound healing. There is an increase in vascular and fibroblast proliferation (152). The flavonoids, glycosides, and phenols of banana peel extracts have antibacterial and anti-inflammatory properties (140).

The histopathological and clinical examinations were used to measure wound healing by assessing the wound contraction rate and epithelialization of the wound tissue in rabbits treated with banana peel extract (153). *M. paradisiaca* peel extract exhibited wound-healing properties in male Wistar rats. The peel's methanol and hexane extract showed better results. This ability is due to the antioxidant property of phytochemicals like alkaloids, phenols, tannins, and saponins in banana peel (154). Methanolic extract from *M. paradisiaca* Linn. stem exhibited greater wound healing ability in albino rats (97). Unripe peel extract has pharmacological properties and decreased WBC counts (155). Kepok banana (*M. paradisiaca* L) peel extract has saponins (that show hemostatic properties), tannins (that show vasoconstrictive properties), and flavonoids (also affect blood

capillaries) that can stop bleeding, and these bioactive phytochemicals of the peel can be used for healing wounds (156).

Antihyperlipidemic Activity

Banana also exhibits antilipidemic activity. The excretion of bile acid and neutral sterols is found to be higher in fiber-fed (from unripe banana) rats. The neutral detergent fiber from *M. paradisiaca* can lower cholesterol absorption in rabbits (157). Administration of flavonoids orally isolated from unripe banana (*M. paradisiaca*) fruits at a concentration of 1 mg per 100 grams body weight/day has a prominent hypolipidemic action in male rats. The quantity of different fats (like cholesterol, phospholipid, and triacylglycerol) significantly decreases in the brain, kidney, and liver (158). The structural similarity of cholesterol with banana phytosterol is also well-accepted. Reports showed that phytosterol replaces the cholesterol in the gut during absorption, thereby reducing the blood cholesterol level (159). Soluble and insoluble components of dietary fiber of banana pulp showed cholesterol lowering property in male rats (160)

The effects of flavonoid, saponin, and tannin present in banana peel of Kepok variety extract in obese male mice*, Mus musculus* L. (at a concentration of 200 mg per kg body weight) in lowering the level of total cholesterol was established (39). In rats supplemented with *M. paradisiaca* (at a dose of 10, 20, and 30%) for 21 days, total serum cholesterol was lowered, thus showing an antihyperlipidemic effect of banana (162). Consuming fresh and dried banana peels may modify the risk of acute liver failure patients. A significant increase in HDL-c was observed in all acute liver failure albino rats administrated with dried banana peels (161). Studies show that ripe banana extract is high in aliphatic alcohols, fatty acids (both ω-3 and ω-6), and α-tocopherol, supporting a healthy life (163). All these works emphasize that bananas can easily step into biologically active functional foods, and its inflorescence can be economically consumed as food and medicine (24). In diabetic rats, Kepok banana peel extract shows an antihyperlipidemic effect (164).

Antihypertensive Activity

Fruit preparations reduced heart rate and mean arterial blood pressure in normal albino rats and in rats previously treated with deoxycorticosterone acetate (DOCA), providing evidence for blood pressure-lowering action. Thus, bananas can lower DOCA-induced increased arterial pressure and hypertension in rats (165). The studies with plantain extract on rats' isolated aorta and portal veins showed that the extract has a direct effect by relaxing the noradrenaline and KCl-contracted aortic rings (166). Banana is reported to decrease both systolic and diastolic blood pressure changes induced by cold stress. The activity of plasma angiotensin-converting enzymes (ACE) is reduced considerably. The poovan variety of banana has a high inhibitory effect on ACE (167). Results of a study with 20 randomly selected women of age group 19-22, daily intake of one banana (*Musa acuminata*) for 7 days showed a lowering of blood pressure in the cold stress test (168). The most important phytochemicals in bananas are inhibitors of angiotensin-converting enzyme (ACE). Ripened banana varieties like nendran, poovan, robusta rasthali, safed velchin, and bontha effectively inhibited the enzyme ACE, with nendran as a strong inhibitor. However, unripe bananas showed only a weak response (169). Notably, *M. paradisiaca* fruit consumption reduced the increase in systolic, diastolic, and arterial blood pressure induced by cold stress. There is a significant drop in plasma ACE activity, implying that the observed blood pressure-lowering effects were due to suppression of this enzyme activity (169).

The potassium in bananas effectively regulates blood pressure by reducing the effect of sodium. Therefore, consuming bananas can help to reduce the feeling of thirst along with muscle weakness caused by potassium deficiency. Incorporating banana juice in the food may reduce blood pressure and protect elderly persons from degenerative disease (170). *M. paradisiaca* has an antihypertensive effect in albino rats and was found to lower arterial blood pressure and prevent the onset of increased blood pressure caused by DOCA injection in rats (171, 172). Banana's low salt content helps regulate blood pressure and prevent strokes (125). A study among hypertensive individuals reported that the phytochemicals in bananas efficiently reduced both systolic and diastolic blood pressures. However, more clinical studies in humans are recommended to provide efficacy evidence (173). Many studies also suggested that the intake of bananas significantly lowers blood pressure in elderly persons (174-176)**.**

Antiatherosclerotic Activity

M. paradisiaca inhibits in vitro cholesterol crystallization and nucleation. The plaque contains cholesterol monohydrate, and *M. paradisiaca* showed anti-atherosclerotic effects in diet-induced atherosclerosis (177). Treatment with *M. paradisiaca* peel extract (at a concentration of 100 mg/Kg) to atherosclerosis-induced Wistar albino male rats ameliorates several biochemical changes caused by the atherogenic diet, indicating the role of peel extract against induced atherosclerosis and thyroid dysfunction (178). An extensive study conducted in Indonesia proposed that Ambon banana peel extract inhibits the atherosclerosis process and can be considered a therapeutic material for the prevention of atherosclerosis (179).

Antiallergic Activity

Methanol extract of *M. paradisiaca* stem has anti-inflammatory properties on chemically induced acute edema, like dextran-caused paw edema (180). The powder of the pseudostem of *M. paradisiaca* displayed an antiallergic potential in rats when treated daily by oral administration (181). The bronchospasm induced in guinea pigs with histamine or acetylcholine is reduced considerably with treatment using hydroalcoholic extract of *M. paradisiaca* flower ($p<0.001$) (182). The study on mice and human macrophages with banana inflorescence extract showed that the inflorescence extract exhibits antiallergic properties and reduced expression of CD86 and HLA-DR receptors on human M1 macrophages, inhibiting eosinophil migration (183).

Anthelmintic Activity

Compared to the usual medication piperazine citrate, the anti-helminthic activity of the corm of banana ethanol extract is dose-dependent and more effective. The anthelmintic qualities of *M. paradisiaca* cv. Puttabale's ethanol extracts on *Pheretima posthuma* are dose-dependent, with a concentration of 100 mg/mL showing a paralyzing time of 42.33 minutes and a death time of 54 minutes, compared to 39.67 minutes for paralysis and 59 minutes for death with piperazine citrate (184). The anthelmintic property of banana peel methanol extract (40 mg/mL) showed the quickest duration for the paralysis and subsequent death of worms compared to the standard drug, albendazole, suggesting the use of banana peels in helminth infestations (185). Sheep fed with dried ground banana leaves may experience a decrease in the survival of *Trichostrongylus colubriformis* eggs, which is potentially valuable for integrated parasite control strategies (186). A study on the anthelmintic activity of Kepok banana peel extract revealed the highest mortality rate against *Ascaridia galli* after 10 hours of treatment with a 75% concentration of ethanol extract (187). Aqueous and ethanolic extracts of *Musa balbisiana* Colla leaves had 100% egg-hatching inhibition rates of *Haemonchus contortus*, while peel and roots showed 93.7% and 62% inhibition, respectively (188).

Menstrual Pain Relief Activity

Banana flowers contain several bioactive compounds like tannins, myoinositol phosphate, vitamin C, and α-tocopherol and are used to treat issues associated with menstrual bleeding and to facilitate lactation (78). Consuming cooked banana blossoms has been used since ancient times to reduce painful bleeding and alleviate muscle cramps by regulating progesterone hormone levels. Reports suggest banana blossoms may benefit women with polycystic ovarian syndrome (189). The antihemorrhagic action of banana blossoms has also been reported, and the flowers can be used as an infusion to alleviate discomfort during menstruation (1).

Hair Growth-Promoting Property

The ability of *M. paradisiaca* unripe fruit extract to stimulate hair growth was assessed in rats, where hair length and follicles were analyzed over 30 days. The study proved that the extract from unripe *M. paradisiaca* fruit could potentially promote hair development (190). Bananas are rich in natural oils, carbohydrates, vitamins, and potassium, contributing to hair softness, preventing breakage and split ends, and maintaining its elasticity and health. Using bananas on hair can enhance shine, promote growth, and help prevent dandruff (1). In a study with banana flower extract, there was an increase in hair root diameter, reduced hair loss, and decreased scalp redness, indicating its potential to stimulate hair growth and inhibit genes associated with hair loss while promoting hair-growth-related genes (191).

Conclusions

M. paradisiaca Linn. has survived ages and has a global distribution throughout tropical regions. The fruit satiates hunger and contributes immensely towards nutrition. The presence of carbohydrates, proteins, flavonoids, sterol glycoside, vitamins, minerals, and catecholamines gives it medicinal and dietetic properties. Several parts of the plant have been exploited for treating cancer, diabetes, depression, diarrhea, urolithiasis, and ulcers. It can also be used as an antibacterial, antiviral, antihyperlipidemia, and hepatoprotective agent. Its use for managing hypertension, atherosclerosis, hair problems and hair growth, wound healing, and many other activities has also been well studied. The available primary information paves the foundation for further phyto-analytical studies and clinical and toxicity evaluations. The future of *M. paradisiaca* lies in its ability to bridge food security, medicine, and sustainability. With the right scientific validation, it could become a cornerstone of global health solutions, offering affordable, natural alternatives to synthetic medicines and contributing to both preventative healthcare and treatments. Trends point towards its greater integration into the wellness, food, and pharmaceutical industries, supported by advances in phytoanalytical research and sustainable practices.

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Acknowledgment

We would like to express our sincere gratitude to Dr. Mini P.V., Head of the Department of Zoology at Government College Kasaragod, and Dr. Jayakrishnan T.V. for their invaluable support and guidance throughout the course of this study. Their expertise and encouragement have been instrumental in the completion of this comprehensive review. We are deeply appreciative of their contributions and dedication to advancing our understanding of the nutritional and pharmacological benefits of bananas.

Conflict of Interest

The authors declare no conflicting interest.

Data Availability

Not applicable.

Ethics Statement

Not applicable.

Funding Information

Not applicable.

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How to cite: Jaleel, A.K., Jacob, S., Ghosh, S.M., Suresh, A.. A Comprehensive Review on Nutrient Profile and Pharmacological Benefits of Musa paradisiaca. Sciences of Phytochemistry. 2024; 3(2):123-143