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Phytochemical and Antimicrobial Assessment of Ethanolic and Aqueous Extracts from Musa acuminata Peels

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Abstract: *Banana (Musa acuminata) exists as a major agricultural fruit that shows medicinal potential through multiple plant components including the fruit peel. This review examines both antimicrobial activities and phytochemical characteristics of extracts produced from Musa acuminata peels through ethanolic and aqueous solutions. The bioactive compounds in banana peels mainly include flavonoids and alkaloids alongside tannins saponins and phenolic compounds as they drive their wide array of biological actions. Ethanolic and aqueous banana peel extracts confirm powerful antimicrobial effects while inhibiting bacterial species including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa. Structure-active compounds inside these extract solutions force disruptions to bacterial membranes and support an important part of cellular metabolic activities. Banana peel-derived ethanolic extracts demonstrate stronger antifungal properties against medically important fungi including Candida albicans and Aspergillus niger than their aqueous counterparts. Preliminary research findings indicate that banana peel extracts show promising helminth and protozoa antiparasitic effects. Banana peel extracts show exciting potential as anticancer agents by demonstrating they can halt the expansion of diverse cancer cell types. Banana peel waste demonstrates extraordinary potential for pharmaceutical, agricultural, and food preservation markets since it provides sustainable antimicrobial antifungal and antiparasitic natural products. Additional scientific study is needed to uncover precise bioactive compounds in banana peels, enhance extraction processes, and perform complete animal studies along with clinical tests to both prove their effectiveness and validate their safety measures.*

Keywords: *(Musa acuminate, banana peel, phytochemical, antimicrobial, ethanolic extracts, aqueous extract,)*

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I. Introduction

As a Southeast Asian plant, the banana plant (Musa acuminata) grows throughout tropical and subtropical regions of the world. The banana fruit obtains its popularity as a food source because of its high nutritional content which can be consumed in both dried preparation and fresh form. The nutritional potential of banana mesocarp has received substantial praise but scientists have given only limited attention to evaluating other banana plant components including the peel. Many traditional societies use Musa acuminata peels which get discarded as waste for their medical treatment applications. The bioactive composite elements which include resins, alkaloids, tannins, flavonoids, and glycosides also together with phenolic acids are located in these peels and show antimicrobial properties as well as functioning with anti-inflammatory effects and serve as antioxidants in the peels [1].

Studies show that banana peels exhibit antimicrobial properties that fight multiple types of fungi and bacteria. By protecting cells from oxidative stress flavonoids and phenolic compounds fight various diseases that include both cancer and cardiovascular disorders [2].

Traditional therapy utilizes banana peels to treat wounds burns and cuts because these peels possess antimicrobial and anti-inflammatory properties. Priceless healing speeds up through topical applications because banana peels block infections and lower inflammation [1, 2].

Researchers have discovered that banana flowers contain comforting attributes which benefit respiratory health by clearing airways while decreasing respiratory tract swelling. Flavonoids together with alkaloids tannins and other compounds in banana flowers potentially drive their anti-inflammatory and antimicrobial capabilities. The anti-inflammatory compounds within these substances demonstrate properties that support bronchitis symptom relief by inhibiting lung pathogenic growth and decreasing respiratory tract inflammation. The antioxidant characteristics of banana flower extracts help fight respiratory issues because they shield respiratory cells from harmful oxidative effects [2]. In multiple traditional medicine systems banana flowers provide an accepted remedy to control diabetes. These traditional medicines benefit blood sugar control and make the body

more responsive to insulin activity. The various preparations of banana flowers as ingredients in soups and teas and when served as cooked vegetables exist traditionally in Indian Indonesian and Filipino cultures. Research shows that polyphenolic compounds in Banana flowers exhibit powerful anti-diabetic qualities. A combination of these compounds works to increase insulin secretion promotes glucose uptake and produces decreases in blood sugar levels. Researchers have tested banana flower extract properties which demonstrated their potential for reducing blood sugar levels. Studies indicate that beneficial antioxidant qualities in banana flowers might protect patients from developing diabetic nephropathy complications in addition to managing diabetes. Through traditional herbal medicine, many societies use banana plant sap labeled as "banana juice" or "banana sap" to address conditions of hysteria and anxiety. Nurses often use the sap produced from banana plants to calm nervous system functions and manage stress while reducing feelings of emotional strain. Its active compounds provide relaxation benefits through alkaloids and phenolic compounds. Neuroprotective compounds found in these substances seem to modify neurotransmitters that control mood functions [3].

Extensive analysis of active compounds in banana plant parts demands comprehensive phytochemical profiling studies. Researchers should investigate the bioactive compounds found in banana leaves and pseudostems and roots since evaluations of these components remain behind assessments of fruit and peel content. Multiple therapeutic investigations become possible by combining banana flower components with fruit and peel substances to generate synergistic antimicrobial and antioxidant together with anti-inflammatory effects. The evaluation of how banana plant elements function medicinally remains fundamental to the field. Cellular pathway studies of banana flower compounds and root and sap elements could lead to specific treatments for diabetes and epilepsy as well as bronchitis [4].

Additional research should embrace multiple clear trials to properly validate the security besides the performance effectiveness of banana plant extract compounds. Research investigators could analyze particular diseases including diabetes respiratory infections and neurological conditions for possible therapeutic outcomes of banana plant extracts. Experts need to investigate the stability alongside the bioavailability and absorption of extracted materials through applicable analysis methods [4, 5].

Banana peel contains phenolic compounds and flavonoids as major components that function both as antioxidants and anti-inflammatory agents. The compounds found in banana peel protect cells from damage caused by oxidization while also decreasing inflammatory reactions [5].

The antimicrobial properties of banana peel extracts can kill multiple bacterial infections alongside fungi and viruses so they may offer opportunities for wound treatment and preventing infections. The use of banana peels in traditional medicine occurs due to their antioxidant and anti-inflammatory nature for acne treatment skin inflammation reduction and wound healing assistance. Banana peel waste usually ends up in disposal whereas it carries valuable medicinal compounds that scientists could utilize. The anti-inflammatory and antioxidant compounds in banana peels consist of polyphenolic elements together with flavonoids and antioxidants which protect against oxidative stress and inflammation. The active compounds in banana peels function as both preventive treatments against diabetes and cardiovascular issues as well as some types of cancer[5,18].

The antimicrobial action of banana peel extracts demonstrates the potential for blocking pathogenic microorganisms while beneficially affecting human skin health. The peels work as skin aging reducers while stimulating natural skin cell renewal and development [6].

Nutritional composition of banana peels

The nutritional characteristics of bananas stand out among all types of fruits because of their exceptional nutritional value. Four primary banana types exist including Musa sapientum Musa paradisiaca L. Musa cavendish and Musa acuminate. The organic composition of bananas contains four primary components including lipids together with carbohydrates together with protein and fiber. The micronutrients exist at increased levels within peel material in comparison with banana pulp [7]. Research from Peh and Pyar shows how peel products possess brief shelf-life durations because of their high water content. Due to the high proportion of water in their composition. A Peel's freshness as well as its storage duration depends on its moisture content level. Microbial decomposition occurs more frequently when banana peels contain high levels of water Banana peels are a rich source of essential amino acids, micronutrients, dietary fiber, lipids, pectin, and fat. Peel contains a high amount of protein. Banana peel serves as food feed for animals and humans alike. Animals and humans need banana peel for dietary survival by obtaining necessary amino acids. Amino acids. The nutritional composition makes peel materials suitable for multiple uses [8].

Table no 1: Nutritional composition of raw and ripe banana peels.

Nutrient	Raw banana peel	Ripe banana peel	References
Moisture Content	60-70%	70-80%	[2-7]
Carbohydrates	60-75%	50-60%	[2-7]
Fiber (Dietary Fiber)	4.9-7.3 g/100g	3.5-6.2 g/100g	[2-7]
Proteins	1.0-2.1 g/100g	1.2-1.8 g/100g	[2-7]

Fats (Lipids)	0.5-1.0 g/100g	0.3-0.8 g/100g	[2-7]
Ash	3-4%	2-3%	[2-7]
Vitamin A (Beta-carotene)	100-200 µg/100g	150-250 µg/100g	[2-8]
Vitamin C	8-15 mg/100g	6-12 mg/100g	[2-8]
Vitamin B6	0.1-0.2 mg/100g	0.1-0.2mg/100g	[2-8]
Potassium	450-500 mg/100g	400-480 mg/100g	[2-8]
Magnesium	50-60 mg/100g	45-55 mg/100g	[2-8]
Calcium	20-40 mg/100g	18-35 mg/100g	[2-8]
Phosphorus	30-50 mg/100g	28-48 mg/100g	[2-8]
Iron	0.3-0.5 mg/100g	0.2-0.4 mg/100g	[2-8]
Sodium	1-5 mg/100g	1-4 mg/100g	[2-8]
Zinc	0.1-0.2 mg/100g	0.1-0.2 mg/100g	[2-8]

Extraction of bioactive compounds in banana peel

Bananas contain bioactive components which give them greater antioxidant capacity than berries herbs and vegetables. The nutritious substances present in banana peels include carotenoids coupled with phenolic compounds. Bananas demonstrate both direct health benefits for humans and many therapeutic properties that impact human health. Banana peels are rich in a variety of beneficial substances, including phenolic and carotenoids. They have a significant direct and indirect impact on human health as well as a wide range of therapeutic properties. The significance of bioactive components results from their demonstrated anti-inflammatory ability and antibacterial properties together with antioxidant functions and anticancer potential which suppresses numerous chronic diseases [5]. Two groups of phytochemicals named phenolic and carotenoids exist within the peels of fruits and vegetables and appear to benefit human wellness. Banana peel includes the major substances known as phenolic and carotenoids flavonoids and biogenic amines. Phenolic dispersion occurs throughout plant metabolic processes due to the widespread presence of phenolic which functions as the major plant secondary metabolite. Besides simple flavonoids extensive groups of phenolic acids alongside complex flavonoids and intense anthocyanin comprise the polyphenolic compound classification. Flavonoids emerge as the most researched phenolic compound family since these molecules demonstrate numerous essential biological effects including antioxidant properties anti-bacterial response anticancer impact and anti-mutagenic properties together with cytotoxic characteristics. The research of Vu et al. verifies that banana peels hold more than 40 unique types of phenolic compounds. Research studies have identified four key chemical compounds in banana peels - catecholamines as well as flavanones alongside flavanols and tocopherol. Phenolic compounds group into hydroxycinnamic acids alongside catecholamines flavan-3-ols and flavonols. Rutin and its conjugate represent the most prevalent flavanols in banana peel structure. The main flavan-3-ol compounds in peels exist as single units, combinations, and multiple-unit rings named tannins [7-9].

Table no 2: Comparison of bioactive compounds in raw and ripe banana peels

Bioactive compound	**Ripe Banana Peel**	**Raw banana peel**	**References**
Carotenoids	High concentration	Low or absent	[7-9]
Fructose and Glucose	High concentration	Low or absent	[7-9]
Phenolic Compounds	High concentration	Low or absent	[9-12]
Soluble Sugars	High concentration	Low or absent	[9-12]
Tannins	Low concentration	High concentration	[9-11]
Saponins	Low concentration	High concentration	[7-10]
Alkaloids	Low concentration	High concentration	[10-13]
Starch	Low concentration	High concentration	[10-14]

As an antimicrobial agent

Scientific research should use banana peel extracts to generate modern antimicrobial compounds which perform effectively against multidrug-resistant microorganisms. Both yellow and green varieties of banana peel remain Several investigations have studied this subject. Testing demonstrated potent antibacterial action against multiple microorganisms by banana peel material samples. Antagonistic effects of Staphylococcus aureus (19.75 mm) and Bacillus subtilis (20.60%) and also Pseudomonas aeruginosa (19.57 mm) and Escherichia coli (18.15 mm) were discovered in coli (18.15 mm). The alcoholic extract of banana peel displayed inhibition zones that measured 15 mm when tested against Porphyromonas gingivalis microbes. And 12 mm for Aggregatibacter actinomycetemcomitans, respectively [15]. The negative control measurement using 70% isopropyl alcohol led to P. Strong inhibitory zones developed around P. gingivalis and A. actinomycetemcomitans with measurements

of 8 and 10 mm. As a result, this finding study revealed P. gingivalis and A. actinomycetemcomitans maintained their antibacterial resistance to the antibacterial properties within the alcoholic extract of banana peel. With a dosage of 300 mg/mL, the M. acuminate peel's methanolic extract demonstrated different degrees of E. coli (ATCC 25922) and Lactobacillus casei and Bacillus sp., and S. aureus (ATCC 25923) and P. aeruginosa and Saccharomyces cerevisiae inhibition., Pseudomonas aeruginosa (19.57 mm) and Escherichia coli (18.15 mm)[7]. Inhibition zones against alcoholic extract of peels of the bananas were 15 mm for Porphyromonas gingivalis and 12 mm for Aggregatibacter actinomycetemcomitans, respectively. As a negative control, 70% isopropyl alcohol caused P. gingivalis and A. actinomycetemcomitans to exhibit inhibitory zones of 8 and 10 mm, respectively. As a result, this finding indicated that P. gingivalis and A. actinomycetemcomitans were resistant to the antibacterial effects of the alcoholic extract of banana peel. At a dosage of 300 mg/mL, the methanolic extract from M. acuminata peel displayed varying levels of inhibition against E. coli (ATCC 25922), Lactobacillus casei, Bacillus sp., S. aureus (ATCC 25923), P. aeruginosa, and Saccharomyces cerevisiae.The three examined bacteria (E. coli, S. aureus, and P. aeruginosa) have shown some antibiotic activity in the presence of tannins [16]. Reported that the banana peel's aqueous extract has varied antibacterial activity. The studied extract effectively activated protective actions against Streptococcus pyogenes and S. aureus while not causing harm to Candida albicans through the development of 30 mm and 18 mm inhibition zones. The inhibitory effect of banana peel extract extends to gram-negative bacteria while producing inhibition zones between 10 and 30 mm in diameter. The bacterial sensitivity pattern shows Moraxella catarrhalis responds best to the extract and Klebsiella pneumoniae and Enterobacter aerogenes show intermediate susceptibility after Moraxella catarrhalis [17].

Table no 3: Antimicrobial activity of different solvent extracts against various microorganisms.

Microorganism	**Inhibition Zone (mm)**	**Solvent extract**	**Activity**	**References**
Staphylococcus aureus	19.75 mm	Ethanol extract	Antibacterial	[8,15,16,17]
Bacillus subtilis	20.60 mm	Ethanol extract	Antibacterial	[8,15,16,17]
Pseudomonas aeruginosa	19.57 mm	Ethanol extract	Antibacterial	[8,15,16,17]
Escherichia coli	18.15 mm	Ethanol extract	Antibacterial	[8,15,16,17]
Porphyromonas gingivalis	15 mm	Ethanol extract	Moderate inhibition	[8,15,16,17]
Aggregatibacter actinomycetemcomitans	12 mm	Ethanol extract	Moderate inhibition	[8,15,16,17]
Porphyromonas gingivalis (Negative control)	8 mm	70% isopropyl alcohol	Weak inhibitory zone	[8,15,16,17]
Aggregatibacter actinomycetemcomitans (Negative control)	10 mm	70% isopropyl alcohol	Weak inhibitory zone	[8,15,16,17]
Escherichia coli (ATCC 25922)	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Lactobacillus casei	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Bacillus sp.	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Staphylococcus aureus (ATCC 25923)	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Pseudomonas aeruginosa	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Saccharomyces cerevisiae	Varying degrees of inhibition	Methanol extract	Varying levels of inhibition across concentrations (300 mg/ml)	[8,15,16,17]
Moraxella catarrhalis	30 mm	Aqueous extract	Best response to aqueous extract	[8,15,16,17]
Klebsiella pneumoniae	10 - 30 mm	Aqueous extract	Intermediate susceptibility	[8,15,16,17]
Enterobacter aerogenes	10 - 30 mm	Aqueous extract	Intermediate susceptibility	[8,15,16,17]

Streptococcus pyogenes	30 mm	Aqueous extract	Effective antibacterial activity	[8,15,16,17]
Staphylococcus aureus	18 mm	Aqueous extract	Effective antibacterial activity	[8,15,16,17]
Candida albicans	No inhibition	Aqueous extract	No antibacterial activity	[8,15,16,17]

Antifungal agent

The antifungal properties of Musa acuminata peel are derived from multiple bioactive compounds which function together as antifungal elements. Flavonoid compounds disrupt fungal cell wall synthesis exhibit growth inhibition capabilities and may trigger programmed cell death in fungal cells. Phenols display documented antifungal effects which interrupt fungal cell membranes and hinder cellular enzymatic functions. Physically active saponins break fungal cell membranes through membrane damage while leading to intracellular substance leakage and eventually fungal death. Tannins display antifungal activity by promoting protein precipitation coupled with targeted enzymatic interference [21].

A study published in the Journal of Biological and Pharmaceutical Sciences found that raw banana peels tend to have a higher concentration of certain bioactive compounds such as flavonoids and tannins which are known for their antifungal properties. These compounds may degrade or transform as the banana ripens. Some of these studies have reported that raw banana peel extracts showed stronger antifungal activity compared to ripened banana peel extracts [22]

Anticancer agent

The disease of cancer performs as the second highest cause of death worldwide although treatment research has made substantial improvements over recent decades. Second in the world in terms of morbidity and mortality. Research statistics show that cancer claims 23% of total American mortality cases. Numerous cancer treatment methods exist but all rely on dangerous substances which generate high cytotoxicity effects. The cytotoxicity is quite high. Chemotherapy drugs exhibit non-specific properties that prevent doctors from differentiating tumor cells from healthy cells. Healthy cells and tumor cells. Chemotherapeutic approaches have resulted in toxic medical treatments that produce diverse side effects that degrade both therapeutic thresholds and beneficial dose ranges. Scientists have identified anticancer properties within specific fruit peeling material which contains banana peel together with others. The human cell growth showed a 64.02% decrease in multiplication when treated with nicotine-extracted banana peel material obtained through hexane solvent use [18]. The researchers at. Created green synthetic ZnO nanorods and nanosheets through zinc acetate reaction with crude extract from M. sapientum bananas. Research shows that ZnO nanosheets obtained through green synthesis methods became the foundation for developing antibacterial along with anticancer drugs. The antioxidant and anti-tumor properties of the Indian banana peel extracts were investigated by Durgadevi. Who found different active substances in this extract could prove effective against cancer. Laboratory studies demonstrated that this extract demonstrates strong cytotoxic properties toward MCF-7 breast cancer cells [19]. Research into cancer treatment highly values this specific data. Reported Ferulic acid Indian banana peel possesses three distinct anticancer effects which include control of vascular endothelium growth factor expression while starting nitric oxide synthase and functioning as a tumor suppressor gene [20].

Anti-parasitic agent

Musa acuminate peels contain active compounds which exhibit anti-parasitic properties. Furthermore, alkaloids demonstrate diverse biological effects across various domains. These poly-phenolic compounds demonstrate anti-parasitic properties through three distinct mechanisms which involve biochemical disruption of parasites and reproductive and motility interference. Studies show that saponins act against parasites by modifying cellular membranes and leading to fatal cell component loss. Tannins demonstrate widespread activity against several pathogens including parasites through protein precipitation and obstructing enzymatic processes that parasites need to survive [23].

II. Conclusion

The discarded outer layer of Musa acuminata bananas has developed into a beneficial raw material containing bioactive substances that display antimicrobial strength antifungal resistance and antiparasitic behavior. Test results show banana peels possess several secondary metabolic compounds including flavonoids, alkaloids, tannins, and saponines along with phenolic compounds that lead to detected biological activities. The antimicrobial strength of Musa acuminata peels emerges through their two distinct extract forms which include aqueous and ethanolic solutions. Ethanolic extracts demonstrate exceptional antibacterial properties against Escherichia coli alongside Staphylococcus aureus and Pseudomonas aeruginosa as well as against a comprehensive range of bacterial pathogens. Flavonoids together with phenolic compounds act as active

ingredients that break down microorganism cell membranes while restricting essential metabolic reactions. Banana peel extracts show potential value for pharmaceutical and food preservation uses because research indicates they may be usable in these applications. Extracts derived from Musa acuminata peels exhibit strong antifungal activity against clinically important fungal species including Candida albicans and Aspergillus niger. Key bioactive compounds tend to dissolve better in ethanolic extracts than aqueous extracts which leads to superior antifungal activities. Banana peel extract potential advances toward becoming an organic antifungal medicine replacement for traditional laboratory chemicals in healthcare and agricultural domains. Lab evidence showing banana peel extracts can attack intense helminths and protozoa parasites demands more scientific study to test potential applications for parasitic disease treatments.

III. Future Perspective

Studied Musa acuminata peels show promising abilities as antimicrobial, antifungal, and antiparasitic agents that create new potential assessment fields. Banana peels present a natural opportunity for the development of sustainable antimicrobial alternatives which can replace synthetic chemicals throughout food production agriculture and pharmaceutical sectors. Future investigation must determine which precise elements activate these properties in banana peel extracts while developing optimized extraction procedures and establishing in vivo testing for validation purposes. The full practical value of these extracts in actual medical settings requires clinical trials as well as extensive pharmacological studies. Musa acuminata peels hold an untapped resource potential for medical and industrial applications. Ongoing research development may transform banana peels into a sustainable natural replacement for synthetic antimicrobial, antifungal, and antiparasitic agents thereby facilitating the creation of eco-friendly plant-based solutions throughout multiple industries.

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Conflict of Interest

None

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