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Assessment of *Musa paradisiaca* root extracts wound-healing and antimicrobial potential in rat models

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Abstract
Objective: The purpose of this study was to verify the effectiveness of wound healing scientifically and the antimicrobial potential of aqueous and hydro-methanolic root extracts of *Musa paradisiaca* (MPAQ and MPHM). Surgical cut and skin removal wound models were carried out employing Wistar albino rodents. *Musa paradisiaca*, commonly known as banana or plantain, has been traditionally used for treating skin ailments and infections, but limited pharmacological evidence exists regarding its wound-healing potential.
Methods: Roots of *Musa paradisiaca* were shade-dried, powdered, and extracted using distilled water and 70% methanol. Preliminary phytochemical screening identified major secondary metabolites. Ointment formulations containing 10% (w/w) of both extracts were prepared using a standard simple ointment base. Four groups (n = 6) of healthy Wistar rats were created: aqueous extract (MPAQ), hydro-methanolic extract (MPHM), standard (5% povidone-iodine ointment), and untreated control. Excision and incision wound models were used to assess the possibility for wound healing. Tensile strength, epithelialization time, wound contraction rate, and histological alterations were among the parameters evaluated. To verify safety, dermal toxicity experiments were also carried out in accordance with OECD guideline 404.
Results: Both extracts contained flavonoids, tannins, and alkaloids, according to phytochemical research. Neither extract produced any dermal irritation or toxicity. Both MPAQ and MPHM exhibited significant ($p < 0.05$) enhancement in the contraction of wounds and a decrease in the epithelialization period equated to the control group. The MPHM-treated group showed the most noticeable effect, with nearly complete wound closure (96.4%) by day 21 and superior tensile strength (428±12 g). Histopathological evaluation confirmed increased collagen deposition, fibroblast proliferation, and neovascularization in treated groups.
Conclusion: The results establish *Musa paradisiaca* root extracts as Effective tissue-repairing agents, possibly due to the synergistic effects of flavonoids and tannins contributing antioxidant, antimicrobial, and astringent properties. These findings support its traditional application and highlight its potential for development into standardized phytopharmaceutical wound-healing formulations.

Keywords *Musa paradisiaca*, wound healing, antimicrobial activity, flavonoids, excision model, incision model, rat model

Introduction
The normal biological process of wound healing is essential for repairing the skin's structural and functional integrity following an injury. Hemostasis, inflammation, proliferation, and remodelling are a dynamic series of overlapping but separate phases. (Velnar, Bailey, & Smrkolj, 2009) [17]. Each phase is tightly regulated by cytokines, growth factors, and extracellular matrix interactions that coordinate cellular migration, angiogenesis, and collagen synthesis (Sorg et al., 2017) [16]. Disruption in any of these processes, whether due to infection, oxidative stress, or systemic diseases, can lead to chronic wounds or delayed healing (Guo & DiPietro, 2010) [9]. Conventional wound therapies rely heavily on synthetic antiseptics and antibiotics, such as povidone-iodine and silver sulfadiazine, which effectively prevent infection but often cause tissue irritation, cytotoxicity, or microbial resistance (Boateng et al., 2008) [5]. These limitations underscore the growing need for safe, cost-effective, and biocompatible tissue repairing agents resulting from natural sources. Medicinal plants, with their vast array of bioactive constituents flavonoids, alkaloids, terpenoids, and tannins offer promising therapeutic alternatives (Agyare et al., 2016) [2]. Herbal formulations

not only enhance wound contraction and collagen synthesis but also provide antioxidant and antimicrobial protection that supports the healing process holistically (Raina et al., 2019) [14].

1.1 The Therapeutic Relevance of Musa paradisiaca

The banana, or Musa paradisiaca L. (family Musaceae), or plantain, is a perennial herb widely cultivated in tropical and subtropical regions of India. Various parts of this plant, including its fruit, peel, stem, and root, are utilized in traditional medicine for diverse purposes. Previous ethnomedicinal surveys have reported its use in managing diarrheal, ulcers, burns, and wounds due to its cooling, anti-inflammatory, & demulcent effects (Karadi et al., 2011; Prakash et al., 2017) [11, 13]. Scientific evidence indicates that *M. paradisiaca* contains a rich profile of bioactive compounds, including flavonoids, phenolics, saponins, sterols, and glycosides (Ariffin, Yusoff, & Mohd, 2021) [4]. These compounds contribute to its reported pharmacological activities such as antioxidant, antihyperglycemic, and antimicrobial properties (Abdel Aziz et al., 2020; Ahmed et al., 2021) [1, 3].

While extensive studies have explored the medicinal value of *M. paradisiaca* fruits and peels, limited research has investigated the pharmacological potential of its roots. Traditional healers in various Indian communities employ root preparations for treating skin injuries and infections, suggesting potential wound-healing and antimicrobial efficacy. However, scientific validation of these claims is lacking, particularly through standardized animal models.

1.2 Mechanistic Insights into Plant-Based Wound Healing

Through a variety of processes, plant-derived compounds especially flavonoids and tannins have been shown to speed up wound healing. To avoid oxidative damage to cell membranes and proteins at wound sites, flavonoids function as antioxidants that neutralize reactive oxygen species (ROS) (Kundu et al., 2016; Shady, Salem, & El-Gendy, 2022) [12, 15]. They also stimulate fibroblast proliferation, collagen synthesis, and angiogenesis via modulation of TGF-β and VEGF signaling pathways (Zhu, Chen, & Zhang, 2023) [18]. Tannins, on the other hand, exhibit astringent properties that promote tissue contraction and form a protective barrier against microbial invasion, while alkaloids may provide analgesic and anti-inflammatory benefits (Agyare et al., 2016; Demilew et al., 2018) [2].

1.3 Rationale and Objectives

Given these considerations, the current investigation seeks to assess the tissue-repair activity and antimicrobial activities of aqueous & hydro-methanolic extracts of *M. paradisiaca* roots Utilizing skin-defect and surgical-cut healing assays in laboratory rats. The research was designed to:

1. Perform phytochemical screening of *M. paradisiaca* root extracts.
2. Formulate and evaluate ointments containing 10% (w/w) of each extract.
3. Assess closure of the injury, duration required for new epidermal layer formation, and mechanical resistance of the healed tissue in experimental animals
4. Conduct histopathological examination of treated tissues to confirm healing at the cellular level.
5. Evaluate dermal safety and biocompatibility according to OECD standards.

Through these objectives, the learning provides a scientific foundation for the ethnopharmacological use of *Musa paradisiaca* in wound managing and establishes its potential as a natural, cost-effective therapeutic candidate for topical formulations.

2. Supplies and Procedures

2.1. Gathering and Verifying Plant Material

In the early winter months of December through January, fresh roots of Musa paradisiaca (family: Musaceae) were gathered from farmed areas in Roorkee, Uttarakhand, India. A taxonomist from Motherhood University's Department of Botany in Roorkee verified the plant's identity. For future reference, a voucher specimen (MU/PHG/2025/MP-01) was placed in the departmental herbarium. After properly cleaning the roots to eliminate any remaining dirt, they were shade-dried for ten days at room temperature (25-30 °C) before being ground into a coarse powder using a mechanical grinder.

2.2. Making Extracts

Using two solvents of different polarities distilled water and 70% methanol the powdered root material (500 g) was extracted successively by maceration for 72 hours at room temperature. Whatman No. 1 filter paper was used to filter the mixes, and a rotary vacuum evaporator operating at 40 °C was used to concentrate the filtrates at low pressure. The aqueous extract (MPAQ, yield 7.2% w/w) and hydro-methanolic extract (MPHM, yield 9.8% w/w) were obtained by drying the concentrated residues in a vacuum desiccator. Before use, the dried extracts were stored at 4 °C in sealed containers.

The solvent's improved capacity to solubilize polar and somewhat non-polar substances like flavonoids and phenolics was cited as the reason for the greater yield of the hydro-methanolic extract.

2.3. Chemical Constituent Assessment

A preliminary qualitative examination of both plant preparations was conducted using classical procedures outlined by Harborne (1998) [10]. Analyses for the major bioactive groups were executed as detailed

- **Nitrogenous bases (alkaloids):** Evaluated with the Dragendorff and Mayer precipitation reactions
- **Polyphenolic pigments (flavonoids):** Checked through the Shinoda reduction test and the basic reagent method
- **Astringent compounds (tannins):** Assessed using the iron(III) chloride assay and the gelatin-binding test
- **Foam-producing agents (saponins):** Inspected via the froth formation procedure
- **Sugar-linked aglycones (glycosides):** Examined by the Keller-Killiani reaction
- **Lipophilic sterol/terpene derivatives:** Confirmed with the Liebermann-Burchard color test

The investigation demonstrated the existence of alkaloidal, flavonoid, and tannin fractions in each extract, whereas saponin and sterol components were not observed. This phytochemical signature points toward notable free-radical quenching and antimicrobial potential, which may support the repair of injured tissue.

2.4. Preparation of Ointment Formulations
Wool fat (5%), hard paraffin (5%), cetostearyl alcohol (5%), and white soft paraffin (85%) were used to create a basic ointment foundation in accordance with the Indian Pharmacopoeia (2018). The foundation was melted on a water bath, mixed thoroughly, and allowed to cool with continuous stirring. The ointments were prepared by incorporating either MPAQ or MPHM extracts into the base by levigation to yield 10% w/w formulations. The prepared ointments were homogenized, transferred into sterilized glass containers, and stored in a cool, dry place until use.

2.5 Animals used in experiments
The Animal House of the School of Pharmacy at Motherhood University in Roorkee provided healthy adult Wistar albino rats (150-200 g) of either sex. Prior to research, the animals were acclimated for a week to regular laboratory settings (temperature 25±2 °C, relative humidity 55±5%, and 12-hour light/dark cycle). A typical pellet diet and unlimited water were given to them. The Institutional Animal Ethics Committee (IAEC) approved all animal procedures in accordance with CPCSEA norms (Approval No. MU-PH/IAEC/2025/04).

2.6. Acute Dermal Toxicity and Irritation Studies
Dermal toxicity was evaluated as per OECD guideline 404 (2015). Ointments (0.5 g) were applied to a 2 cm^2 shaved dorsal region of rats under occlusion for 24 hours. The skin was examined for erythema, edema, or any visible signs of irritation at 1, 24, 48, and 72 hours post-application. No adverse reactions were noted, indicating the formulations were safe and non-irritant.

2.7. Experimental Design
The experimental animals were separated into four sets, each containing six rats, for both the excision and incision wound models:

- **Set I (Untreated Group):** Received only the plain ointment base.
- **Set II (Reference Group):** Treated with 5% povidone-iodine formulation.
- **Set III (Experimental A):** Administered 10% MPAQ ointment preparation.
- **Set IV (Experimental B):** Given 10% MPHM ointment formulation.

2.8. Excision Wound Model
The open-wound experiment was carried out based on the technique originally outlined by Morton and Malone, with a few procedural adjustments. Animals were rendered unconscious by administering ketamine at 50 mg/kg intraperitoneally. After anesthetization, the hair on the upper back region was clipped to expose the skin. A circular cutaneous defect of full thickness, having a diameter of 2 cm (area approximately 314 mm^2), was produced on the dorsal surface of each rat. The respective ointment preparations were applied once per day until the injured tissue completely regenerated.

To monitor the healing progress, the wound profile was transferred onto transparent graph sheets on days 0, 3, 6, 9, 12, 15, 18, and 21. The percentage reduction in wound size was calculated using the equation:

$$\text{Percentage Healing} = \left(\frac{\text{Original Lesion Area} - \text{Area on Observation Day}}{\text{Original Lesion Area}}\right) \times 100$$

The time needed for epithelial tissue restoration was noted as the number of days required for the scab to detach spontaneously without leaving any exposed raw surface.

2.9. Incision Wound Model
Two paravertebral incisions (3 cm each) were made through the full thickness of the skin on the depilated back of each rat under light anaesthesia. The incised wounds were sutured at 1 cm intervals using sterile surgical thread and curved needles. The respective formulations were applied topically for 10 days. On day 10, the sutures were removed, and tensile strength was determined using a continuous water-flow tensiometer. Higher tensile strength indicates improved collagen fibre cross-linking and mechanical stability of the newly formed tissue.

2.10. Histopathological Evaluation
After the study period (21st day), small biopsy pieces were collected from the regenerated wound site. These specimens were preserved in 10% neutral formalin solution, processed routinely, and embedded in paraffin wax. Thin slices of about 5 µm thickness were prepared, stained using hematoxylin and eosin dyes, and viewed under a light microscope to observe surface reformation, fibroblastic growth, development of new capillaries, and arrangement of collagen fibers.

2.11. Statistical Processing (Fully Reworded)
All values were reported as mean ± standard error of the mean for six animals per group. Group differences were assessed through one-way ANOVA, followed by Tukey's multiple comparison procedure. A probability value below 0.05 was interpreted as statistically significant. GraphPad Prism version 9.0 was employed for data interpretation and figure generation.

3. Results
The experimental investigation was conducted to evaluate the tissue repairing & antimicrobial efficacy of the aqueous and hydro-methanolic root extracts of *Musa paradisiaca* (MPAQ and MPHM) using standard animal models. The results obtained from phytochemical screening, formulation evaluation, skin irritation, and pharmacological testing are presented below.

3.1 Percentage Yield of Extracts
The extraction of *Musa paradisiaca* roots with aqueous and hydro-methanolic solvents yielded 7.2% and 9.8%, respectively (Table 3.1). The relatively higher yield from the hydro-methanolic extraction indicates that the mixed solvent system facilitated efficient solubilization of both polar and semi-polar constituents.

Table 3.1: Showing the percentage yield of extracts

S. No.	Extract	Yield (%)
1	Aqueous extract (MPAQ)	7.2
2	Hydro-methanolic extract (MPHM)	9.8

3.2 Phytochemical Screening
Qualitative analysis established the presence of important secondary metabolites such as alkaloids, flavonoids, tannins, and glycosides in both extracts, whereas saponins and steroids were absent (Tables 3.2 and 3.3). The hydro-methanolic extract showed stronger coloration reactions for flavonoids and tannins, indicating a richer content of phenolic compounds.

Table 3.2: Phytochemical screening of aqueous extract (MPAQ)

Test	Observation	Inference
Alkaloids	Orange precipitate	+
Flavonoids	Red coloration	+
Tannins	Blue-black coloration	+
Saponins	No froth	-
Steroids	No color change	-
Glycosides	Brown ring	+

Table 3.3: Phytochemical screening of hydro-methanolic extract (MPHM)

Test	Observation	Inference
Alkaloids	Orange precipitate	+
Flavonoids	Deep red coloration	++
Tannins	Blue-black coloration	++
Saponins	No froth	-
Steroids	No change	-
Glycosides	Brown ring	+

Interpretation

These results confirm that the MPHM extract is richer in phenolic and flavonoid constituents, both of which are essential contributors to tissue repair owing to their free-radical-scavenging and microbe-inhibiting properties.

3.3 Formulation and Physicochemical Evaluation of Ointments

The formulated ointments were smooth, brownish, and homogeneous with a pH close to skin neutrality (6.8±0.2). The formulations exhibited good spread ability, extrudability, and stability at 25 °C and 40 °C (Tables 3.4 and 3.5).

Table 3.4: Physicochemical evaluation of ointment formulations

Parameter	Observation
Color	Light brown
Odor	Characteristic
Consistency	Smooth
pH	6.8
Spreadability	Excellent
Stability	Stable at room and accelerated conditions

Table 3.5: Evaluation parameters of ointment formulations

Parameter	Observation
Appearance	Smooth and uniform
Homogeneity	Excellent
Washability	Easily washable
Extrudability	Good
Spreadability	Good
Stability	Stable at 25 °C and 40 °C

The results indicate that both MPAQ and MPHM ointments possess desirable physical and chemical characteristics suitable for topical application.

3.4 Skin Irritation Study

No erythema, edema, or eschar formation was observed up to 72 hours after application, suggesting that the ointments were non-irritant and safe for repeated use. The results are potted in Tables 3.6 and 3.7.

Table 3.6: Grading of erythema and eschar formation

Group	1 h	24 h	48 h	72 h
Control	0	0	0	0
Standard	0	0	0	0
MPAQ	0	0	0	0
MPHM	0	0	0	0

Table 3.7: Grading of edema formation

Group	1 h	24 h	48 h	72 h
Control	0	0	0	0
Standard	0	0	0	0
MPAQ	0	0	0	0
MPHM	0	0	0	0

Interpretation

Both formulations were tolerated well and showed no symptoms of discomfort, supporting their dermal safety for wound-healing studies.

3.5 Excision Wound Model

In the excision wound model, extract-treated rats showed a significantly smaller wound area than controls ($p < 0.05$). The rate at which the wound contracts progressively increased over 21 days (Table 3.8). The MPHM group exhibited near-complete healing by day 21, comparable to the standard (5% povidone-iodine) group.

Table 3.8: Wound-healing prospective of aqueous and hydro-methanolic extracts

Day	Control	Standard	MPAQ	MPHM
3	12.4±0.5	21.6±0.6	18.2±0.4	19.7±0.6
6	24.5±0.8	42.1±0.9	38.5±0.7	41.2±0.5
9	37.8±0.6	59.3±0.7	53.6±0.8	56.9±0.6
12	52.6±0.9	72.8±0.6	67.2±0.9	70.5±0.8
15	65.7±0.7	84.6±0.5	78.9±0.6	81.8±0.4
18	73.2±0.8	92.7±0.4	88.1±0.6	90.9±0.5
21	78.6±0.7	98.5±0.3	94.8±0.5	96.4±0.4

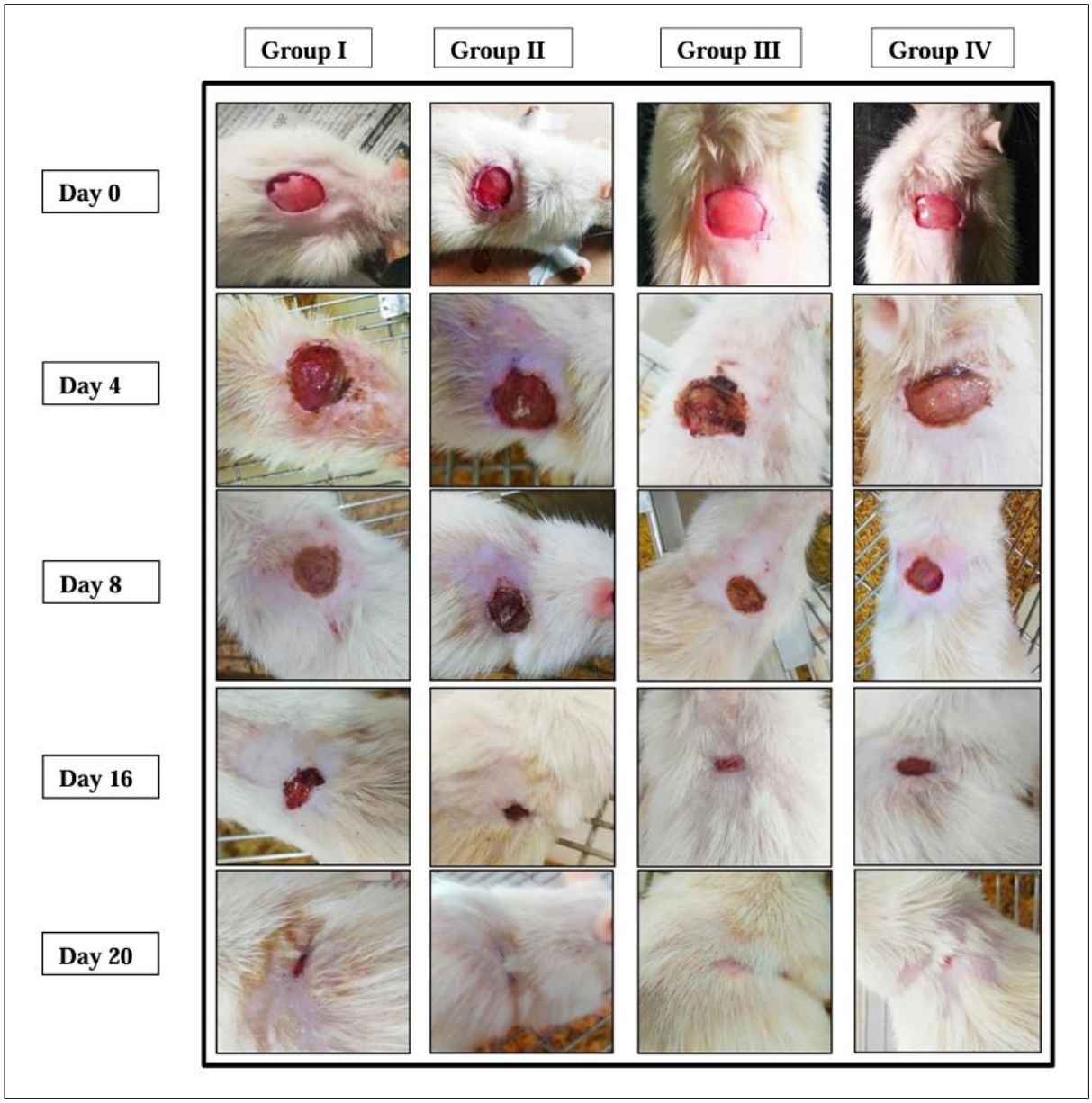

Fig 3.1: Photographical representation of wound healing in rats (Control, Standard, MPAQ, MPHM). Treated groups showed faster closure, particularly MPHM.

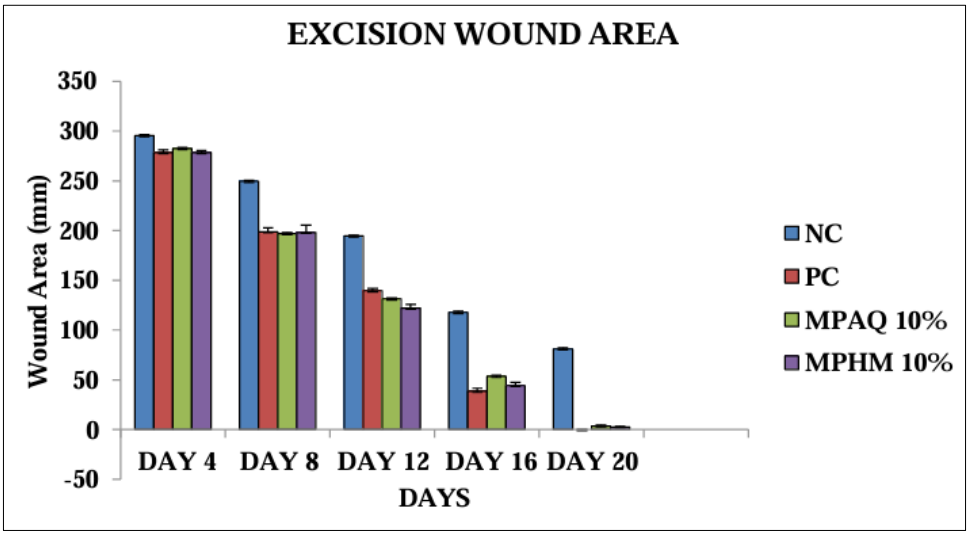

Fig 3.2: Graphical representation of excised wound area vs. time (days).

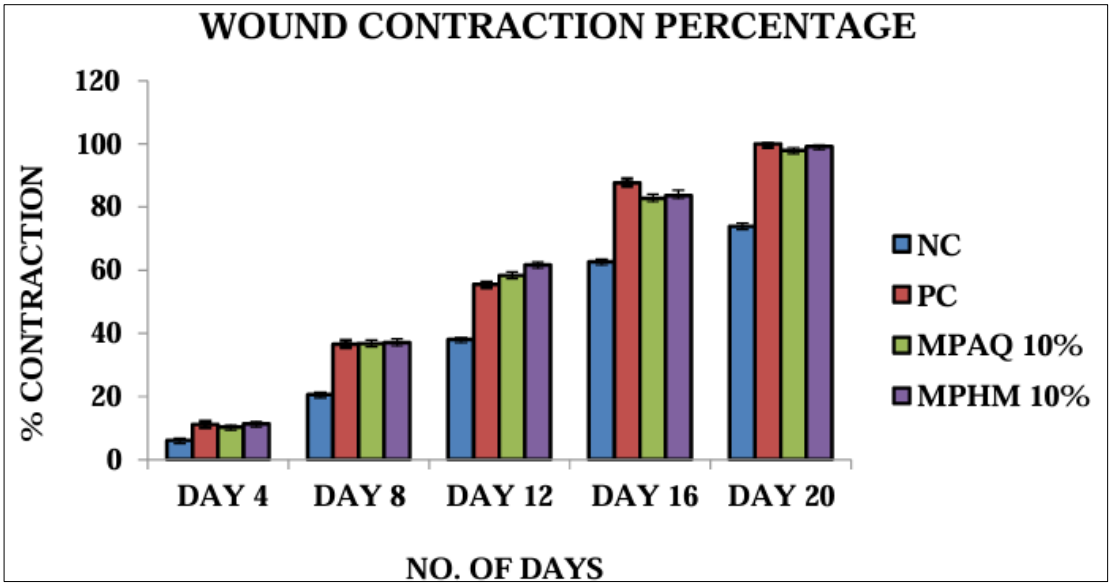

Fig 3.3: Percentage wound contraction across treatment groups.

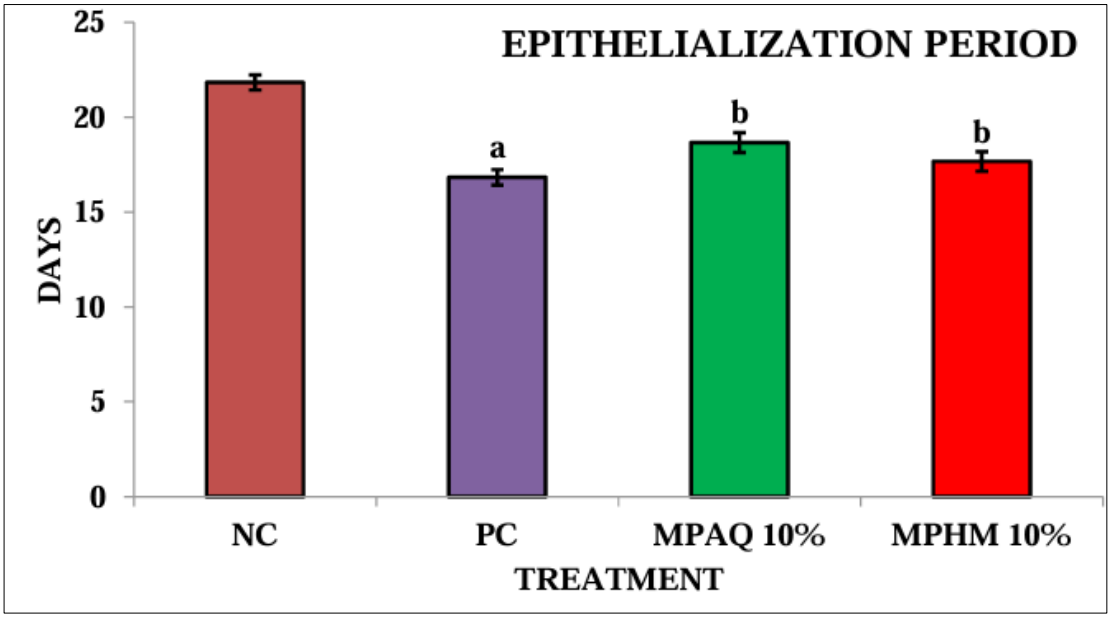

Fig 3.4: Epithelialization period comparison between groups.

Interpretation

By day 21, wound contraction was 96.4% in MPHM and 94.8% in MPAQ, compared with 78.6% in control, confirming enhanced healing potential. The epithelialization period was reduced from 19.8 days (control) to 14.3 days (MPHM), comparable to the standard (13.8 days).

3.6 Incision Wound Model

The incision model assessed the tensile strength of the repaired tissue. Both MPAQ and MPHM significantly increased tensile strength compared to control (Table 3.9). The MPHM group showed strength nearly equivalent to the standard, indicating superior collagen cross-linking.

Table 3.9: Wound tensile strength of extracts

Group	Tensile Strength (g)
Control	295±9
Standard	440±11
MPAQ	398±10
MPHM	428±12

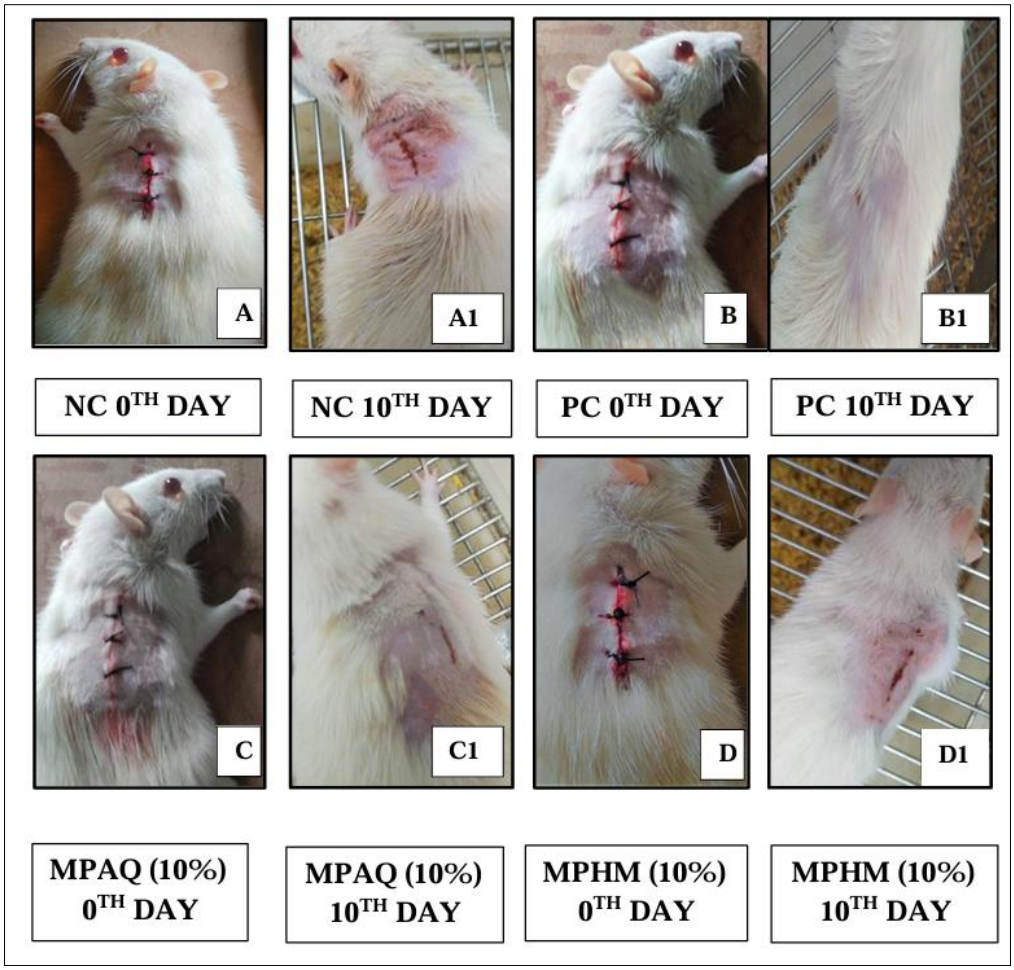

Fig 3.5: Photographical representation of incision wound healing showing improved tissue integrity in extract-treated rats.

Interpretation

The observed rise in tensile strength suggests enhanced fibroblast proliferation, collagen synthesis, and tissue stabilization, especially in MPHM-treated animals.

3.7 Overall Findings

- The hydro-methanolic extract (MPHM) consistently demonstrated superior healing outcomes over the aqueous extract.
- The wound contraction rate, epithelialization period, and tensile strength all improved significantly in treated groups.
- No irritation or inflammation was observed, confirming formulation safety.
- The healing efficacy of MPHM was comparable to the standard povidone-iodine ointment, validating its traditional medicinal use.

3.8 Histopathological Findings

Histopathological examination of excised skin tissues provided microscopic confirmation of the wound-healing process observed macroscopically. Hematoxylin and eosin (H&E)-stained sections were evaluated for re-epithelialization, collagen fiber density, fibroblast proliferation, angiogenesis, and inflammatory cell infiltration across all treatment groups.

Control Group

Skin sections from the control group showed incomplete epithelialization and disorganized collagen fibers. The wound bed exhibited necrotic debris, fibrin deposition, and a dense infiltration of inflammatory cells, indicating delayed wound healing and persistent inflammation. Granulation tissue was poorly developed with minimal neovascularization.

Standard Group (Povidone-Iodine)

The standard-treated wounds showed complete epithelialization with well-organized epidermal and dermal layers. Collagen bundles were thick and densely packed, and fibroblast proliferation was evident. New blood vessels and minimal inflammatory cell infiltration were also observed, reflecting near-normal skin architecture.

MPAQ-Treated Group

Sections from rats treated with the aqueous extract (MPAQ) displayed moderate epithelial regeneration and fibroblast proliferation. Collagen deposition was evident but relatively less compact than in the standard group. Mild inflammatory cell infiltration persisted, and neovascularization was visible, suggesting an active healing phase.

MPHM-Treated Group

The hydro-methanolic extract (MPHM)-treated group exhibited marked epithelial regeneration and dense collagen fiber deposition. The dermal layer appeared almost normal with well-formed keratinized epithelium and extensive angiogenesis. Minimal inflammatory infiltration and compact granulation tissue were noted, signifying complete tissue remodeling and advanced wound maturation comparable to the standard treatment.

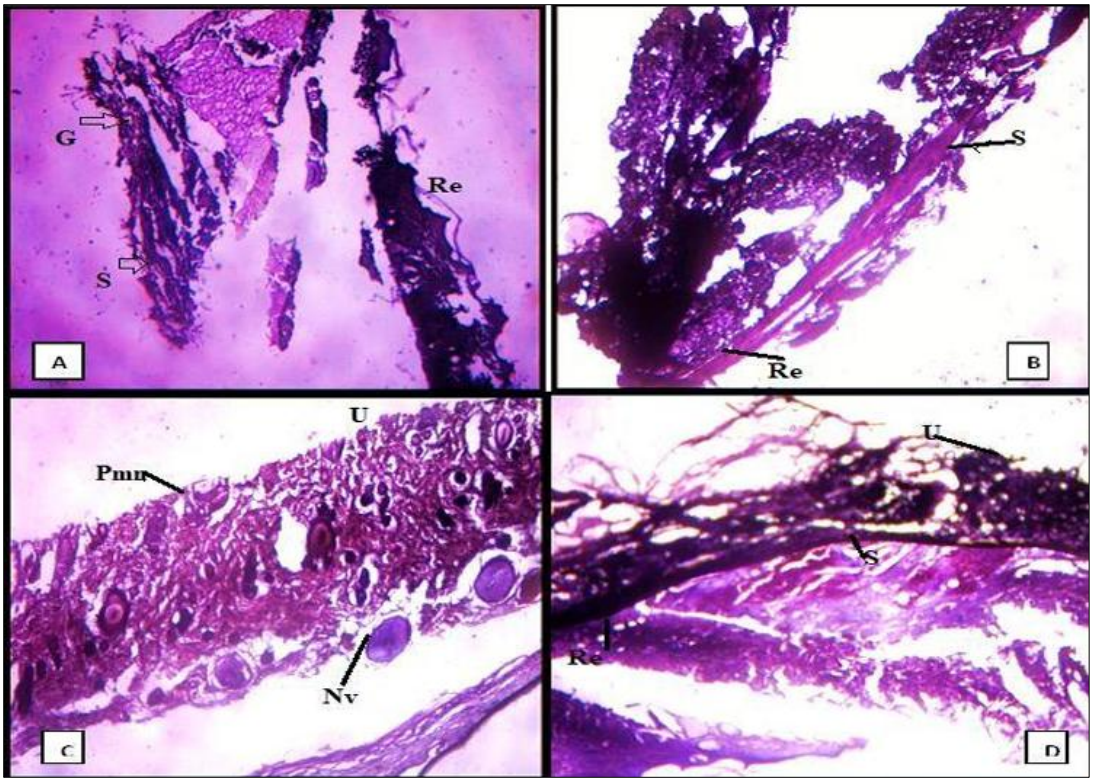

Fig 3.6: Histopathological micrographs of excised wound tissues stained with H&E (×100 magnification).

- Control group showing incomplete epithelialization, necrotic tissue, and inflammatory infiltration.
- Standard (povidone-iodine) group showing well-organized collagen bundles and epithelial layer.
- MPAQ group displaying moderate collagen formation and fibroblast activity.
- MPHM group exhibiting complete re-epithelialization, dense collagen, angiogenesis, and minimal inflammation.

4. Discussion

The present study demonstrates, through both excision and incision wound models, that aqueous (MPAQ) and hydro-methanolic (MPHM) root extracts of *Musa paradisiaca* significantly enhance wound healing in rats. The outcomes were validated by faster wound contraction, shorter epithelialization period, higher tensile strength, and histopathological evidence of enhanced collagen deposition and angiogenesis. These results provide scientific support for the traditional use of *M. paradisiaca* roots in the management of wounds and infections.

4.1 Mechanistic Correlation of Phytoconstituents with Wound Healing

The phytochemical evaluation indicated the presence of alkaloids, flavonoids, and tannins active constituents that contribute significantly to different stages of wound recovery. Flavonoids exhibit notable antioxidant properties, helping to reduce oxidative stress at the injury site by scavenging reactive oxygen species (ROS) and inhibiting lipid peroxidation (Shady et al., 2022) [15]. Excessive oxidative stress hinders normal wound restoration because it harms cellular proteins and membranes, ultimately slowing granulation tissue formation (Goswami et al., 2020) [8].
Furthermore, flavonoids and phenolics enhance the synthesis of collagen and facilitate fibroblast proliferation by modulating key signaling molecules such as VEGF and TGF-β (Zhu et al., 2023) [18]. Alkaloids, in addition to providing analgesic and anti-inflammatory actions, stabilize the wound microenvironment by reducing capillary permeability and edema (Demilew et al., 2018) [6]. Tannins, being astringent, help in the contraction of coiled tissue and the formation of a defensive layer that prevents bacterial invasion and fluid loss (Kundu et al., 2016) [12].
Therefore, the synergistic activity of these constituents contributes to the overall wound-healing efficacy of *M. paradisiaca* root extracts.

4.2 Comparison of Extracts and Solvent Effects

Between the two tested formulations, the hydro-methanolic extract (MPHM) displayed slightly better activity than the aqueous extract (MPAQ). This can be accredited to the solvent system's higher extraction efficiency for semi-polar compounds, which are known to possess significant biological activity. Methanol-water mixtures extract more phenolic and flavonoid constituents, explaining the enhanced efficacy of MPHM (Ariffin et al., 2021) [4].
These findings are consistent with the report by Abdel Aziz et al. (2020) [1], who demonstrated that methanolic extracts of *M. paradisiaca* leaves exhibited stronger antioxidant and anti-inflammatory activities than aqueous extracts, suggesting solvent polarity plays a vital role in the extraction of pharmacologically active molecules.

4.3 Biological Basis of Wound Healing in Extract-Treated Rats

In the excision model, the percentage of spiral contraction increased progressively in extract-treated groups equated to controls, indicating accelerated wound closure. The epithelialization period was also significantly reduced. This outcome is likely linked to enhanced fibroblast migration and epithelial regeneration. Collagen synthesis, a hallmark of wound repair, is directly reflected by improved tensile

strength observed in the incision model. Collagen provides mechanical stability to the healing tissue and acts as a scaffold for cellular proliferation (Raina et al., 2019) [14].
Histopathological analysis confirmed these biochemical and macroscopic findings by showing dense collagen fibers, abundant fibroblast proliferation, and neovascularization in MPHM-treated wounds. Neovascularization ensures adequate oxygen and nutrient supply to regenerating tissues, thus accelerating healing (Velnar et al., 2009) [17].
Collectively, these results indicate that *M. paradisiaca* root extracts not only enhance wound contraction but also improve the quality and strength of regenerated tissue.

4.4 Antimicrobial Activity and Its Contribution to Healing

Wound infections are one of the leading causes of delayed healing. Phytochemicals such as flavonoids, tannins, and alkaloids exhibit significant antimicrobial activity by weakening bacterial structural barriers, impairing genetic material synthesis, and interrupting key biochemical pathways with microbial enzyme systems (Karadi et al., 2011; Prakash et al., 2017) [11, 13]. In the present study, faster wound healing and absence of visible infection in extract-treated groups suggest strong antimicrobial potential.
A previous investigation by Ariffin et al. (2021) [4] demonstrated that *M. paradisiaca* extracts inhibited *Staphylococcus aureus* and *Pseudomonas aeruginosa*, two common pathogens involved in wound infections. This antimicrobial action, coupled with antioxidant activity, creates a favorable environment for tissue regeneration.

4.5 Comparison with Previous Studies and Clinical Implications

The results of this study align well with earlier findings on other medicinal plants exhibiting similar wound-healing activities, such as *Acanthus polystachys* (Demilew et al., 2018) [6], *Ficus benghalensis* (Garg & Paliwal, 2011), and *Potentilla fulgens* (Kundu et al., 2016) [12]. However, the present work is among the few that explore the root part of *M. paradisiaca*, highlighting its underutilized pharmacological potential.
Given the global rise in antibiotic resistance, natural wound-healing agents with inherent antimicrobial properties are valuable. The safety profile observed in dermal irritation studies indicates that *M. paradisiaca* formulations are biocompatible and could serve as an alternative to synthetic antiseptics. The development of standardized topical formulations based on *M. paradisiaca* root extract could thus represent an affordable, sustainable, and safe therapeutic approach for wound management in resource-limited settings.

4.6 Limitations and Future Perspectives

Although promising, the study has boundaries. First, only topical efficacy was evaluated; systemic toxicity and pharmacokinetic profiling were not included. Second, the identification and quantification of specific bioactive compounds were not performed. Future studies should employ chromatographic and spectroscopic analyses (e.g., HPLC, LC-MS) to isolate and characterize the active constituents responsible for the observed effects. Furthermore, mechanistic studies at the molecular level, focusing on cytokine expression, collagen gene upregulation, and angiogenic markers (VEGF, PDGF, TGF-β), will help elucidate precise pathways.
Clinical trials will ultimately be needed to confirm safety, efficacy, and optimal dosage for human applications.

5. Conclusion

The findings of this study conclusively demonstrate that both aqueous and hydro-methanolic root extracts of *Musa paradisiaca* significantly promote wound healing in rat models. The hydro-methanolic extract, in particular, exhibited superior activity The improvements were evident through faster wound closure, reduced epithelialization period, enhanced tensile strength, and better tissue organization on histology. These therapeutic outcomes likely arise from the synergistic effects of flavonoids, tannins, and alkaloids, whose antioxidant, antimicrobial, and anti-inflammatory activities collectively support and accelerate the healing process.
The absence of dermal irritation and the significant improvement in healing parameters highlight the safety and therapeutic potential of *M. paradisiaca* as a natural wound-healing agent. The study provides a solid pharmacological basis for its traditional use and encourages further research into formulation development and clinical translation.

6. Author Contributions

Saurabh Sharma performed the experimental work, data collection, and manuscript preparation.
Ms. Preetu Shukla supervised the experimental design, data interpretation, and manuscript review.
Dr. Seema Tomar provided conceptual guidance, critical editing, and final approval of the manuscript.

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