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Natural Biomaterial in Drug Delivery: A Review on Banana-Leaf-Based Transdermal Patches and their Anti-Microbial Activity

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ABSTRACT:

This paper explores the many uses of the banana plant, Musa paradisiaca, including its proven therapeutic use and its promise as a sustainable supply of cutting-edge biomaterials. Sterilized banana leaves have long been acknowledged as a cheap and efficient substitute for traditional wound dressings, especially in settings with limited resources. When compared to traditional petroleum jelly gauze, clinical findings demonstrate the leaf's excellent quality as a totally non- adherent material that minimizes stress and lessens pain during dressing changes. The leaves' complex phytochemical profile, which consistently reports the presence of flavonoids, phenols (polyphenols), tannins, and saponins, is connected to their innate medicinal efficacy. These substances effectively scavenge DPPH free radicals in solvent extracts, demonstrating their strong antioxidant activity. This bioactivity is essential for supporting the initial phases of wound healing and offering defense against infection and oxidative stress.The significant amount of agro-waste produced by banana farming is seen as an environmentally beneficial reservoir in the context of material science and sustainability. Cellulose and high-value biopolymers, particularly nanocellulose (NC), are extracted from different plant sections as part of valorization activities. The development of next-generation, biodegradable pharmaceutical platforms, such as hydrogels and matrices for contemporary drug delivery methods, such as transdermal patches, is made possible by this material breakthrough. To maximize the use of banana trash for a sustainable bioeconomy and to standardize the clinical application of the leaves, more study is necessary.

Keywords: Musa paradisiacal, microcirculation, nanocellulose, Antimicrobial**,** bioeconomy, transdermal patches

1. INTRODUCTION

1.1. History:

When the skin was initially identified as a practical channel for controlled drug administration in the late 1960s, the development of Transdermal Drug Delivery Systems (TDDS) got underway. The FDA's approval of the scopolamine patch, the first transdermal medicinal method, in 1979 marked a significant turning point. The nitroglycerin patch was then introduced in 1981, making TDDS a therapeutically important delivery system. Efficiency and safety were improved by later developments in polymers, rate-controlling membranes, and pressure-sensitive adhesives in the 1990s and early 2000s. These days, TDDS is a sophisticated, non-invasive device that is frequently used in systemic drug delivery and chronic therapy.

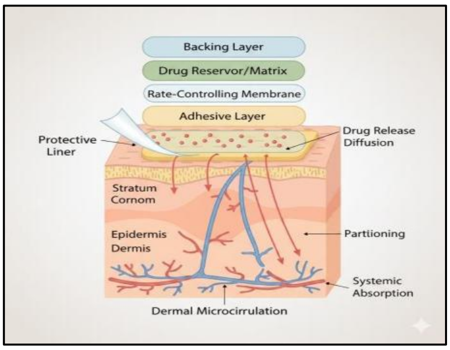

Fig.no.1. Transdermal Drug Delivery System (TDDS)

Transdermal Drug Delivery Systems (TDDS), which are designed to administer a prescribed dosage of medication through the skin and straight into the systemic circulation, are a major improvement in drug administration. They are frequently offered as medicated adhesive patches. The avoidance of hepatic first-pass metabolism, which improves drug bioavailability, is one of the delivery method's many benefits over traditional methods. Additionally, TDDS offers painless, non-invasive therapy that increases patient compliance, particularly for patients with chronic diseases or those who are intolerant to oral dosage forms. It also offers controlled and sustained release of the active substance over extended periods of time. Modern pharmaceutical science increasingly emphasizes the development of herbal TDDS employing non-toxic, biodegradable, and renewable materials, whereas standard patches rely on synthetic materials.[1,2]

1.1. Types Of Transdermal Patches:

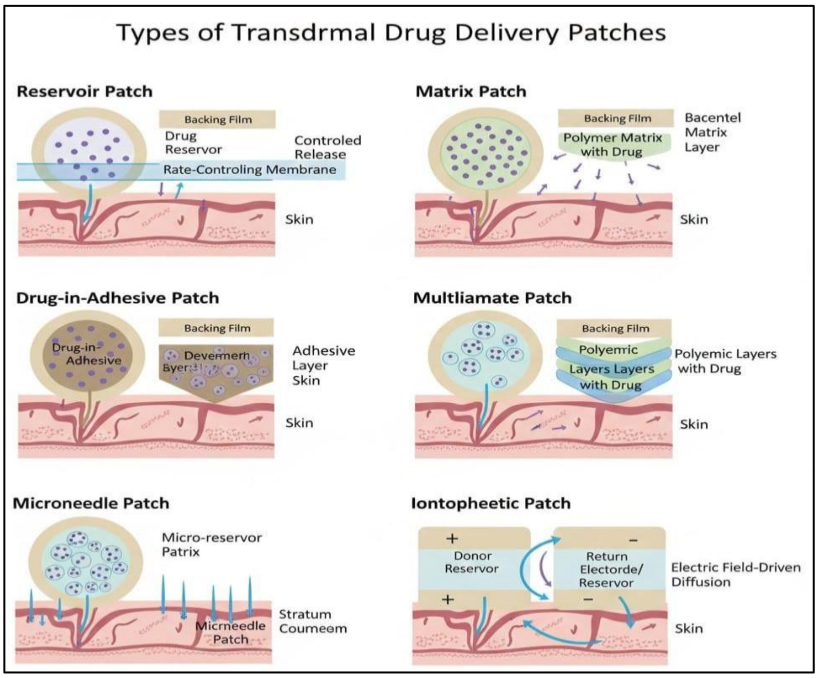

Fig.no.2.Types of transdermal patches

1.2. Traditional Use of Banana Leaves

Banana leaves (Musa paradisiaca) have long been used in medicine, especially in nations like India where they were traditionally used as a wound dressing. Desirable physical characteristics of the leaves include their huge surface area, cold, waxy surface, and non-adherent qualities that keep them from adhering to open wounds. Due to the leaves' cooling and non-adherent properties, smallpox sufferers were treated with this traditional method. [3,4]

Fig. no.3. Banana tree

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In comparison to traditional petroleum jelly gauze dressing, sterile banana leaf dressing has been shown in contemporary clinical evaluations to produce quick epithelization in partial thickness burn wounds and skin transplant donor sites. It is also linked to less pain during dressing changes. Banana leaves' historic effectiveness is highly relevant to today's cost-constrained healthcare situations because they are an easily accessible and affordable substitute, particularly in tropical locations.[5,6]

1.3. Relevance in Modern Drug Delivery and Antimicrobial Activity

Banana leaves' traditional use is currently being investigated for innovative pharmaceutical uses, especially in transdermal delivery and wound care, where materials with inherent therapeutic properties are always needed. Research has shown that a number of bioactive substances, including tannins, saponins, flavonoids, and phenolic compounds, are present in banana leaves and their extracts and have important therapeutic benefits. Along with critical antibacterial activity, these phytoconstituents also contribute vital biological functions, such as anti-inflammatory and antioxidant properties. Research has demonstrated that extracts from species such as M. Paradisiaca are efficient against a variety of pathogenic microorganisms that are frequently linked to wound infections, including the fungi Candida albicans and Cryptococcus neoformans, as well as the bacterium Staphylococcus aureus (S. aureus).[7,8]

Additionally, pure banana leaf derivatives may make excellent, biocompatible matrix components for transdermal patches since cellulose and nanocellulose made from banana waste are promising sustainable biopolymers appropriate for contemporary drug delivery systems. A sustainable foundation for medication administration and an active defense against microbial contamination are two benefits of using these naturally occurring antibacterial and structural elements into transdermal patches. In order to create innovative transdermal patches with proven antibacterial activity, our research attempts to take advantage of these natural advantages by combining historic usage with contemporary pharmaceutical manufacturing procedures.[9,10]

1.4. Mechanism of Action (MOA) Of TDDS:

A Transdermal Drug Delivery System (TDDS), typically an adhesive patch, delivers a predetermined dosage of medication through the skin and into the bloodstream (systemic circulation).

In short, the mechanism involves:

1. Controlled Release**:** The patch provides a controlled release of the medication. The goal is to maximize the flux (flow) of the drug through the skin into the systemic circulation.
2. Delivery Method**:** This controlled drug delivery often occurs through different methods:
A porous membrane covering a drug reservoir.
Body heat melting thin layers of embedded in the adhesive.
3. Absorption**:** The active drug ingredient must possess suitable physicochemical properties to enable its absorption through the skin and entry into the microcirculation.
Overall, TDDS is a system designed to deliver a therapeutically effective dose of a drug across a patient's skin at a controlled rate to the systemic circulation.[9, 10]

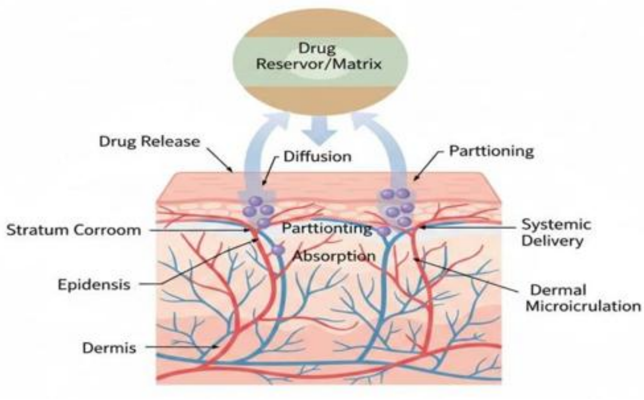

Fig.no.4. Mechanism Of Action (MOA) Of TDDS

2. Rationale for the Use of Banana Leaves in Transdermal Drug Delivery Systems (TDDS)

Additionally, as cellulose and nanocellulose derived from banana waste are promising sustainable biopolymers suitable for modern drug delivery methods, pure banana leaf derivatives may create excellent, biocompatible matrix components for transdermal patches. Two advantages of incorporating these naturally existing antibacterial and structural components into transdermal patches are a sustainable basis for drug delivery and an active defense against microbial contamination.

Our study aims to capitalize on these natural benefits by fusing traditional use with modern pharmaceutical production processes to develop novel transdermal patches with demonstrated antibacterial effectiveness.[11,12]

Physical and Economic Benefits: Compared to highly specialized dressings like collagen or biosynthetic materials, banana leaves are 1500–5000 times less expensive. In tropical settings, they provide as an endless, year-round source of biomaterial. Importantly, research assessing their conventional application as burn and laceration wound dressings emphasizes their advantageous physical properties, such as a waxy, cold, and non-adherent surface. Compared to traditional petroleum jelly gauze dressings, this non-adherence is a significant benefit since it immediately results in less discomfort and trauma during dressing changes. This characteristic reduces secondary trauma, which can impede the healing of wounds.[13,14]

Table 1. Critical Comparison of Banana-Leaf-Based Materials and Conventional Polymers Used in Transdermal Patch Systems

Parameter	Banana-Leaf-Based Materials	Conventional Transdermal Patch Polymers	Critical Evaluation/ Translational Implications
Permeability Control	Moderate and highly variable; dependent on plant source, extraction, and processing	Highly predictable and tunable through polymer selection, thickness, and plasticizers	Natural variability limits reproducibility and dose control; conventional polymers enable precise drug flux regulation
Skin Permeation Mechanism	Diffusion through natural cellulose networks and hydrophilic domains	Engineered diffusion pathways and controlled polymer matrices	Lack of structural uniformity in banana-based films complicates permeation modeling
Antimicrobial Efficacy	Intrinsic antimicrobial activity due to phytochemicals (polyphenols, flavonoids, tannins)	Generally absent; requires incorporation of antimicrobial agents	Advantage for banana-leaf materials in reducing microbial contamination, but activity is non-standardized
Spectrum of Activity	Broad but inconsistent; influenced by phytochemical content	Customizable and targeted depending on added agents	Conventional systems allow reproducible antimicrobial performance
Mechanical Strength	Low to moderate tensile strength; prone to brittleness without modification	High tensile strength and elasticity, optimized for skin application	Mechanical reinforcement or blending is essential for banana-based materials
Flexibility and Conformability	Limited; improved only with plasticizers or polymer blending	Excellent skin conformability and adhesion	Reduced patient comfort and durability in unmodified banana-based patches
Moisture Sensitivity	High hydrophilicity leads to swelling and stability concerns	Moisture resistance can be tailored	Stability issues may shorten shelf life of banana-based patches
Biocompatibility	Generally good; plant-derived and biodegradable	Excellent; clinically validated	Banana-based materials require comprehensive toxicological evaluation
Batch-to-Batch Consistency	Poor; affected by cultivar, season, and processing	High consistency and reproducibility	Major regulatory and manufacturing barrier for banana-based TDDS
Sustainability	Renewable, biodegradable, eco-friendly	Mostly synthetic, limited biodegradability	Key advantage supporting green pharmaceutical development
Key Limitations	Variability, mechanical weakness, permeation unpredictability, lack of clinical data	Environmental burden, need for antimicrobial additives	Banana-leaf materials are promising but remain at an exploratory stage
Overall Suitability for TDDS	Emerging and experimental	Established and industry standard	Translation requires standardization, optimization, and clinical validation

Additionally, valuable biopolymers like cellulose and nanocellulose may be produced from banana cultivation wastes and waste products, making banana leaves a great raw material for environmentally friendly and sustainable herbal patch compositions.[15] Inherent Therapeutic and Antimicrobial efficacy: The phytochemical components of banana leaves, such as flavonoids, tannins, saponins, alkaloids, phenols, terpenoids, and anthraquinones, provide intrinsic therapeutic efficacy in addition to structural and financial advantages. These substances have important biological functions, including antibacterial and antioxidant properties.[16]

Antimicrobial qualities are essential for wound care since patches need to prevent contamination. Studies verify that extracts from banana leaves are susceptible to important pathogenic microorganisms commonly linked to wound infections, such as the bacterium S. aureus and the fungus Candida albicans. Additionally, by scavenging reactive oxygen species (ROS), the natural antioxidant activity aids in regulating the healing process. Banana leaf extracts' capacity to offer both an appropriate physical platform and active therapeutic chemicals clearly justifies their development into innovative TDDS, providing a highly efficient, inexpensive, and multipurpose drug delivery method with integrated antimicrobial defense.[17]

3. Physiochemical and Biopolymer Properties of Banana Leaves

Banana leaves (Musa paradisiaca) are physically and chemically appropriate candidates for integration into transdermal drug delivery systems (TDDS) due to their natural qualities. Physically, the leaves have a huge surface area and a cool, smooth, waxy surface. Their non- adherent nature, which causes less discomfort and trauma during dressing changes when compared to conventional petroleum jelly gauze, is a crucial feature supporting their medicinal applicability. According to research, autoclaving at 121^0C for 15 minutes is the essential and efficient way to fully sterilize leaves before using them while maintaining their advantageous qualities.[18]

Banana plants are an important source of natural biopolymers in terms of composition. Important components, particularly cellulose and nanocellulose (NC), can be obtained from banana farming residues and waste products. The most economically significant biopolymer derived from plant biomass is cellulose. Banana waste-derived nanocellulose has potential for high-value biomedical uses, such as medication delivery and wound healing.

Additionally, the presence of many secondary metabolites is confirmed by phytochemical screening of methanolic extracts from banana leaves. Saponins, alkaloids, flavonoids, phenols, tannins, terpenoids, and anthraquinones are among them.

These phytochemicals have important therapeutic effects; for example, tannins have antibacterial and antioxidant properties related to wound care, and saponins are associated with collagen formation. The use of banana leaves as a sustainable, multipurpose matrix for transdermal patches is justified by their superior physical structure and inherent bioactive components.[19]

4. Processing and Modification Techniques for Banana Leaves in Transdermal Drug Delivery Systems (TDDS):

To ensure asepsis, improve durability, and maximize drug compatibility, a number of pre- processing and modification approaches are required for the successful integration of banana leaves (Musa paradisiaca) into contemporary Transdermal Drug Delivery Systems (TDDS).[20]

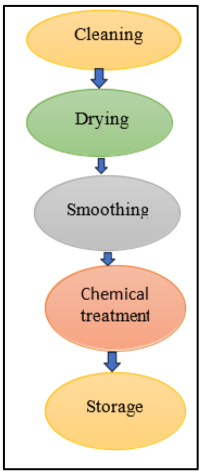

Fig.no.5. Steps of Process

4.1. Cleaning, Drying, And Sterilization:

For medical use, the raw biomaterial must first be prepared. To get rid of dust, grime, and any pesticides, freshly picked banana leaves need to be properly cleaned with soap or detergent. Importantly, it is known that untreated leaves are highly polluted with pathogenic flora, such as molds and aerobic spore-forming bacilli. The best method for attaining asepsis is steam sterilization, or autoclaving, which completely inactivates mesophilic bacteria without sacrificing the leaf's advantageous qualities. The gathered leaves must first be dried in the shade before being ground into a fine powder for extraction.[21]

4.2. Enhancing Durability and Structural Modification:

Along the venation, the native banana leaf structure is prone to tearing. Heating the leaf using various techniques, such as exposure to a flame or boiling water, is one of the traditional procedures used to improve durability and suppleness.

For making patches from extracted biopolymers, chemical modification methods are applied.[22] Banana trash is a rich source of biopolymers like cellulose. Alkalization (with NaOH, for example) and acid hydrolysis are common methods used to extract these components. These chemical treatments are vital for preparing sustainable base materials and can significantly enhance mechanical characteristics, such as improving the tensile strength (TS) of the resultant fibers or films.[23]

4.3. Drug Compatibility and Formulation Techniques:

The Solvent Casting Method is the most widely used technique for creating thin, consistent transdermal patches from plant extracts. This entails dissolving different polymers and the extracted herbal active in an appropriate solvent solution (e.g., ethanol, chloroform, or mixes thereof).[24]

Plasticizers like glycerin or propylene glycol are added to the final polymer film to increase its flexibility and reduce brittleness, hence enhancing its folding endurance. Additionally, permeation enhancers like Tween 80 are usually added to the formulation mixture to improve the penetration of the active chemicals through the skin's barrier. Compatibility is also influenced by the choice of solvent system as it has an impact on drug solubilization and polymer dissolution, both of which are essential for obtaining film homogeneity.[25]

5. The integration of Banana leaves (Musaparadisiaca):

As a structural component in traditional transdermal patch design is currently unreported in the sources; instead, their utilization is mostly limited to typical alternative wound dressing materials. The leaf's smooth, waxy surface is highlighted as a potential natural backing layer. Importantly, the leaf is fully non-adherent to the skin in wound care applications, reducing pain and stress during removal. Because typical methods require an adhesive coating to provide prolonged adherence to the skin, its non-adherent nature predicts poor compatibility with adhesives needed for transdermal patches. The banana leaf needs a tiny piece of gauze and tissue plaster to keep it in place when used as a dressing.

The therapeutic qualities of banana leaf extracts, which contain phytochemicals with antioxidant and antibacterial activity such flavonoids and saponins, are the subject of current research regarding the impact on drug penetration. It is known that these substances are absorbed by the surface skin tissues to promote the healing of wounds. Nevertheless, information assessing the impact of intact leaf material on the regulated penetration rate or kinetics of a pharmaceutical drug across the epidermal barrier is absent from the sources cited.[26]

6. Phytochemical Profile: -

The existence of various important secondary metabolites that have therapeutic actions is confirmed by the phytochemical profile of *Musaparadisiaca* leaves.[27]High concentrations of flavonoids, tannins, and phenols (polyphenols) were consistently found in methanolic banana leaf extracts after qualitative screening. The antibacterial and wound-healing properties of the leaves are supported by these components.[28]

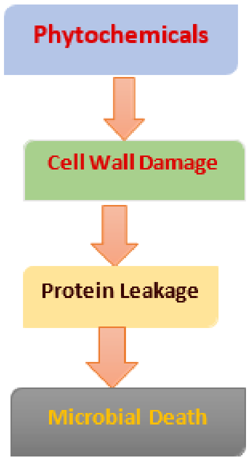

Fig.no.6. Antimicrobial Mechanism

These bioactive substances, which work to modify healing processes, including combating infection and oxidative stress, are intrinsically linked to the antibacterial action of banana leaf extracts. In particular, tannins give the extracts antioxidant and antibacterial properties. Similar to this, flavonoids are well known for their strong antioxidant qualities and inherent antibacterial activity. Extracts show encouraging effectiveness against common wound pathogens, such as Staphylococcus aureus, Candida albinos, and C. neoformans, according to research. Phytochemicals work in concert to speed up the healing process, in part by accelerating the inflammatory stage of wound healing.[29]

7. Advantages and Applications:

Particularly in low-clinic environments, banana leaves and their derivatives provide a year-round, economical, and environmentally beneficial resource.[30]The non-toxic and biocompatible qualities of banana fiber and its derived biopolymers meet the increasing demand for environmentally friendly and sustainable healthcare products. They also promote a circular bioeconomy because they are fully recyclable and biodegradable. However, the high moisture content and inherent heterogeneity of the source material restrict the commercial scaling of banana waste valorization. The extremely alkaline effluent from current extraction procedures creates environmental issues because they frequently need substantial energy consumption and chemical solvents. This promotes the development of sustainable polymer synthesis and nanocellulose for use in the future.[31]

8. Conclusion:

Due to their bioactive phytochemicals, banana leaves (Musa paradisiaca) offer better pain relief than traditional gauze and are a safe, economical, and efficient alternative wound dressing. Despite these benefits, there are a number of significant obstacles that restrict practical translation, such as inconsistent phytochemical composition, a lack of standardized processing and sterilization techniques, poor mechanical durability, and a lack of extensive clinical and toxicological data.

Standardization of extraction and fabrication procedures, optimization of waste-derived nanocellulose synthesis for reliable performance, and thorough in vivo and clinical testing to confirm safety and effectiveness should be the top priorities for future study. Transforming banana-leaf-based dressings into sustainable, clinically approved wound-care products also requires scalable production, long-term stability studies, and regulatory-aligned quality control.

9. Acknowledgement:

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