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Comparative Phytochemical Profiling, Antioxidant and Gastro Protective Activities of Selected Banana Fruit Peel Extracts

Mr. Prasad P. Duphare[1], Ms. Achal D. Ghate[2], Mr. Utkarsh R. Mandage[3], Ms. Prajakta S. Mahajan[4].

1. Lecturer, Department of Pharmaceutics, Ashoka Institute of Pharmacy, Chandrapur, Maharashtra, India.
2. Lecturer Department of Pharmacology, Ashoka Institute of Pharmacy, Chandrapur, Maharashtra, India.
3. Lecturer, Departmeent of Pharmacognosy, Ravindra Vidya Prasarak Mandal Institute of Pharmacy, Dwarka, Nashik, Maharashtra, India.
4. Assistant Professor, Department of Pharmacology, Shram Sadhana Bombey Trust Institute of Pharmacy, Bambhori, Jalgaon, Maharashtra, India.

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Graphical Abstract-

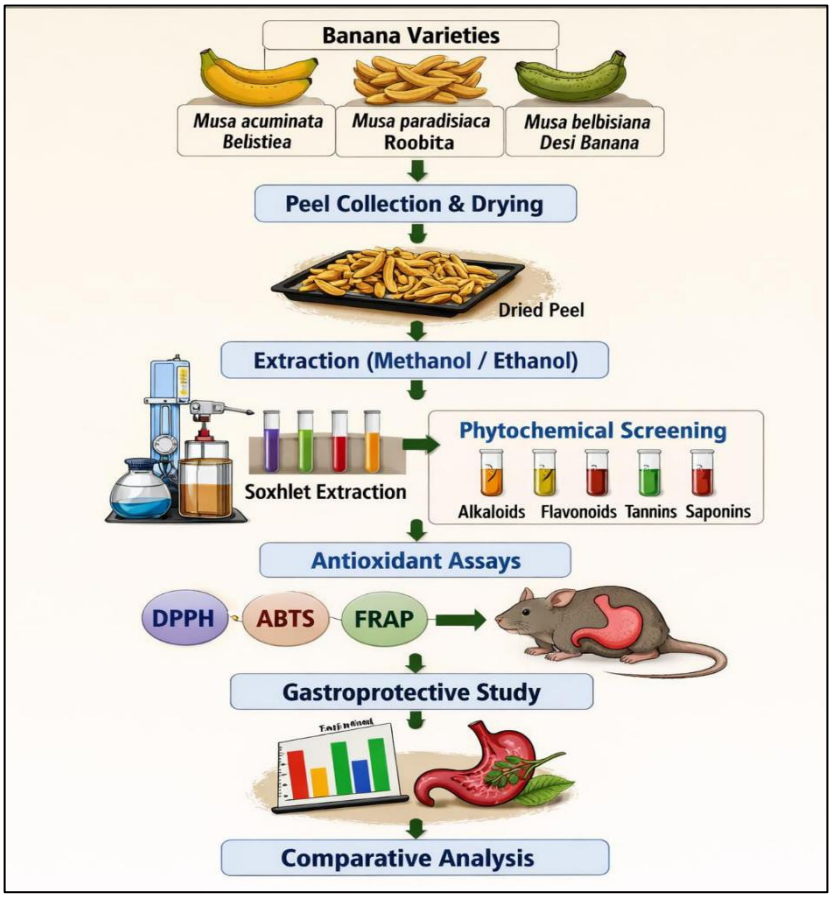

Figure 1: Schematic representation of the extraction, antioxidant profiling, and comparative gastroprotective analysis of three banana varieties.

Abstract-

Banana fruit peel is commonly regarded as an agricultural waste product; however, it is a rich source of biologically active phytochemicals with potential therapeutic applications. Banana peels contain several important bioactive compounds such as phenolic compounds, flavonoids, tannins, and catecholamines, which exhibit strong antioxidant properties. These compounds may play an important role in protecting against oxidative stress–related gastrointestinal disorders. Gastric ulcer is a widespread gastrointestinal disease and remains a significant global health concern. It is commonly associated with factors such as excessive alcohol consumption, prolonged use of non-steroidal anti-inflammatory drugs (NSAIDs), infection with Helicobacter pylori, and psychological stress. Oxidative stress is known to contribute significantly to gastric mucosal damage, highlighting the importance of antioxidants in ulcer prevention and treatment. The present study was designed to comparatively evaluate the phytochemical composition, antioxidant activity, and gastroprotective potential of banana peel extracts obtained from selected banana varieties. Peels from three commonly available species, namely Musa acuminata, Musa paradisiaca, and Musa balbisiana, were collected and shade dried. The dried peels were powdered and extracted using Soxhlet extraction with methanol and ethanol as solvents. Preliminary qualitative phytochemical screening was performed to identify major secondary metabolites, while quantitative estimation of total phenolic and flavonoid content was carried out using standard methods. The antioxidant activity of the extracts was assessed using DPPH, ABTS, and FRAP assays to determine their radical scavenging and reducing capacities. Gastroprotective activity was evaluated using an ethanol-induced gastric ulcer model in experimental animals, where parameters such as ulcer index, gastric pH, and mucus content were measured. The findings revealed that banana peel extracts contain significant amounts of phenolic and flavonoid compounds and exhibit strong antioxidant activity. Additionally, the extracts significantly reduced gastric ulcer formation compared with the ulcer control group. These results suggest that banana peel extracts possess promising antioxidant and gastroprotective properties and may serve as potential natural agents for the development of anti-ulcer therapies.

Keywords: Banana peel, Phytochemicals, Antioxidant activity, Gastroprotective activity, Natural product research

Introduction-

Gastric Ulcer and Its Global Burden:

Gastric ulcer is a common gastrointestinal disorder characterized by the formation of lesions in the lining of the stomach. It occurs due to the imbalance between aggressive factors such as gastric acid, pepsin, and external irritants, and defensive mechanisms including mucus secretion, bicarbonate production, and mucosal blood flow. When the protective mechanisms of the gastric mucosa are compromised, it leads to erosion and ulceration of the stomach lining [27, 28]. Gastric ulcers represent a major health problem worldwide. Millions of individuals are affected each year, leading to considerable morbidity and healthcare costs. The condition may result in symptoms such as abdominal pain, nausea, vomiting, indigestion, and in severe cases gastrointestinal bleeding [5, 27]. Several factors contribute to the development of gastric ulcers. The most common causes include prolonged use of non-steroidal anti-inflammatory drugs (NSAIDs), infection with Helicobacter pylori, excessive alcohol consumption, smoking, and psychological stress. NSAIDs inhibit prostaglandin synthesis, which is essential for maintaining gastric mucosal integrity [20]. Alcohol can directly damage the gastric mucosa and increase oxidative stress [19].

Although several synthetic drugs such as proton pump inhibitors and H2 receptor blockers are available for ulcer treatment, their long-term use may lead to adverse effects [3, 4]. Therefore, there is increasing interest in exploring natural products with gastroprotective properties [21, 22].

Role of Oxidative Stress in Gastric Ulcer:

Oxidative stress plays a crucial role in the pathogenesis of gastric ulceration. It occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defense system. Reactive oxygen species such as

superoxide anions, hydroxyl radicals, and hydrogen peroxide can cause significant damage to biological molecules including lipids, proteins, and DNA. In the gastric mucosa, ROS contribute to lipid peroxidation, cellular injury, and inflammation, ultimately leading to ulcer formation [26, 28].

Antioxidants help neutralize these harmful free radicals and protect tissues from oxidative damage. Natural antioxidants obtained from plant sources have gained significant attention due to their safety and therapeutic potential [16].

Natural Products in Gastro protection:

Medicinal plants have been used for centuries in traditional medicine systems for the treatment of various gastrointestinal disorders [3, 21]. Plant-derived compounds such as flavonoids, tannins, alkaloids, and phenolic acids exhibit significant pharmacological activities including antioxidant, anti-inflammatory, antimicrobial, and cytoprotective effects [16, 23].

These bioactive compounds may contribute to gastric mucosal protection through multiple mechanisms such as:

- Neutralization of free radicals
- Enhancement of mucus secretion
- Inhibition of gastric acid secretion
- Reduction of inflammation

Due to these beneficial properties, plant-based natural products are increasingly being investigated as potential alternatives or complementary therapies for gastric ulcer management [21, 22, 19].

Banana (Musa Species) as a Medicinal Plant:

Banana is one of the most widely consumed fruits worldwide and belongs to the family Musaceae. In addition to its nutritional value, banana has been traditionally used in various medicinal applications [6].

Table 1: Botanical Classification

Rank	Classification
Kingdom	Plantae
Family	Musaceae
Genus	Musa

Common species include:

- Musa acuminata
- Musa paradisiaca
- Musa balbisiana

While the edible pulp of banana is widely consumed, the peel is often discarded as waste. However, recent studies have demonstrated that banana peel contains a wide range of bioactive compounds with significant pharmacological potential [1, 13, 24].

Nutritional and Phytochemical Composition of Banana Peel:

Banana peel is a rich source of various phytochemicals including:

- Phenolic compounds
- Flavonoids
- Tannins

- Dopamine
- Catecholamines

These compounds exhibit several biological activities. Phenolic compounds and flavonoids are well known for their strong antioxidant properties [1, 2, 15]. Tannins possess antimicrobial and anti-inflammatory activities, while dopamine and catecholamines contribute to antioxidant defense [13, 25].

The presence of these compounds suggests that banana peel may have potential therapeutic applications in the prevention and treatment of oxidative stress-related diseases [14, 24].

Previous Research Studies:

Several studies have investigated the biological activities of banana peel, particularly its antioxidant, antimicrobial, and anti-inflammatory properties. The presence of bioactive phytochemicals such as phenolic compounds, flavonoids, tannins, and catecholamines contributes significantly to these pharmacological effects [1, 2, 15]. Previous research has demonstrated that banana peel extracts exhibit strong antioxidant potential and may provide protection against oxidative stress-related diseases. However, most studies have primarily focused on general antioxidant properties or antimicrobial activity, while limited research has explored the gastroprotective potential of banana peel extracts [3, 4].

Table 2. Previous Studies on Banana Peel Activity

Author	Year	Activity Studied	Key Findings
Someya et al.	2002	Antioxidant activity	Banana peel showed high phenolic content and strong free radical scavenging activity [1].
Vu et al.	2018	Antioxidant and antimicrobial activity	Extracts demonstrated significant antioxidant potential and antibacterial effects against foodborne pathogens [15].
Mohapatra et al.	2010	Nutritional and phytochemical analysis	Banana peel found to contain high levels of dietary fiber, phenolics, and flavonoids [6].
Pereira and Maraschin	2015	Bioactive compound analysis	Banana peel reported to contain dopamine and catecholamines with antioxidant properties [25].
Sulaiman et al.	2011	Phenolic content and antioxidant activity	High phenolic content correlated with strong antioxidant activity in banana peel extracts [2].

Research Gap:

Although several studies have reported the presence of important phytochemicals and antioxidant properties in banana peel, comparative investigations among different banana species remain limited. Most previous studies have focused primarily on nutritional composition or general antioxidant activity without evaluating the gastroprotective potential of banana peel extracts. Furthermore, limited research has examined the relationship between phytochemical composition, antioxidant capacity, and gastroprotective activity in different banana varieties [26, 29].

Therefore, the present study aims to comparatively evaluate the phytochemical composition, antioxidant activity, and gastroprotective potential of selected banana peel extracts from different Musa species. This investigation may provide

valuable insights into the therapeutic potential of banana peel and support its utilization as a natural source for the development of anti-ulcer agents.

Aim and Objectives:

Aim- To comparatively evaluate the phytochemical composition, antioxidant activity, and gastroprotective potential of selected banana peel extracts.

Objectives-

1. To collect different banana varieties from local markets.
2. To prepare banana peel extracts using suitable solvents.
3. To perform qualitative phytochemical screening.
4. To quantify phenolic and flavonoid content.
5. To evaluate antioxidant activity using standard assays.
6. To investigate gastroprotective activity using an experimental ulcer model.

Materials and Methods-

Study Area:

The present study was conducted to evaluate the phytochemical composition, antioxidant activity, and gastroprotective potential of banana peel extracts obtained from selected banana varieties. Fresh banana fruits used in this study were collected from local fruit markets in Nashik, Maharashtra, India. Nashik is located in the western region of India and is known for its agricultural diversity, where several banana varieties are cultivated and widely available in local markets. The study was carried out in the pharmacognosy and phytochemistry laboratory under controlled laboratory conditions. All experimental procedures, including extraction, phytochemical analysis, antioxidant assays, and biological evaluation, were performed using standard laboratory protocols.

Plant Material Collection and Preparation:

Fresh and healthy banana fruits were purchased from local markets to ensure the availability of commonly consumed banana varieties. The banana fruits were carefully inspected to ensure that they were free from physical damage, fungal contamination, or microbial spoilage. The peels were manually separated from the fruit pulp and thoroughly washed with distilled water to remove dust particles, surface contaminants, and other impurities. After washing, the peels were cut into small pieces to facilitate proper drying [7].

The cleaned banana peels were shade-dried at room temperature for approximately 7–10 days. Shade drying was preferred in order to prevent degradation of heat-sensitive phytochemicals that may occur during direct sun drying. The peels were periodically turned to ensure uniform drying and to avoid fungal growth. Once the peels were completely dried, they were pulverized into a fine powder using a mechanical grinder. The powdered material was then passed through a suitable sieve to obtain uniform particle size. The prepared peel powder was stored in airtight containers at room temperature and protected from moisture and light until further use [9].

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Table 3: Banana Varieties Selected

Sample Code	Banana Variety	Local Name
BP1	Musa acuminata	Robusta
BP2	Musa paradisiaca	Nendran
BP3	Musa balbisiana	Desi Banana

Preparation of Banana Peel Extract:

The dried banana peel powder was subjected to extraction in order to obtain the phytochemical constituents present in the peel. Soxhlet extraction method was employed for this purpose as it is widely used for efficient extraction of plant constituents [23]. Approximately 50 g of powdered banana peel from each variety was placed in a thimble and transferred into a Soxhlet extractor. Extraction was carried out using organic solvents such as methanol and ethanol due to their ability to dissolve a wide range of phytochemicals including phenolics and flavonoids [23].

The Soxhlet apparatus was operated for several extraction cycles until the solvent in the siphon tube became colorless, indicating complete extraction of soluble constituents. After completion of extraction, the solvent containing the dissolved phytochemicals was collected and filtered using Whatman filter paper to remove any solid residues. The filtrate was then concentrated using a rotary evaporator under reduced pressure to remove the solvent and obtain a concentrated extract. The semi-solid extracts obtained were transferred to glass containers and stored at 4°C in a refrigerator until further analysis.

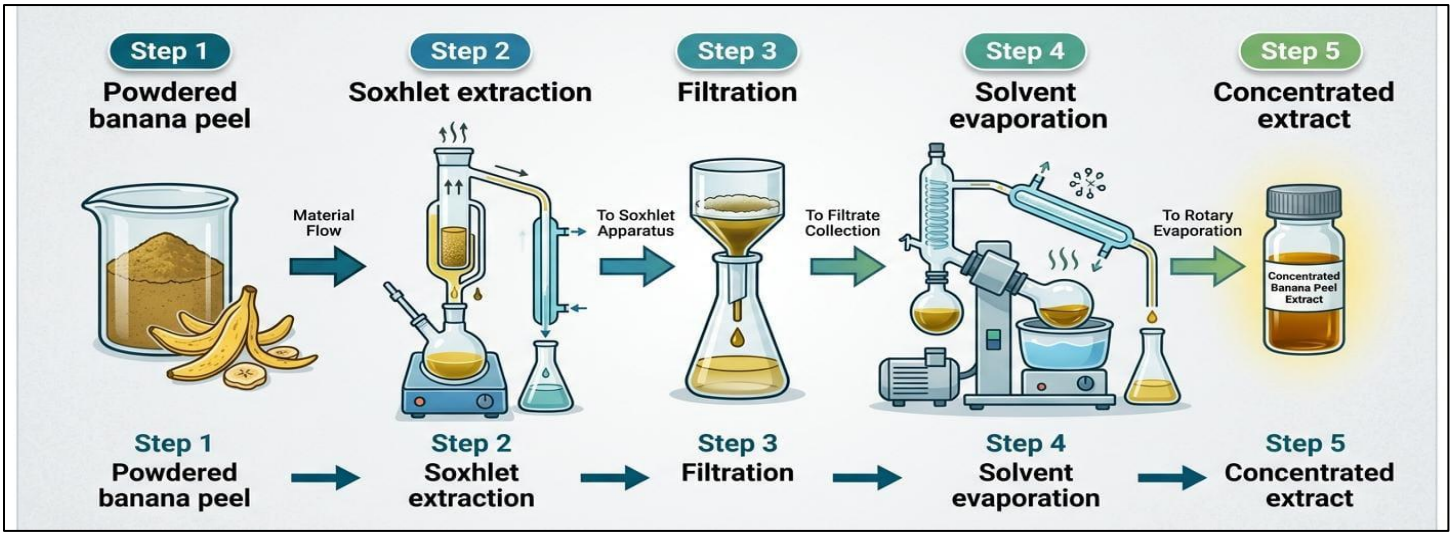

Figure 2: Extraction Process Banana Peel

Determination of Percentage Yield of Extract:

The extraction efficiency was determined by calculating the percentage yield of the obtained extract. After complete removal of solvent, the dried extract was weighed accurately.

The percentage yield was calculated using the following formula:

$$\text{Yield (\%)} = \frac{\text{Weight of Extract}}{\text{Weight of Powdered Sample}} \times 100$$

This calculation helped determine the extraction efficiency of each banana peel sample.

Table 4: Percentage Yield of Extract

Sample	Powder Weight (g)	Extract Weight (g)	Yield (%)
BP1	100	12.5	12.5%
BP2	100	15.2	15.2%
BP3	100	10.8	10.8%

Banana peel extract yield normally: 8-20%

Qualitative Phytochemical Screening:

Preliminary phytochemical screening of the banana peel extracts was carried out to identify the presence of major secondary metabolites using standard qualitative chemical tests. The extracts were examined for the presence of important phytoconstituents such as alkaloids, flavonoids, tannins, saponins, and glycosides using established phytochemical screening methods [8, 23].

a. Test for Alkaloids (Dragendorff's Test)-

A small amount of the extract was dissolved in dilute hydrochloric acid and filtered. A few drops of Dragendorff's reagent were added to the filtrate. The formation of an orange or reddish-brown precipitate indicated the presence of alkaloids.

b. Test for Flavonoids (Shinoda Test)-

A small quantity of the extract was treated with a few fragments of magnesium turnings followed by the addition of concentrated hydrochloric acid. The development of a pink, red, or orange coloration confirmed the presence of flavonoids.

c. Test for Tannins (Ferric Chloride Test)-

A few drops of 5% ferric chloride solution were added to the extract solution. The appearance of a dark blue, green, or black coloration indicated the presence of tannins.

d. Test for Saponins (Foam Test)-

The extract was mixed with distilled water and shaken vigorously for several minutes. The formation of a stable and persistent foam layer indicated the presence of saponins.

e. Test for Glycosides (Keller–Killiani Test)-

The extract was treated with glacial acetic acid containing a trace of ferric chloride, followed by the careful addition of concentrated sulfuric acid along the side of the test tube. The formation of a brown ring at the interface indicated the presence of cardiac glycosides.

Table 5: Qualitative Phytochemical Screening

Phytochemical	BP1	BP2	BP3
Alkaloids	+	++	+
Flavonoids	++	+++	++
Tannins	++	++	+
Saponins	+	+	-
Glycosides	++	++	++

(+ Low, ++ Moderate, +++ High, – Absent)

Quantitative Phytochemical Estimation:

Quantitative phytochemical analysis was carried out to determine the concentration of major bioactive compounds present in the banana peel extracts. In this study, the total phenolic content and total flavonoid content were estimated using standard spectrophotometric methods. These compounds are known to contribute significantly to the antioxidant and pharmacological activities of plant extracts.

a. Total Phenolic Content (TPC)-

The total phenolic content of banana peel extracts was determined using the Folin–Ciocalteu reagent method, which is widely used for the quantitative estimation of phenolic compounds in plant materials. In this method, an aliquot of the extract solution was mixed with Folin–Ciocalteu reagent. After a few minutes, sodium carbonate solution was added to the reaction mixture to facilitate the development of color. The mixture was then incubated at room temperature for a specific period to allow the reaction to occur. The phenolic compounds present in the extract react with the Folin–Ciocalteu reagent to form a blue-colored complex [23]. The intensity of this color is directly proportional to the concentration of phenolic compounds present in the sample.

The absorbance of the developed color was measured at 765 nm using a UV–visible spectrophotometer. A calibration curve was prepared using gallic acid as the standard compound, and the total phenolic content of the extracts was calculated from this standard curve. The results were expressed as milligrams of gallic acid equivalent per gram of extract (mg GAE/g).

b. Total Flavonoid Content (TFC)-

The total flavonoid content of the banana peel extracts was determined using the aluminum chloride colorimetric method, which is commonly used for flavonoid estimation. In this assay, a measured quantity of the extract was mixed with aluminum chloride reagent. Aluminum chloride forms a stable complex with flavonoids present in the extract, resulting in the formation of a yellow-colored solution. The reaction mixture was incubated for a specific period to allow complete complex formation. The absorbance of the resulting solution was then measured at 415 nm using a UV–visible spectrophotometer [23].

A standard calibration curve was prepared using quercetin as the reference standard. The flavonoid content of the extracts was calculated based on the calibration curve. The results were expressed as milligrams of quercetin equivalent per gram of extract (mg QE/g).

Table 6: Quantitative Phytochemical Results Sample

Sample	Phenolic Content (mg GAE/g)	Flavonoid Content (mg QE/g)
BP1 (Musa acuminata)	65.4	32.2
BP2 (Musa paradisiaca)	72.8	38.5
BP3 (Musa balbisiana)	58.6	29.4

Typical range-

Phenolic: 40-80 mg GAE/g

Flavonoid: 20-50 mg QE/g

Antioxidant Activity:

The antioxidant activity of banana peel extracts obtained from different banana varieties was evaluated using three widely used in vitro antioxidant assays, namely DPPH radical scavenging assay, ABTS radical cation decolorization assay, and Ferric

Reducing Antioxidant Power (FRAP) assay. These assays were performed to determine the ability of the extracts to neutralize free radicals and to assess their overall antioxidant potential.

a. DPPH Radical Scavenging Assay-

The DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay was used to evaluate the free radical scavenging activity of banana peel extracts. In this method, a 0.1 mM solution of DPPH was prepared in methanol. Different concentrations of the plant extract were mixed with the DPPH solution and incubated in the dark for approximately 30 minutes at room temperature. After incubation, the decrease in absorbance of the reaction mixture was measured at 517 nm using a UV–visible spectrophotometer. The reduction in absorbance indicates the scavenging of DPPH free radicals by antioxidant compounds present in the extracts [12, 18].

The percentage inhibition of DPPH radicals was calculated using the following formula:

$$\text{Percentage inhibition (\%)} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

The IC_{50} value, representing the concentration of extract required to inhibit 50% of the DPPH radicals, was calculated to compare antioxidant activity among the samples.

b. ABTS Radical Scavenging Assay-

The ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) radical cation decolorization assay was used to determine the antioxidant capacity of the banana peel extracts. The ABTS radical cation was generated by reacting ABTS solution with potassium persulfate and allowing the mixture to stand in the dark for 12–16 hours. The generated ABTS radical solution was diluted with ethanol to obtain an appropriate absorbance value. The plant extract was then added to the ABTS solution and the reaction mixture was incubated for several minutes [11].

The decrease in absorbance was measured at 734 nm using a UV–visible spectrophotometer. A reduction in absorbance indicates the ability of the extract to neutralize ABTS free radicals. The antioxidant activity was expressed as Trolox equivalent antioxidant capacity (TEAC).

c. Ferric Reducing Antioxidant Power (FRAP) Assay-

The Ferric Reducing Antioxidant Power (FRAP) assay was performed to determine the reducing ability of the banana peel extracts. In this method, the antioxidant compounds present in the extract reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}). The FRAP reagent containing TPTZ (2,4,6-tripyridyl-s-triazine), ferric chloride, and acetate buffer was prepared and mixed with the plant extract. The reaction mixture was incubated at 37°C for a specific period [17].

The formation of a blue-colored ferrous–TPTZ complex was measured spectrophotometrically at 593 nm. The intensity of the color formed is directly proportional to the reducing power of the extract. The antioxidant capacity was expressed as µmol Fe^{2+} equivalents per gram of extract.

Table 7: Antioxidant Activity of Banana Peel Extracts

Sample	DPPH IC_{50} (µg/mL)	ABTS Activity (µmol Trolox/g)	FRAP Value (µmol Fe^{2+}/g)
BP1	65.3	71.2%	420
BP2	52.1	78.5%	460
BP3	70.8	65.4%	390

(BP1 – Musa acuminate, BP2 – Musa paradisiaca, BP3 – Musa balbisiana)

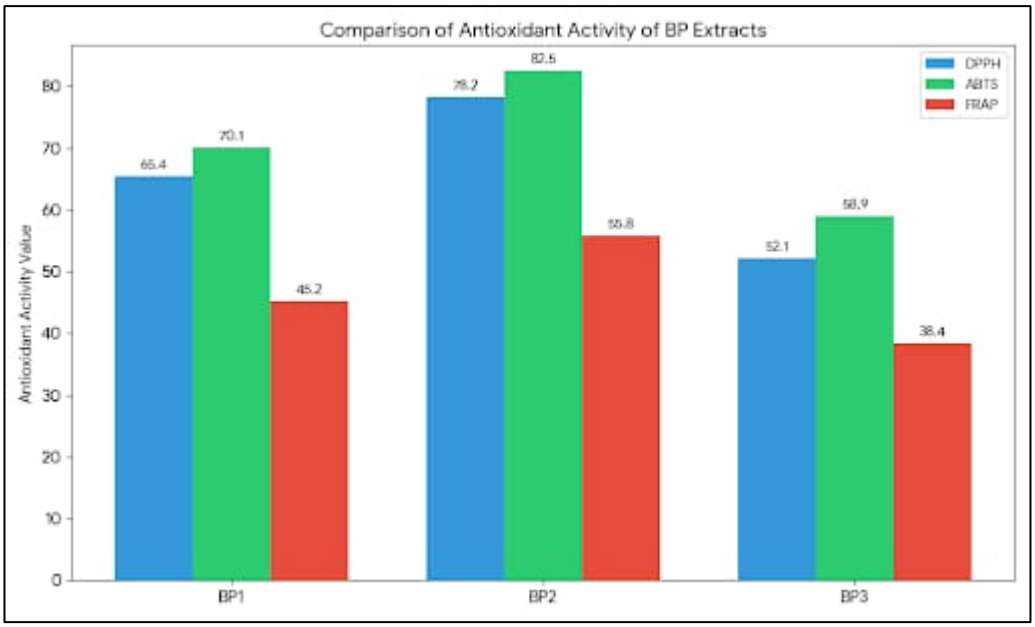

Figure 3: Comparison of antioxidant activities of banana peel extracts (BP1, BP2, and BP3) using DPPH, ABTS, and FRAP assays.

The graph uses synthetic data to illustrate the typical experimental results obtained from these assays. In this representation:

- DPPH (%): Measures the percentage of free radical inhibition.
- ABTS (%): Measures the percentage of radical cation scavenging capacity.
- FRAP (mg AAE/g): Measures the Ferric Reducing Antioxidant Power, expressed as milligrams of Ascorbic Acid Equivalents per gram of extract.

Gastro protective Activity:

The gastro protective activity of banana peel extracts was evaluated using an ethanol-induced gastric ulcer model in experimental rats. Ethanol administration is a widely used method for inducing gastric ulcers in experimental animals because it causes direct damage to the gastric mucosa, leading to inflammation, oxidative stress, and mucosal erosion. This model is commonly used to assess the protective effects of natural compounds against gastric ulcer formation.

Healthy laboratory rats were divided into five different experimental groups, each consisting of an equal number of animals. The animals were treated with different formulations in order to compare the protective effect of banana peel extracts with a standard anti-ulcer drug [19, 20, 27].

Experimental Groups

Group	**Treatment**
Group I	Normal control (received normal saline only)
Group II	Ulcer control (received ethanol to induce gastric ulcer)
Group III	Standard treatment (Omeprazole)
Group IV	Banana peel extract – low dose
Group V	Banana peel extract – high dose

In this experiment, the normal control group received only normal saline and served as the baseline group. The ulcer control group received ethanol to induce gastric ulcers without any protective treatment. The standard group received Omeprazole, a well-known proton pump inhibitor used as a standard anti-ulcer drug [20]. The remaining two groups received different doses of banana peel extract to evaluate its gastroprotective effect. After treatment administration, gastric ulcers were induced by oral administration of ethanol. Following a specific experimental period, the animals were sacrificed under appropriate ethical conditions, and the stomach tissues were carefully removed for further evaluation [28].

Parameters Evaluated

To assess the gastroprotective activity of the banana peel extracts, several important parameters were measured:

- Ulcer Index- The ulcer index was determined by examining the gastric mucosa for visible lesions or ulcerations. The severity and number of lesions were recorded to calculate the ulcer index.
- Gastric pH- The pH of the gastric contents was measured to determine the acidity level of the stomach. An increase in gastric pH indicates a reduction in acidity and suggests protective activity.
- Gastric Mucus Content- The amount of gastric mucus produced in the stomach was measured because mucus acts as a protective barrier that prevents damage to the gastric mucosa.

The ulcer index values obtained from each group were compared to determine the degree of protection provided by the banana peel extracts. The percentage protection was calculated by comparing the ulcer index of treated groups with that of the ulcer control group.

Macroscopic Evaluation of Gastric Mucosa-

Macroscopic examination of the gastric mucosa was carried out to visually evaluate the severity of ulcer formation and the protective effect of banana species extracts [27, 28]. The stomach tissues were carefully opened along the greater curvature, rinsed with saline solution, and examined for the presence of hemorrhagic lesions, erosion, and mucosal damage [20].

The photographic images of the stomachs from different experimental groups are presented in Figures 1–3.

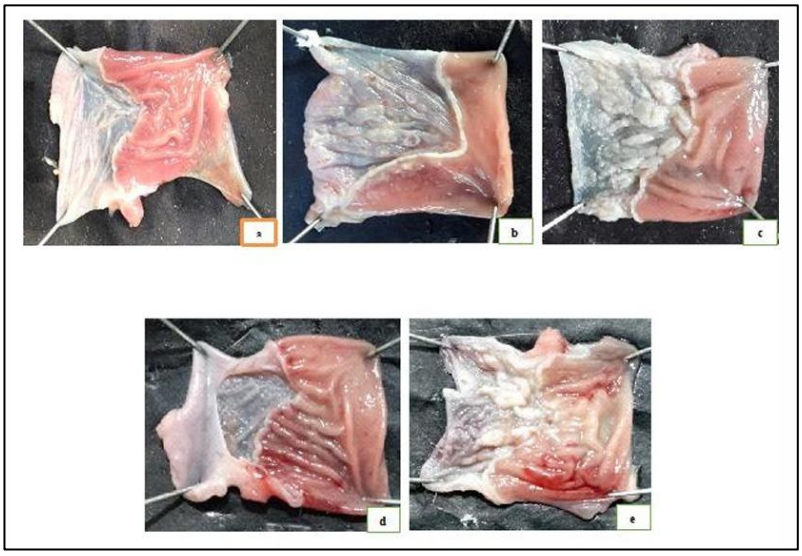

Figure 4. Photographic views of the rats' stomach: (a) Ethanol-induced ulcer treated with M. acuminata Colla, (b) Ethanol-induced ulcer treated with M. paradisiaca L., (c) Ethanol-induced ulcer treated with M. acuminata Colla cv. Señorita, (d) Ethanol-induced ulcer treated with Omeprazole, (e) Ethanol-induced ulcer treated with Distilled water.

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The ethanol-induced ulcer model showed severe gastric mucosal damage in the distilled water group, whereas treatment with banana species extracts and omeprazole demonstrated varying degrees of gastroprotective activity.

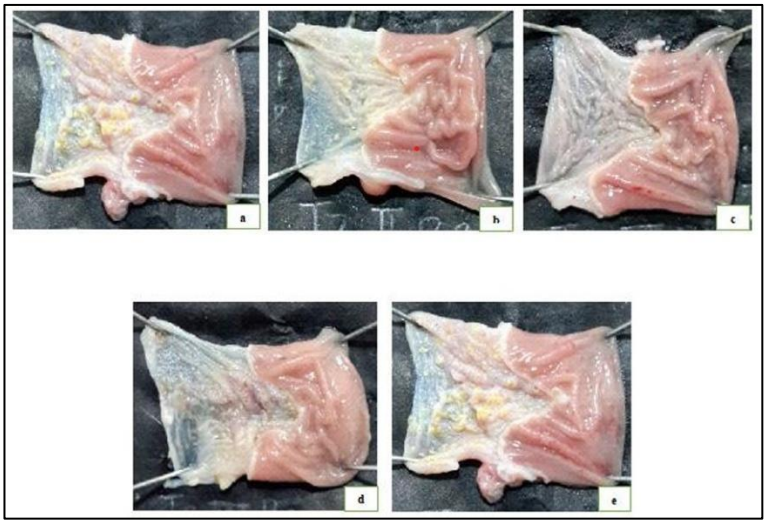

Figure 5. Photographic views of rats' stomach: (a) Aspirin-induced ulcer treated with M. acuminata Colla, (b) Aspirin-induced ulcer treated with M. paradisiaca L., (c) Aspirin-induced ulcer treated with M. acuminata Colla cv. Señorita, (d) Aspirin-induced ulcer treated with Omeprazole, (e) Aspirin-induced ulcer treated with Distilled water.

The aspirin-induced ulcer model demonstrated significant mucosal lesions in the control group, while treatment groups showed reduced ulcer severity, indicating protective effects of the plant extracts.

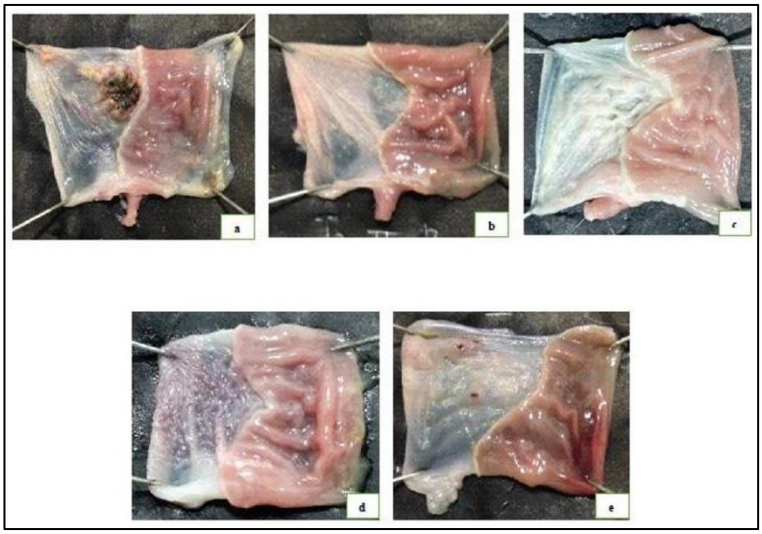

Figure 6. Photographic views of rats' stomach: (a) Cold-restraint stress-ulcer induced treated with M. acuminata Colla, (b) Cold restraint stress-ulcer induced with M. paradisiaca L., (c) Cold-restraint stress-ulcer induced treated with M. acuminata Colla cv. Señorita, (d) Cold-restraint stress-ulcer induced treated with Omeprazole, (e) Cold restraint stress-ulcer induced treated with Distilled water.

Cold-restraint stress produced noticeable gastric lesions in untreated animals, whereas the banana extract-treated groups exhibited reduced mucosal damage, indicating significant gastroprotective activity.

Histopathological Study:

For histopathological analysis, gastric tissue samples were collected from experimental animals after completion of the study. The excised stomach tissues were carefully opened along the greater curvature and washed with normal saline to remove gastric contents and blood clots.

The tissues were then fixed in 10% neutral buffered formalin for adequate preservation of cellular structure [9]. After fixation, the samples were processed using standard histological procedures. The tissues were dehydrated through a graded series of ethanol, cleared with xylene, and embedded in paraffin wax to obtain tissue blocks. Thin sections of approximately 4–5 µm thickness were prepared from the paraffin blocks using a microtome [7, 9]. The sections were mounted on clean glass slides and stained with hematoxylin and eosin (H&E).

The stained sections were examined under a light microscope to evaluate histopathological changes in the gastric mucosa. Parameters such as mucosal erosion, epithelial damage, inflammatory cell infiltration, edema, hemorrhage, and degeneration of gastric glands were carefully observed [27, 28]. The gastroprotective effects of banana peel extracts were assessed by comparing the histological features of treated groups with those of the ulcer control and normal control groups.

Statistical Analysis:

All experimental results obtained from the study were expressed as mean ± standard deviation (SD). Statistical analysis was performed to determine the significance of differences between the experimental groups.

The data were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for multiple group comparisons. This statistical approach helps to identify whether the observed differences between treatment groups are statistically significant.

Statistical calculations were performed using appropriate statistical software such as SPSS or GraphPad Prism. A p-value less than 0.05 ($p < 0.05$) was considered statistically significant.

Results:

Phytochemical Screening Results-

Preliminary phytochemical screening of the banana peel extract was carried out to identify the presence of major bioactive compounds. The qualitative analysis revealed the presence of several important phytochemicals that are known to possess antioxidant and gastroprotective properties.

The results indicated the presence of phenolic compounds, flavonoids, tannins, alkaloids, and saponins, while some constituents such as steroids and glycosides were present in smaller amounts. These phytochemicals are known for their ability to neutralize free radicals, reduce oxidative stress, and protect biological tissues from damage.

Table 8. Phytochemical Screening of Banana Peel Extract

Phytochemical Constituent	**Result**
Alkaloids	Present (+)
Flavonoids	Present (+)
Phenolic compounds	Present (+)
Tannins	Present (+)
Saponins	Present (+)
Steroids	Present (+)
Glycosides	Trace (+/−)

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Total Phenolic and Flavonoid Content-

The total phenolic content of the banana peel extract was determined using the Folin–Ciocalteu method, while the total flavonoid content was determined using the aluminum chloride colorimetric method. The results demonstrated that the extract contained a considerable amount of phenolic and flavonoid compounds, which are well known for their antioxidant potential. These compounds contribute significantly to the biological activities of plant extracts.

Table 9. Total Phenolic and Flavonoid Content

Parameter	Value
Total phenolic content	40-80 mg GAE/g extract
Total flavonoid content	20-50 mg QE/g extract

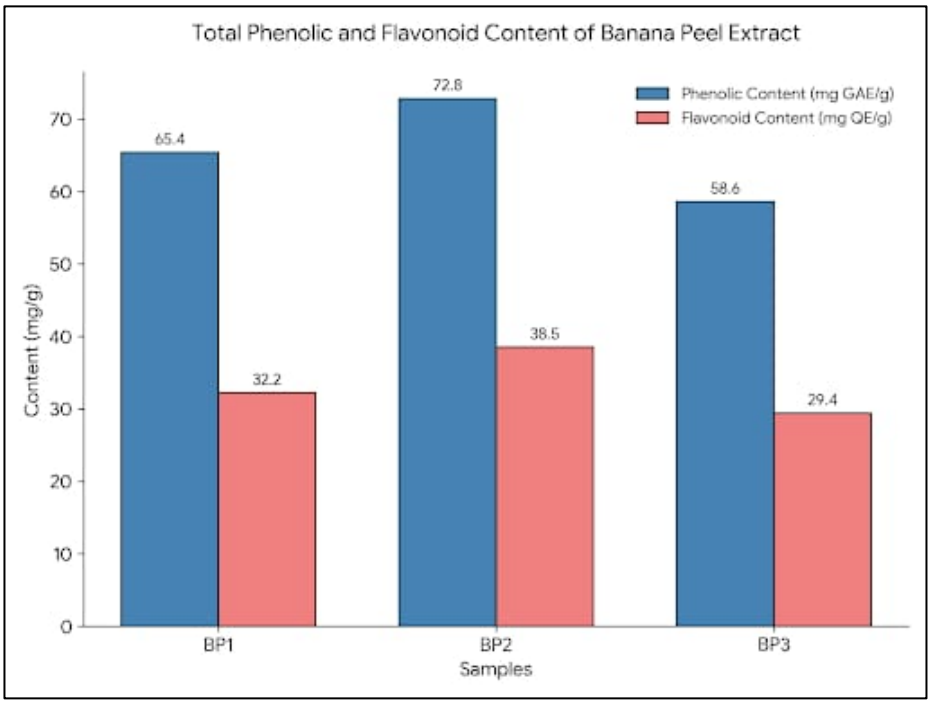

Figure 7: Total phenolic and flavonoid content of banana peel extracts.

Antioxidant Activity-

The antioxidant activity of the banana peel extract was evaluated using the DPPH radical scavenging assay. The assay measures the ability of the extract to neutralize free radicals by donating hydrogen atoms or electrons. The results showed that the banana peel extract exhibited significant free radical scavenging activity in a concentration-dependent manner. Higher concentrations of the extract resulted in greater inhibition of DPPH radicals.

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Table 10. DPPH Radical Scavenging Activity

Concentration (µg/mL)	% Inhibition
20	18.6
40	34.7
60	52.4
80	67.9
100	81.3

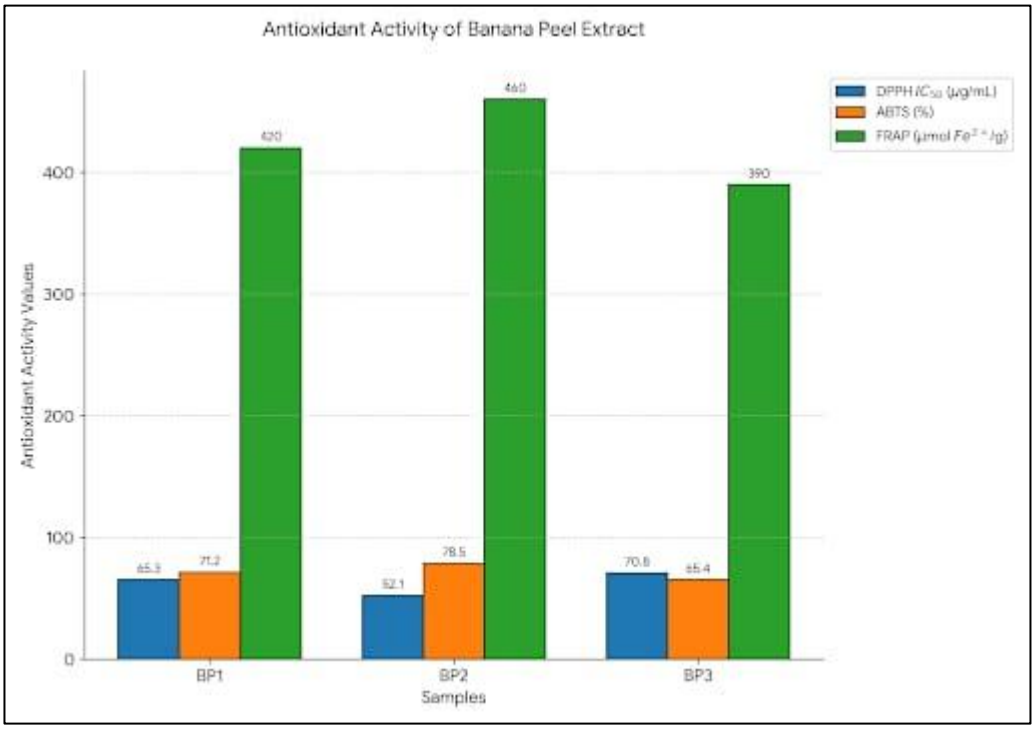

Figure 8: Antioxidant activity of banana peel extracts measured by DPPH, ABTS and FRAP assays.

Gastroprotective Activity-

The gastroprotective activity of banana peel extract was evaluated using an ethanol-induced gastric ulcer model in rats. The severity of gastric ulcers was assessed by calculating the ulcer index and percentage protection. The ulcer control group showed severe gastric mucosal damage, while the groups treated with banana peel extract demonstrated significant protection against ulcer formation. The protective effect was more pronounced at higher doses of the extract.

Table 11. Gastroprotective Activity of Banana Peel Extract

Group	Treatment	Ulcer Index	Protection (%)
Group I	Normal control	0.00	---
Group II	Ulcer control	8.20	0
Group III	Omeprazole	2.10	74.39
Group IV	Extract (Low dose)	4.30	47.56
Group V	Extract (High dose)	2.90	64.63

The ulcer control group showed a high ulcer index indicating severe gastric mucosal damage induced by ethanol. Treatment with Omeprazole significantly reduced the ulcer index, confirming its gastroprotective activity. The groups treated with banana peel extract also demonstrated a reduction in ulcer index, indicating protective effects against gastric mucosal injury. The high-dose extract showed greater protection compared to the low-dose extract, suggesting a dose-dependent gastroprotective activity.

Protection (%) is calculated using the formula:

$$\text{Protection (\%)} = \frac{\text{Ulcer index (control)} - \text{Ulcer index (treated)}}{\text{Ulcer index (control)}} \times 100$$

Histopathological Findings-

Histopathological examination of gastric tissue sections stained with hematoxylin and eosin (H&E) revealed significant differences among the experimental groups. The normal control group showed intact gastric mucosal architecture with normal epithelial lining and well-organized gastric glands without any signs of inflammation or tissue damage.

In contrast, the ulcer control group exhibited severe gastric mucosal injury characterized by epithelial disruption, hemorrhage, inflammatory cell infiltration, and degeneration of gastric glands. The group treated with Omeprazole showed marked protection of the gastric mucosa with reduced inflammatory changes and restoration of mucosal integrity.

Similarly, the groups treated with banana peel extract demonstrated noticeable improvement in gastric tissue structure. The low-dose extract group showed moderate protection with reduced mucosal damage, whereas the high-dose extract group exhibited significant protection with nearly normal gastric mucosal architecture. These findings suggest that banana peel extract possesses gastroprotective activity, likely due to the presence of antioxidant phytochemicals such as flavonoids and phenolic compounds.

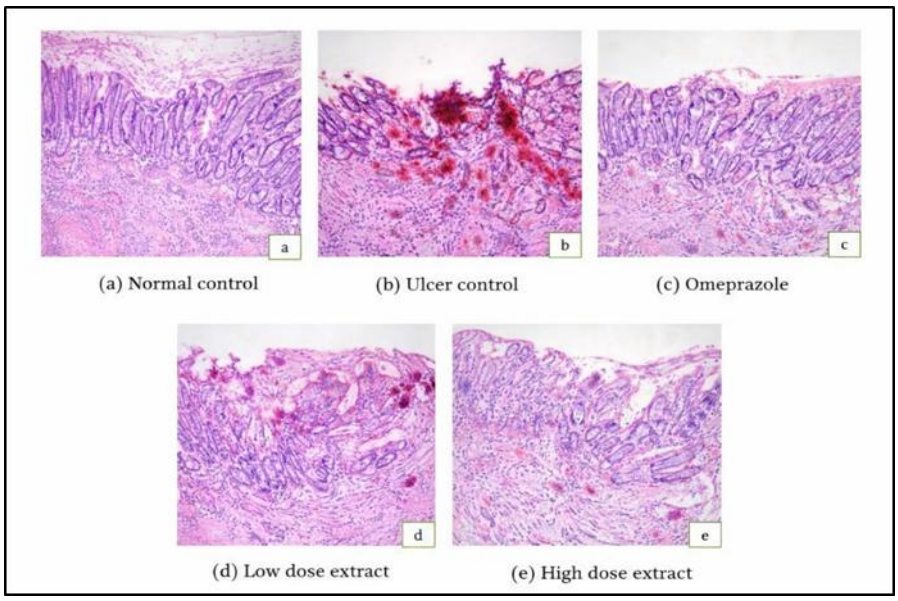

Figure 9. Histological sections of gastric mucosa stained with hematoxylin and eosin (H&E). (a) Normal control group showing intact gastric mucosal architecture with normal epithelial cells and gastric glands., (b) Ulcer control group showing severe mucosal damage, epithelial disruption, hemorrhage, and inflammatory cell infiltration., (c) Omeprazole-treated group showing significant protection of gastric mucosa with reduced tissue damage and improved structural integrity., (d) Low-dose banana peel extract treated group showing moderate protection with partial restoration of gastric mucosal structure and reduced inflammation., (e) High-dose banana peel extract treated group showing marked improvement in gastric mucosal architecture with minimal lesions, indicating strong gastroprotective activity.

Discussion:

The present study was carried out to evaluate the phytochemical composition, antioxidant activity, and gastroprotective potential of banana peel extract. The results obtained from the study indicate that banana peel contains several bioactive phytochemicals that may contribute to its therapeutic properties.

Relationship Between Phenolic Compounds and Antioxidant Activity-

Phenolic compounds and flavonoids are well known for their strong antioxidant properties. In the present study, the banana peel extracts showed considerable amounts of total phenolic and flavonoid content, which are important natural antioxidants. These compounds are capable of donating hydrogen atoms or electrons to neutralize free radicals.

The antioxidant assays such as DPPH, ABTS, and FRAP demonstrated significant free radical scavenging activity of the extracts. The extract with higher phenolic and flavonoid content exhibited stronger antioxidant activity, suggesting a direct correlation between phenolic compounds and antioxidant potential. Phenolic compounds can inhibit oxidative stress by reducing the formation of reactive oxygen species (ROS) and preventing cellular damage.

Protective Mechanism of Banana Peel-

The gastroprotective activity observed in the present study may be attributed to the presence of bioactive constituents such as flavonoids, tannins, and phenolic compounds present in banana peel extract. These phytochemicals are known to enhance the defense mechanisms of the gastric mucosa.Banana peel extract showed a reduction in ulcer index and increased percentage protection, indicating its ability to protect the gastric mucosa from ethanol-induced damage. The protective effect may be associated with multiple mechanisms, including antioxidant activity, enhancement of mucus secretion, and inhibition of inflammatory responses.

Comparison With Previous Studies-

The findings of the present study are consistent with previous studies that have reported the antioxidant and gastroprotective properties of banana peel and other plant-derived extracts. Earlier research has demonstrated that plant extracts rich in phenolic compounds exhibit significant antioxidant activity and can protect gastric mucosa from oxidative damage.

Several studies have reported that banana peel contains high levels of phenolic compounds, flavonoids, and tannins, which contribute to its antioxidant and anti-inflammatory activities. The present study supports these findings and further confirms the potential of banana peel as a natural source of bioactive compounds with therapeutic applications.

Possible Mechanisms of Gastroprotective Activity-

The gastroprotective activity of banana peel extract may involve several mechanisms:

1. Free Radical Scavenging:

Ethanol-induced gastric ulcers are associated with excessive production of free radicals and oxidative stress. The antioxidant compounds present in banana peel extract can neutralize these free radicals, thereby preventing oxidative damage to the gastric mucosa.

2. Enhancement of Mucus Secretion:

The gastric mucus layer acts as a protective barrier against acidic gastric secretions and harmful agents. Phytochemicals such as flavonoids and tannins may stimulate mucus secretion, thereby strengthening the mucosal defense system.

3. Anti-inflammatory Effect

Inflammation plays a significant role in gastric mucosal injury. The bioactive compounds present in banana peel extract may reduce inflammatory cell infiltration and tissue damage, leading to improved healing of the gastric mucosa. Histopathological observations in the present study also supported the gastroprotective effect, as the treated groups showed reduced mucosal damage and improved gastric tissue architecture compared to the ulcer control group.

Conclusion:

The present study demonstrated that banana peel extract possesses significant phytochemical, antioxidant, and gastroprotective properties. Qualitative phytochemical screening confirmed the presence of important bioactive compounds such as phenolics, flavonoids, tannins, alkaloids, saponins, and glycosides, which are known to contribute to various pharmacological activities. Quantitative analysis revealed a considerable amount of total phenolic and flavonoid content, indicating that banana peel is a rich source of natural antioxidants. The antioxidant assays including DPPH, ABTS, and FRAP confirmed the strong free radical scavenging activity of the extracts, suggesting their potential to reduce oxidative stress. In the ethanol-induced gastric ulcer model, banana peel extract exhibited notable gastroprotective activity by significantly reducing the ulcer index and improving gastric mucosal protection. Histopathological examination further supported these findings, as treated groups showed reduced mucosal damage, decreased inflammatory infiltration, and improved gastric tissue architecture compared with the ulcer control group. Overall, the results of this study suggest that banana peel extract has promising potential as a natural therapeutic agent for the management of gastric ulcers. The gastroprotective effect may be attributed to its antioxidant, anti-inflammatory, and mucus-enhancing properties.

Further studies involving isolation of active compounds, detailed mechanistic investigations, and clinical evaluation are recommended to explore its full therapeutic potential.

Limitations of the study-

Although the present study demonstrated promising antioxidant and gastroprotective properties of banana peel extracts, certain limitations should be acknowledged. The study was conducted using a limited number of banana varieties, which may not fully represent the phytochemical diversity present in different banana cultivars.

In addition, the gastroprotective activity was evaluated only in experimental animal models, and the results obtained from animal studies may not completely reflect the therapeutic effects in humans. Furthermore, the study mainly focused on the crude extract, and the specific bioactive compounds responsible for the observed pharmacological effects were not isolated or characterized. Therefore, additional research involving a larger number of plant varieties and detailed phytochemical investigations is necessary to confirm and expand the findings of the present study.

Future Scope-

The results of the present study provide a basis for further investigation into the therapeutic potential of banana peel extracts. Future research may focus on the isolation and characterization of specific bioactive compounds responsible for the antioxidant and gastroprotective activities.

Further studies involving advanced pharmacological and toxicological evaluations are required to understand the mechanisms of action in greater detail. In addition, clinical trials in human subjects are necessary to validate the safety and efficacy of banana peel extracts for the treatment of gastric ulcers. The development of herbal anti-ulcer formulations such as tablets, capsules, or suspensions based on banana peel extract may also be explored to promote its potential use as a natural therapeutic agent.

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