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# Herbal Betel Leaf (Piper Betle L.) Gel: A Comprehensive Review of Phytochemistry, Pharmacological Activities, Formulation and Evaluation

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**Abstract:** *Piper betel L., commonly known as Paan, belongs to the Piperocaine family. It contains important phytochemicals such as polyphenols, flavonoids, alkaloids and essential oils. Betel leaves possess antioxidant, antimicrobial, antifungal and anti-inflammatory properties. These medicinal properties make them useful for developing herbal products. This review focuses on the potential use of Betel Leaf extract in herbal gel formulation, its wound-healing potential and evaluation parameters such as pH, viscosity, spreadability and stability. Further studies are required to confirm its safety and effectiveness.*

**Keywords:** Piper betel, Betel Leaf, Herbal Gel, Phytochemicals, Antioxidant, Wound Healing

## I. INTRODUCTION

Piper betel L., commonly known as betel leaf or Paan, belongs to the family Piperaceae. It is a perennial climbing plant widely cultivated in India and other Asian countries. The leaves have been traditionally used for medicinal purposes, including wound care, cuts, boils, bruises, digestion and mouth freshness [1–3].

Betel leaves contain several bioactive compounds, including polyphenols, phenylpropanoids and volatile oil constituents. These constituents have been investigated for potential antibacterial, antifungal, antioxidant and anti-inflammatory activities [1–6,8,9].

Wound healing is a natural process of repairing damaged tissues. It involves four stages: hemostasis, inflammation, proliferation and remodeling. These stages help stop bleeding, remove damaged tissues, form new skin and restore tissue strength. However, infection, diabetes, oxidative stress and poor nutrition may delay wound healing.

Due to its traditional uses and reported biological properties, Piper betel has gained attention in herbal pharmaceutical formulations. Therefore, the present study focuses on formulating a herbal betel leaf gel and evaluating its antimicrobial, antifungal and potential wound-healing properties.

## II. OBJECTIVES

- To summarize the botanical and phytochemical characteristics of Piper betle L.
- To review reported antioxidant, antibacterial and antifungal activities of betel-leaf extracts and constituents.
- To describe extraction and characterization approaches relevant to topical formulation research.
- To discuss the principles and excipient functions involved in developing a betel-leaf gel.
- To outline quality evaluation, stability and skin-safety considerations.
- To identify research gaps and future opportunities for standardized topical formulations.

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## III BOTANICAL PROFILE OF PIPER BETLE

### 3.1 Taxonomy and nomenclature

The accepted botanical name used in the literature is Piper betle L. It belongs to the family Piperaceae and is commonly known as betel vine or betel leaf. The leaf is the plant part most frequently discussed in relation to traditional use and phytochemical research [1–3].

### 3.2 Morphological features

Piper betle is a perennial climbing vine. The leaves are generally simple, alternate, glossy and heart-shaped, with a characteristic aroma. Leaf size, colour, aroma and chemical profile can differ among cultivars. Correct botanical identification and documentation of the source plant are essential for research reproducibility.

### 3.3 Distribution and cultivation

The plant is cultivated in India and several other tropical and subtropical Asian countries. Different regional cultivars are recognized. Environmental conditions, cultivation practices and post-harvest handling may influence the chemical composition of the leaves. A formulation study should therefore record the plant source, collection location, collection date, cultivar where known and authentication details.

### 3.4 Plant authentication and quality

Plant material should be authenticated by a qualified botanist or pharmacognosist, and a voucher specimen should be retained where facilities permit. Leaves should be inspected for contamination, damage and fungal growth. Drying and storage conditions should be documented because heat, light, moisture and oxygen may affect volatile and phenolic constituents.

## IV. PHYTOCHEMICAL CONSTITUENTS

The phytochemical composition of P. betle is complex. Reviews describe polyphenols, phenylpropanoids, terpenes and volatile oil constituents in different leaf extracts and essential oils [1–3]. The profile depends on cultivar and analytical method; no single constituent list or concentration should be assumed to apply to every sample.

| Constituent/group | Examples reported in literature | Research relevance |
|---|---|---|
| Phenolic compounds | Hydroxychavicol and related phenolics | Investigated for antioxidant and antimicrobial properties. |
| Phenylpropanoids | Chavicol, chavibetol, eugenol and related compounds | Contribute to aroma and may contribute to observed biological activity. |
| Flavonoids | Different flavonoid compounds reported in plant extracts | Commonly investigated for antioxidant activity. |
| Tannins and other polyphenols | Polyphenolic constituents | May contribute to astringent and antioxidant characteristics. |
| Terpenes/volatile constituents | Various mono- and sesquiterpenes reported in essential oils | Contribute to volatile profile and may influence biological activity. |

### 4.1 Phenolic compounds

Phenolic compounds are a broad group of plant secondary metabolites. Hydroxychavicol is frequently discussed in betel-leaf literature. Its presence and amount can vary with the sample and extraction procedure. Analytical confirmation is preferable to relying only on general phytochemical screening.

### 4.2 Volatile constituents and essential oil

Betel leaves contain volatile aromatic constituents. Essential oil composition can be investigated by techniques such as gas chromatography coupled with mass spectrometry (GC–MS). Hydrodistillation and steam distillation are among the

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methods used to obtain volatile fractions. Essential oil and solvent extracts are different materials and should not be treated as interchangeable.

### 4.3 Flavonoids, tannins and other constituents

Flavonoids and tannins are often reported in phytochemical studies of medicinal plants. Preliminary colour tests can indicate broad classes of constituents but are not sufficient to identify individual molecules. More specific analytical methods, such as HPLC or LC–MS, can provide stronger evidence for identity and quantity.

## V. REPORTED PHARMACOLOGICAL ACTIVITIES

### 5.1 Antioxidant activity

Different betel-leaf extracts and their constituents have been investigated using in-vitro antioxidant assays and, in some studies, animal models [4–8]. Such tests estimate the ability of an extract to react with selected radicals or participate in defined redox reactions. Results depend on the assay, solvent, concentration and extract composition. An in-vitro or animal antioxidant result does not automatically demonstrate a clinical benefit when the extract is applied to skin.

### 5.2 Antibacterial activity

Published studies and reviews report antibacterial activity for selected P. betle extracts or essential-oil preparations against some bacterial strains [2,3]. The observed effect may vary with the bacterial species, strain, plant variety, extraction solvent, test concentration and laboratory method. The activity of a crude extract should not be assumed to be the same as the activity of a finished gel, because the gel base may affect release and diffusion.

### 5.3 Antifungal activity

Antifungal properties have also been investigated for betel-leaf extracts and volatile constituents [2]. Findings from laboratory testing are preliminary evidence and do not establish that a topical gel can prevent or treat fungal disease in humans. Any claim about an antifungal product would require appropriate formulation-specific testing and, where relevant, clinical evidence.

### 5.4 Anti-inflammatory potential

Some betel-leaf constituents and extracts have been investigated in cell-based and animal experimental models related to inflammation [5,5,9]. The strength and relevance of this evidence depend on the model and preparation tested. It is important to distinguish preclinical observations from demonstrated effects in people.

5.5 Summary and limitations of pharmacological evidence

Overall, the literature supports continued investigation of betel-leaf phytochemicals. However, plant-extract studies are heterogeneous and cannot be used as direct proof of efficacy for a particular topical gel. Standardized extracts, appropriate controls, reproducible methods and formulation-specific studies are needed.

## VI. EXTRACTION AND CHARACTERIZATION

### 6.1 Preparation of plant material

Research begins with authenticated, healthy leaves. The collection details and condition of the material should be recorded. Washing, drying, size reduction and storage should be carried out under controlled, documented conditions appropriate to the target constituents. Excessive heat or prolonged exposure to light may affect sensitive compounds.

### 6.2 Extraction approaches

Maceration, Soxhlet extraction, ultrasound-assisted extraction and other solvent-based approaches may be used for non-volatile constituents. Hydrodistillation or steam distillation may be used when the objective is to obtain volatile oil. Each method has advantages and limitations related to solvent use, temperature, time, yield and chemical selectivity [1]. The selected method should match the research objective.

### 6.3 Solvent selection

Water, ethanol and hydroalcoholic mixtures are commonly considered in plant extraction research. Solvent selection depends on the polarity and stability of the target compounds, intended application, safety and ability to remove residual

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solvent. Methanol may be useful in analytical research but is generally not an appropriate residual solvent for a product intended for direct skin application.

### 6.4 Extract characterization

Useful characterization measures may include extract appearance, percentage yield, moisture content where relevant, preliminary phytochemical screening, total phenolic content and chromatographic fingerprinting. A marker compound may be selected when scientifically justified. Reporting the extraction ratio, solvent, method and yield improves reproducibility.

### 6.5 Standardization

Standardization aims to reduce batch-to-batch variation. It may include botanical authentication, defined extraction conditions, a chromatographic fingerprint and limits for relevant quality attributes. A standardized extract is a stronger starting material for formulation development than an extract described only by colour or yield.

## VII. TOPICAL GEL FORMULATION

### 7.1 Definition and characteristics

A gel is a semisolid system in which a liquid phase is immobilized within a three-dimensional network. Topical gels are designed to spread over the application site and remain sufficiently consistent during use. Their properties depend on the polymer, solvent system, pH, extract and other excipients.

### 7.2 Possible excipient categories

| Excipient category | Examples | Main function |
|---|---|---|
| Gelling polymer | Carbomer/carbopol or another suitable polymer | Provides structure and viscosity. |
| Humectant | Glycerin | Helps retain moisture and may improve feel. |
| Cosolvent | Propylene glycol, where appropriate | May aid solubilization of selected ingredients. |
| Preservative | A suitable approved preservative system | Controls microbial growth in the aqueous product. |
| pH adjuster/neutralizer | A suitable neutralizing agent | Adjusts pH and may support polymer thickening. |
| Vehicle | Purified water or a justified vehicle | Forms the continuous liquid phase. |

### 7.3 Selection of gelling agent

The polymer should be selected according to compatibility with the extract, target viscosity, pH range, desired sensory properties and stability. Carbomer polymers are commonly used in topical gels, but the most appropriate polymer must be established experimentally. Natural polymers and cellulose derivatives may also be considered.

### 7.4 Compatibility considerations

Plant extracts may contain electrolytes, acids, bases, pigments and volatile constituents that influence polymer hydration, viscosity, colour or odour. Compatibility should be assessed before finalizing the formulation. Preservative effectiveness should be demonstrated for the finished product rather than assumed from the presence of a preservative.

### 7.5 Formulation development strategy

A formulation-development programme should define the intended product, select a characterized extract, screen compatible excipients, prepare trial batches using an approved laboratory protocol, and evaluate the resulting gels. The

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final composition should be selected using predefined quality criteria. This review does not provide a validated formula or claim that a particular composition has been experimentally optimized.

## VIII. EVALUATION OF HERBAL GEL

| Parameter | Purpose/what is assessed |
|---|---|
| Appearance and odour | Colour, clarity/opacity, visible changes and characteristic odour. |
| Homogeneity | Uniformity and absence of visible lumps or foreign particles. |
| pH | Acidity/alkalinity and suitability for the intended skin application. |
| Viscosity/rheology | Flow behaviour, consistency and changes under defined conditions. |
| Spreadability | Ease and uniformity of spreading. |
| Extrudability | Ease of dispensing from the intended container, if applicable. |
| Content/marker assay | Amount or consistency of a selected marker constituent, where a validated method exists. |
| Microbial quality | Microbial limits and, where applicable, preservative effectiveness. |
| Stability | Changes in physical, chemical and microbiological quality during storage. |
| Skin compatibility | Safety assessment using appropriate validated and ethically approved methods. |

### 8.1 Physical appearance and homogeneity

The formulation should be visually examined for colour, odour, consistency, phase separation and visible particles. Homogeneity is important for dose uniformity and user acceptability. Observations should be recorded using consistent conditions and preferably photographs.

### 8.2 pH and rheological properties

The pH should be measured using a calibrated instrument and a defined sample preparation method. Viscosity should be measured using a suitable viscometer or rheometer with the spindle, speed, temperature and sample conditions reported. Since gels may be non-Newtonian, a single viscosity value may not fully describe their flow behaviour.

### 8.3 Spreadability and extrudability

Spreadability and extrudability are performance-related properties. Methods should be selected in advance and applied consistently across batches. The intended packaging should be considered because container design can influence dispensing.

### 8.4 Microbiological evaluation

A water-containing topical product may support microbial growth if it is inadequately preserved or manufactured. Microbial quality testing and preservative effectiveness assessment should follow applicable pharmacopeial or regulatory guidance. Antimicrobial activity against a test organism is not a substitute for preservative efficacy testing.

### 8.5 Stability studies

Stability studies should evaluate the product in its proposed packaging under justified storage conditions. Relevant attributes may include appearance, odour, pH, viscosity, marker content, phase separation and microbiological quality. Study design, time points and acceptance criteria should be defined before testing.

### 8.6 Skin safety

Skin compatibility is a key requirement for topical products. The assessment should use appropriate validated methods and ethical oversight. Potential irritation or sensitization should not be dismissed because an ingredient is plant-derived. Human testing should only be conducted under appropriate institutional and ethical approval.

## IX. POTENTIAL APPLICATIONS

A betel-leaf gel may be explored as a research prototype for topical cosmetic or pharmaceutical applications. Potential areas of investigation include the delivery of characterized plant constituents to the skin surface and evaluation of formulation properties. Any specific antimicrobial, antifungal, wound-healing or therapeutic claim requires direct

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evidence from the finished formulation and appropriate safety and efficacy studies. The current literature should not be interpreted as a recommendation to use an experimental gel to treat a medical condition.

## X. SAFETY AND TOXICOLOGICAL CONSIDERATIONS

The safety profile of a topical product depends on the complete formulation, not solely on the plant name. Relevant considerations include plant identity, extract composition, concentration, residual solvent, impurities, microbial quality, preservative system, packaging and exposure conditions. Individual constituents may have different safety profiles, and the possibility of irritation or allergic contact reactions should be considered.

The literature on P. betle includes discussion of safety and toxicity [2,7], but findings from oral use, isolated compounds, essential oils or non-topical experimental models cannot be directly transferred to a finished skin gel. A formulation-specific safety programme is required before human use or commercial claims.

## XI. RESEARCH GAPS AND FUTURE SCOPE

- Establish authenticated plant sources and consistent extract specifications.
- Develop validated analytical methods for selected marker constituents.
- Compare extraction methods using yield and chemical-profile data.
- Assess compatibility between the extract and candidate gelling polymers.
- Optimize the formulation using predefined quality attributes and suitable experimental design.
- Evaluate release or skin-delivery characteristics when relevant to the intended product.
- Conduct formulation-specific antimicrobial testing with suitable controls.
- Establish microbial quality, preservative effectiveness and stability.
- Assess skin irritation and sensitization using appropriate validated approaches.
- Undertake further preclinical or clinical studies only when justified by the preceding evidence.

## XII. DISCUSSION

The available literature identifies P. betle as a chemically diverse medicinal plant with several reported biological activities [1–3]. The strongest rationale for investigating it in a topical gel is the combination of an established history of traditional use, identifiable phytochemical constituents and laboratory reports of biological activity. However, a rational formulation project must avoid overstatement. Results obtained from a leaf extract, essential oil or isolated molecule are not equivalent to results obtained from a finished gel.

A key development challenge is extract variability. A reproducible formulation requires botanical authentication and chemical characterization. Another challenge is the interaction between the extract and the gel base. Changes in pH, viscosity, colour or odour may occur, and these must be measured rather than assumed. The finished product also needs suitable microbiological controls and stability data.

For a student project, a clearly defined objective may be to formulate and evaluate a topical gel containing a characterized P. betle leaf extract and to assess selected physicochemical quality attributes. Antimicrobial testing, if undertaken, should be described as an in-vitro investigation and should include appropriate controls. Conclusions should be limited to the tests actually performed.

## XIII. CONCLUSION

Piper betle L. is a medicinal plant of the family Piperaceae containing a range of phenolic and volatile phytochemicals. Published reviews describe antioxidant, antibacterial and antifungal activities for selected extracts and constituents. These findings provide a scientific basis for further investigation of betel-leaf extracts in topical formulation research.

A gel is a practical semisolid dosage form that can be developed using suitable polymers and excipients. Nevertheless, successful development of a betel-leaf gel requires authenticated plant material, standardized extract, excipient

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compatibility, appropriate formulation evaluation, microbial quality, stability and skin-safety assessment. Evidence for the plant should not be presented as proof of clinical effectiveness of the finished gel. Further systematic research is needed to determine its suitability for any specific topical application.

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