Exploring the Therapeutic Potential of *Aegle marmelos* and *Piper betle* Leaf: A Comprehensive Review

Dhruti Mehta*[1], Dr Udichi Kataria[1]

Geetanjali Institute of Pharmacy, Geetanjali University, Udaipur 313001, Rajasthan, India

***Corresponding Author**: Department of Pharmaceutics, Geetanjali Institute of Pharmacy, Geetanjali University, Udaipur 313001, Rajasthan, India*
***Email address:** dhruti.bhatt008@gmail.com , udichikataria@gmail.com*

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ABSTRACT:
Aegle marmelos (Bael) and *Piper betle* (Betel leaf) are two prominent plants with significant cultural and medicinal value in traditional systems of medicine. This review explores their pharmacological properties, therapeutic potential, and applications in modern pharmaceutical science. *Aegle marmelos* is known for its wide range of bioactive compounds, including alkaloids, flavonoids, and tannins, which contribute to its anti-inflammatory, antimicrobial, antioxidant, and antidiabetic effects. Recent studies have highlighted its role in supporting digestive health, managing blood sugar levels, and alleviating symptoms of various gastrointestinal disorders. *Piper betle* leaf, a staple in Ayurvedic and traditional medicine, is also rich in essential oils, alkaloids, flavonoids, and phenolic compounds. Its therapeutic applications are diverse, ranging from antimicrobial and anticancer properties to promoting oral health and improving respiratory function. Betel leaf's active constituents have shown promise in combating infections, reducing oxidative stress, and potentially preventing cancer. This review consolidates current research on the therapeutic benefits of *Aegle marmelos* and *Piper betle*, examining their mechanisms of action and potential as complementary treatments in modern pharmacology. Furthermore, it discusses the safety, bioavailability, and challenges associated with the integration of these plants into pharmaceutical formulations. Given their rich phytochemical profiles and proven therapeutic activities, both *Aegle marmelos* and *Piper betle* present exciting opportunities for the development of novel therapeutic agents. This review aims to provide a comprehensive understanding of their pharmacological potential and encourage further investigation into their applications in contemporary medicine.

INTRODUCTION

Aegle marmelos (commonly known as Bael) and *Piper betle* (betel leaf) have been integral components of traditional medicine for centuries, particularly in South Asia and Southeast Asia. These plants are widely recognized not only for their cultural significance but also for their therapeutic properties, which have been extensively utilized in Ayurvedic, Unani, and traditional Chinese medicine[(1)]. As the global focus on natural products and alternative therapies increases, the pharmacological potential of these plants has gained renewed attention in the pharmaceutical industry. This review aims to explore the therapeutic potential of *Aegle marmelos* and *Piper betle* leaf, shedding light on their bioactive compounds, medicinal properties, and the promising role they can play in modern pharmaceutical research[(3)].

Aegle marmelos, commonly known as Bael, is a fruit-bearing tree native to the Indian subcontinent. It has long been used in traditional medicine for a variety of ailments, ranging from gastrointestinal disturbances to fever management. The plant is rich in bioactive compounds, including alkaloids, flavonoids, terpenoids, and tannins, which contribute to its antioxidant, antimicrobial, anti-inflammatory, and antidiabetic activities. Modern research has confirmed its effectiveness in managing metabolic disorders, improving digestive health, and even showing potential in cancer prevention. Bael has also demonstrated significant therapeutic effects in treating various infections, dysentery, and diarrhea, making it an important candidate for pharmaceutical development[(1,2)].

Piper betle, on the other hand, is a tropical vine known for its leaves, which have been used in traditional medicine for centuries. The leaves contain essential oils, alkaloids (such as chavicine), flavonoids, and phenolic compounds, all of which exhibit potent antimicrobial, antioxidant, and anti-inflammatory activities. Betel leaf has been traditionally used to treat a variety of health issues, including respiratory disorders, oral infections, digestive problems, and even as a stimulant for mental clarity. Additionally, recent studies have suggested its anticancer, hepatoprotective, and antidiabetic effects, indicating its potential as a therapeutic agent for various chronic conditions[(2)].
Both plants have demonstrated a wide range of biological activities, supported by emerging scientific evidence. As natural sources of therapeutic agents, *Aegle marmelos* and *Piper betle* offer promising avenues for the development of new pharmaceutical formulations. However, despite their vast potential, the mechanisms of action of many of these bioactive compounds remain poorly understood, and further research is necessary to fully harness their capabilities. This review will explore the available scientific literature on these plants, focusing on their pharmacological properties, mechanisms of action, and potential therapeutic applications in contemporary medicine[(3)].

Some of the examples of well-known traditional medicinal systems include:

1. **Ayurveda:** Originating in India, Ayurveda is a holistic system of medicine that emphasizes balance in the body's doshas (energies) and uses herbs, diet, and lifestyle practices for healing.
2. **Traditional Chinese Medicine (TCM):** TCM, rooted in ancient China, includes acupuncture, herbal medicine, cupping therapy, and practices like tai chi and qigong.
3. **Indigenous Healing Practices:** Indig.enous communities worldwide have their own unique healing traditions, which often involve a deep connection with nature and the spiritual world.
4. **Herbalism:** Herbal medicine is a common component of many traditional medicinal systems, utilizing the medicinal properties of plants for various ailments.

These traditional medicinal systems continue to be important sources of healthcare and cultural identity for many communities around the world, and they contribute to our understanding of holistic approaches to well-being[(2,3)].
Using plant sources in formulating pharmaceutical medicines offers several benefits Plant-derived medicines are sourced from nature, which can be appealing to individuals seeking more natural and holistic treatment options. Many people prefer plant-based remedies due to concerns about synthetic chemicals. Plants contain a wide range of bioactive compounds with potential therapeutic benefits. These compounds can target specific biological pathways and provide therapeutic effects. These compounds can target specific biological pathways and provide therapeutic effects. Traditional medicine systems in various cultures have long relied on plant-based remedies[(3)].
Utilizing this traditional knowledge can lead to the discovery of new pharmaceutical compounds and treatment options. Plant-derived medicines often have fewer side effects compared to synthetic pharmaceuticals. This can be especially advantageous when treating chronic conditions or when seeking alternatives to medications with significant side effects. Plants offer a vast diversity of chemical compounds, allowing for the development of medicines targeting a wide range of conditions. This diversity can lead to the discovery of novel drug candidates[(1)].
Many pharmaceutical plants can be grown and harvested sustainably, reducing the environmental impact of drug production. Sustainable practices can also support local communities and biodiversity conservation. In regions where traditional herbal medicine is widely accepted, plant-based pharmaceuticals may be more culturally accepted and accessible to patients. Plants can serve as sources for multiple compounds, allowing for the

development of combination therapies that target multiple aspects of a disease simultaneously. The study of plant-based medicines continues to drive research and innovation in pharmaceuticals. This research may lead to the development of new drugs and treatment approaches. In many countries, there are regulatory frameworks for the approval of herbal medicines, ensuring their safety and efficacy. This allows for the integration of plant-based medicines into mainstream healthcare[2].

Plants have long played a significant role in hair growth stimulating, offering a natural and holistic approach to managing hair loss. Their rich phytochemical composition provides a myriad of therapeutic effects that target various underlying causes of hair loss, making them valuable allies in promoting hair growth and maintaining scalp health.

Many plants contain bioactive compounds such as polyphenols, flavonoids, vitamins, and essential oils, which exhibit antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial properties. These properties are crucial in addressing the multifactorial nature of hair growth, including oxidative stress, inflammation, hormonal imbalances, and microbial infections. Plants like Aloe vera, Ginseng, Saw palmetto, Rosemary are just a few examples of botanicals that have been extensively studied for their efficacy in promoting hair growth and preventing hair loss. These plants work by stimulating hair follicle proliferation, prolonging the anagen phase of the hair cycle, inhibiting the activity of enzymes involved in hormone metabolism, and maintaining a healthy scalp environment. In addition to their therapeutic effects, plant-based treatments for alopecia offer several advantages, including fewer side effects, lower cost, and cultural acceptance in traditional medicine systems worldwide. As our understanding of the pharmacological properties of plants continues to deepen, harnessing their therapeutic potential for alopecia holds promise for developing safe, effective, and sustainable treatment options for individuals experiencing hair loss[3].

Triterpenoids, a class of organic compounds derived from plants, have emerged as promising agents in the hair growth promoting due to their diverse pharmacological activities. These bioactive compounds exhibit anti-inflammatory, antioxidant, immunomodulatory, and anti-androgenic properties, making them valuable in addressing the underlying mechanisms involved in hair loss. One of the primary causes of hair loss is inflammation, which can disrupt the hair growth cycle and lead to follicle miniaturization. Triterpenoids exert anti-inflammatory effects by inhibiting pro-inflammatory cytokines and enzymes, thereby reducing inflammation within the scalp and promoting a conductive environment for hair follicle function and growth. Moreover, triterpenoids possess antioxidant properties that help mitigate oxidative stress, which is implicated in the excessive hair loss. By scavenging free radicals and enhancing cellular antioxidant defenses, triterpenoids protect hair follicles from oxidative damage and support their vitality. Furthermore, some triterpenoids exhibit immunomodulatory effects by modulating the activity of immune cells involved in autoimmune-mediated hair loss conditions. By regulating the immune response, these compounds help alleviate autoimmune-driven inflammation and promote hair regrowth[4].

Additionally, certain triterpenoids have been shown to inhibit the activity of 5-alpha reductase, an enzyme responsible for converting testosterone to dihydrotestosterone (DHT), a hormone associated with hair miniaturization. By blocking DHT production, triterpenoids help prevent follicular shrinkage and prolong the anagen phase of the hair cycle. Triterpenoids represent a promising avenue for hair loss treatment due to their multifaceted pharmacological effects, including anti-inflammatory, antioxidant, immunomodulatory, and anti-androgenic properties. Further research into specific triterpenoid compounds and their mechanisms of action may lead to the development of novel therapeutic interventions for individuals experiencing hair loss[4,5].

Several plants containing triterpenoids have shown promise in treatment of hair growth stimulating, offering natural and effective solutions for individuals experiencing hair loss.

These botanicals harness the therapeutic potential of triterpenoids, which exhibit anti-inflammatory, antioxidant, immunomodulatory, and anti-androgenic properties, addressing multiple underlying factors contributing to hair loss. Here are some plants rich in triterpenoids that have been studied for their efficacy in alopecia treatment:

1. **Ginseng** is renowned for its adaptogenic properties and contains various triterpenoid saponins called ginsenosides. These compounds have been shown to promote hair growth by stimulating hair follicle proliferation, prolonging the anagen phase of the hair cycle, and inhibiting 5-alpha reductase activity, thus reducing the conversion of testosterone to dihydrotestosterone (DHT).
2. **Gotu kola** is a herbaceous plant rich in triterpenoid compounds such as asiaticoside and madecassoside. These triterpenoids exhibit anti-inflammatory and antioxidant effects, which help alleviate scalp inflammation and oxidative stress, supporting optimal conditions for hair follicle function and growth.
3. **Licorice root** contains triterpenoid saponins known as glycyrrhizin, which possess anti-inflammatory properties. These compounds have been shown to inhibit 5-alpha reductase activity and modulate immune responses, making licorice a potential therapeutic agent for alopecia treatment, particularly in autoimmune-driven conditions.
4. **Ganoderma**, also known as reishi mushroom, contains triterpenoids called ganoderic acids, which exhibit anti-inflammatory and immunomodulatory effects. These compounds have been studied for their potential in mitigating autoimmune-mediated hair loss and promoting hair regrowth by modulating immune responses and reducing inflammation within the scalp[6].

Among these plants one such plant is *Aegle marmelos* combined with the therapeutic effects of *Piper betle*, which contains triterpenoids, which have gained attention for their potential role in the treatment of hair loss. Within *Aegle marmelos* and *Piper betle*, triterpenoids contribute to its medicinal properties, offering anti-inflammatory, antioxidant, immunomodulatory, and anti-androgenic effects that are pertinent to addressing the underlying mechanisms of excessive hair loss.

Triterpenoids present in both the plants exhibit anti-inflammatory properties, which are crucial for managing scalp inflammation. Inflammation disrupts the hair growth cycle and contributes to follicular damage, leading to hair loss. By reducing inflammation within the scalp, triterpenoids help create a conducive environment for hair follicle function and growth. Triterpenoids possess immunomodulatory effects, which are beneficial in autoimmune-mediated forms of alopecia such as alopecia areata. By modulating immune responses, triterpenoids help alleviate autoimmune-driven inflammation and promote hair regrowth in affected individuals[2,7].

Aegle marmelos and *Piper betle* containing triterpenoids present a promising botanical option for alopecia treatment, offering a natural and holistic approach to managing hair loss. Its diverse pharmacological properties, including anti-inflammatory, antioxidant, immunomodulatory, and anti-androgenic effects, make it a valuable ally in promoting scalp health and hair regrowth.

1. AEGLE MARMELOS

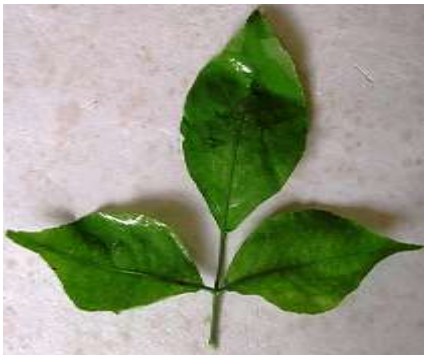


Figure 1: *Aegle marmelos* leaf

Aegle marmelos, commonly known as the bael tree or bael fruit tree, is a species of tree native to India and other parts of South Asia. It belongs to the family Rutaceae. It is a culturally and medicinally significant plant in many regions due to its various uses, particularly in traditional medicine. This tree holds cultural, religious, and medicinal significance in many parts of South Asia, particularly in India. It is a deciduous tree that can reach heights of up to 15 meters. The tree's distinctive features include compound leaves with an aromatic scent, thorny branches, and greenish-white flowers. *Aegle marmelos* produces a unique and woody fruit, often referred to as the "Bael fruit," which is one of its most well-known and utilized parts.[2]

The leaves of *Aegle marmelos* are compound, with 3 to 5 leaflets arranged alternately along the stem. Each leaflet is ovate or elliptical, with serrated margins, and measures 5 to 15 centimeters in length. The leaves are aromatic when crushed and have a pleasant fragrance. *Aegle marmelos* produces small, greenish-white flowers that are typically fragrant. The flowers are bisexual and are borne in clusters or panicles. The fruit of *Aegle marmelos* is one of its most distinctive features. The fruit is large, round, or slightly oblong, with a woody and hard rind that can be difficult to open. When ripe, the outer shell may turn yellow or grayish-green, and it can have a rough or smooth texture.[2,8]

Figure 2: *Aegle marmelos* fruit

Kingdom	Plantae
Sub kingdom	Tracheophytes
Super divison	Angiosperms
Division	Magnoliophyta
Class	Rosidae
Order	Sapindales
Family	Rutaceae
Genus	Aegle
Species	*Aegle marmelos*
Binomial name	*Aegle marmelos* (L.) Correa
Synonyms	*Belou marmelos* (L.) A. Lyons
	Crateva marmelos L.

Table 1: Scientific Classification of *Aegle marmelos*

1.1 Phytochemical Profile [8]

Aegle marmelos is known for its diverse array of phytochemicals, which contribute to its medicinal properties. These bioactive compounds are found in different parts of the plant, including the fruit, leaves, bark, and roots.

Flavonoids

Flavonoids are a group of plant compounds known for their antioxidant and anti-inflammatory properties. *Aegle marmelos* is rich in flavonoids such as imperatorin, aegelin, lupeol, and eugenol. These flavonoids contribute to the plant's therapeutic effects and may play a role in preventing oxidative damage and inflammation in the body.

Terpenoids

Terpenoids are another class of compounds present in *Aegle marmelos*. They have been found to have various biological activities, including antioxidant, antimicrobial, and anticancer effects. Some of the terpenoids identified in *Aegle marmelos* include cineol, citronellal, and lupeol.

Carotenoids

Carotenoids are pigments that give fruits and vegetables their vibrant colors. *Aegle marmelos* contains carotenoids such as beta-carotene, which is a precursor to vitamin A. These compounds have antioxidant properties and play a crucial role in maintaining eye health and supporting the immune system.

Coumarins

Coumarins are aromatic compounds that have been associated with various health benefits. *Aegle marmelos* contains coumarins such as aegeline, marmelin, and marmelosin. These compounds have been studied for their potential antidiabetic, antioxidant, and anti-inflammatory effects.

Other Bioactive Compounds

In addition to flavonoids, terpenoids, carotenoids, and coumarins, *Aegle marmelos* contains other bioactive compounds such as essential oils, tannins, and phlobatannins. These compounds contribute to the overall medicinal properties of the plant and are the subject of ongoing research.

1.2 Pharmacological profile [9]

The rich phytochemical composition of *Aegle marmelos* contributes to its potential health benefits. Numerous studies have explored the therapeutic effects of this medicinal plant, highlighting its antioxidant, anti-inflammatory, antimicrobial, and anticancer properties.

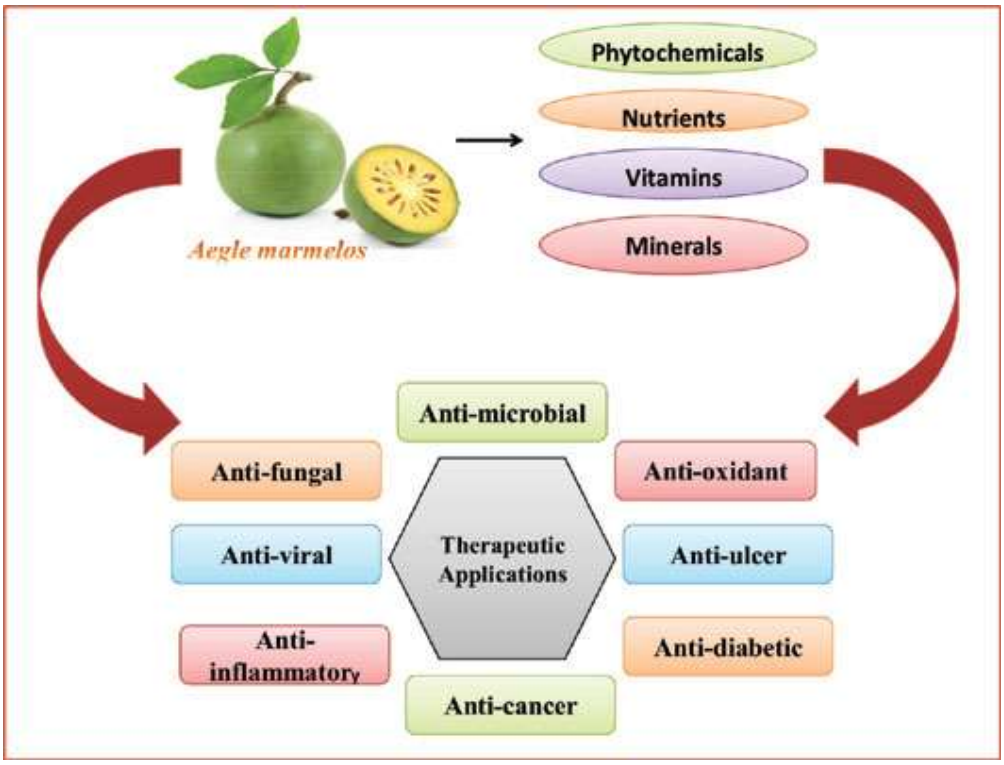


Figure 3: Therapeutic Applications of *Aegle marmelos* fruit

Anti-inflammatory and Analgesic Effects

Extracts from Aegle marmelos have demonstrated significant anti-inflammatory and analgesic properties in various animal models. These effects are attributed to the presence of bioactive compounds like flavonoids and alkaloids.

Antioxidant Activity

The plant has strong antioxidant properties due to its high content of phenolic compounds and flavonoids. These antioxidants help neutralize free radicals, which can reduce oxidative stress and prevent cellular damage.

Antimicrobial Activity

Aegle marmelos exhibits antimicrobial activity against a range of bacteria and fungi. This includes both gram-positive and gram-negative bacteria, as well as certain fungal species. This property supports its traditional use in treating infections.

Anti-diabetic Effects

Several studies suggest that Aegle marmelos can help in managing diabetes. Its extracts have shown the ability to lower blood glucose levels and improve insulin sensitivity, possibly through mechanisms involving the modulation of carbohydrate metabolism.

Gastroprotective Effects

The plant has been used traditionally for gastrointestinal issues. Pharmacological studies have indicated its potential to protect against gastric ulcers and enhance overall gastrointestinal health, possibly due to its antioxidant and anti-inflammatory actions.

Anticancer Activity

Preliminary research indicates that *Aegle marmelos* may have anticancer properties. Its extracts have shown potential in inhibiting the growth of various cancer cell lines, although more research is needed to fully understand these effects and their mechanisms.

Hepatoprotective Effects

Aegle marmelos has been studied for its liver-protective effects. It appears to safeguard the liver from damage caused by toxins and oxidative stress, which is beneficial for overall liver health.

Cardioprotective Effects

The plant may offer cardioprotective benefits through its antioxidant and anti-inflammatory actions, potentially reducing the risk of cardiovascular diseases.

Immune Modulatory Effects

Extracts from *Aegle marmelos* may modulate the immune system, enhancing its response and possibly providing protective effects against various diseases.

Antidepressant and Neuroprotective Effects

Some studies suggest that *Aegle marmelos* could have potential antidepressant and neuroprotective effects, potentially through its impact on neurotransmitter systems and reduction of oxidative stress in the brain.

Traditional Uses

In traditional medicine systems, *Aegle marmelos* is used for a variety of ailments including digestive disorders, respiratory infections, and fever. It is also valued for its potential benefits in enhancing general wellness.

Overall, while bael shows promise in various pharmacological areas, more clinical trials and studies are needed to establish its efficacy and safety for widespread therapeutic use.

Commercial Applications

The medicinal properties of *Aegle marmelos* have led to its exploration in various commercial applications. The plant and its extracts are utilized in the nutraceutical, cosmetic, and

pharmaceutical industries. *Aegle marmelos* is increasingly being used in the development of nutraceuticals and functional foods. Nutraceuticals are products derived from food sources that provide health benefits beyond basic nutrition. The bioactive compounds present in *Aegle marmelos* make it a valuable ingredient in the formulation of functional foods and dietary supplements. The antioxidant and anti-inflammatory properties of *Aegle marmelos* make it a potential ingredient in cosmetics and skincare products. The plant extracts may help protect the skin against oxidative damage, reduce inflammation, and promote overall skin health. The therapeutic properties of bael have attracted the attention of the pharmaceutical industry. The plant extracts are being studied for their potential use in the development of novel drugs for various health conditions, including cancer, diabetes, and gastrointestinal disorders.

2. PIPER BETLE

Figure 4: *Piper betle* leaf

The betel vine, scientifically known as *Piper betle* L., is a fascinating plant that holds great promise in various fields such as nutrition, pharmacology, and economics. With its magnificent green heart-shaped leaves, the betel vine, also known as Paan in India, belongs to the Piperaceae family. Cultivated in the coastal regions of Odisha, India, including Balasore, Jagatsinghpur, Puri, Khordha, and Ganjam, the betel vine is consumed by over 1 million people in the state. However, its high nutritional quality and numerous health benefits remain largely unrecognized.(7)

In this article, we will explore the nutritional, pharmacological, and economic potential of the betel vine. We will delve into its various properties, including its antimicrobial, antioxidant, and anti-inflammatory attributes. Additionally, we will discuss the economic significance of betel vine farming, which serves as a source of income for remote farmers. We will also touch upon the challenges faced in betel vine cultivation and the potential for the development of medicines derived from this remarkable plant.

The betel vine offers a myriad of nutritional benefits that often go unnoticed. Rich in essential nutrients, it is considered a superior natural reservoir of nutrition. The leaves of the betel vine contain a significant amount of vitamins, minerals, and dietary fibers. These nutrients contribute to overall well-being and play a vital role in maintaining a healthy diet. Piper species have been used in a variety of traditional medicine such as Traditional Chinese Medicine, Ayurvedic system and folklore medicine of Latin America and West Indies.

The plants of genus *Piper* are also used for many other purposes such as foods and spices, fish bait, fish poison, hallucinogens, insecticides, oils, ornaments, perfumes etc. It is an effective anti wormal agent because of its pungent taste. It is an excellent anti-infectious agent again because of its pungent taste. It helps in normalizing the digestive tract hence is very effective in maintaining the digestive system because of its light properties. It also helps in expelling out the mucus from the infusion prepared from the leaves and stems are supposed to be useful in treating indigestion, bronchitis, constipation, congestion, coughs and asthma. The leaf juice is given systemically to treat cough and indigestion in children.(10)

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Piperales
Family	Piperaceae
Genus	*Piper*
Species	*betle*

Table 2: Scientific Classification of *Piper betle*

2.1 Phytochemical Profile

The phytochemical constituents of *Piper betle* include compounds such as chavibetol, chavibetol acetate, caryophyllene, aristololactam A-II, 4-allyl resorcinol, stigmast-4-en-3,6-dione, 5-(2-propenyl)-1,3 benzodioxol, eugenol, and acetate-phenol. These compounds contribute to the various medicinal properties of betel leaf, including its carminative, aphrodisiac, tonic, laxative, and appetite-improving effect. Betel leaf also contains alkaloids, flavonoids, tannins, and saponins that contribute to its flavor and aroma. These bioactive substances, including polyphenols and terpenes, have antioxidant, anti-inflammatory, and antimicrobial properties, making betel leaf suitable for medicinal purposes.(11)

The *Piper betle* leaf has been described to have Piperol-A, Piperol-B, methyl piper betlol and they also have been isolated. The betle leaves have starch, sugars, diastases and an essential oil composing of terpinen-4-ol, safrole, allyl pyrocatechol monoacetate, eugenol, eugenyl acetate, hydroxyl chavicol, eugenol, piper betol and the betle oil contains cadinene carvacrol, allyl catechol, chavicol, p-cymene, caryophyllene, chavibetol, cineole, estragol, etc. as the key components.(12)

Phytochemical analysis on leaves revealed the presence of Alkaloids, Tannins, Carbohydrate, Amino acids and Steroidal components. The chief component of the leaves is a volatile oil in the leaves from different countries, called betle oil and contains 2 phenols, betle phenol (Chavibetol and Chavicol). Codinene has also been found.

Leaves contain protein 3-3.5%, carbohydrate 0.5-6.10%, minerals 2.3-3.3%, and tannins 0.1-1.3%. It contains calcium, phosphorus, iron, iodine and potassium, it is also contains Vitamin B, vitamin C and vitamin A. It also contains some aromatic compounds and stable oils like phenol and terpene. Besides, it contains eugenol, chavibetol and hydroxychavicol. Major constituents of common betel were found to be safrole (48.7%) and chavibetol acetate (12.5%). Malabulath does not contain these two compounds.(11,12)

The major compound in Malabulath oil is allylpyrocate choldiacetate (34.0%), which is the third major compound in common betel oil (11.3%).

Further, pcymene, 4-terpineol, safrole, eugenol, βcaryophellene and chavibetol acetate detected in common betel leaf oil were not detected in Malabulath leaf olive. The presence of hydroxychavicol acetate, allylpyrocatechol piperbetol, isoeugenol, anethole, stearic acid, methyl eugenol, carvacrol, polyphenol, alkaloids, saponin, tannin, steroids and other compounds like chavicol, allylpyrocatechol, are also found in *Piper betle*.

The essential chemical constituents along with their quantity (in percentage) are Chavibetol 53.1, Chavibetol acetate 15.5, Caryophyllene 3.71, Allylpyrocatechol Diacetate 0.71, Campene 0.48, Chavibetol methyl ether 0.48, Eugenol 0.32, a-Pinene 0.21, f-Pinene 0.21, u-Limonene 0.14, Saprobe 0.11, 1,8-Cineol 0.04, Allylpyrocatechol Monoacetate 0.23.(13)

Chavibetol and Chavibetol Acetate contribute to the characteristic aroma and flavor of betel leaves. Caryophyllene is a terpene found in betel leaves and is responsible for its distinct fragrance. Aristololactam A-II is isolated from the roots of *Piper betle* and has been traditionally used for its contraceptive properties. 4-Allyl Resorcinol is another phenolic compound found in the roots of *Piper betle*. Stigmast-4-en-3,6-dione is isolated from the petroleum-ether extract of *Piper betle* roots and Eugenol is a phenolic compound present in betel leaves and is known for its antioxidant and antimicrobial properties.(14)

2.2 Pharmacological profile[15]

Piper betle, commonly known as betel leaf, has a rich pharmacological profile due to its diverse phytochemical constituents. The plant possesses various medicinal properties, making it a significant herb in traditional medicine practices. Here is a brief overview of the pharmacological profile of *Piper betle*:

Piper betle, commonly known as betel leaf, has several pharmacological properties that have been studied:

Antimicrobial Activity

Betel leaf extracts showed antimicrobial properties against a wide range of bacteria and fungi. This included activity against common pathogens such as *Staphylococcus aureus, Escherichia coli,* and *Candida albicans.*

Anti-inflammatory Properties

While much of the research was preclinical, betel leaf extracts showed promise in alleviating symptoms of inflammatory conditions such as arthritis and dermatitis. These effects were attributed to its ability to modulate inflammatory responses.

Antioxidant Activity

Betel leaf contained antioxidants such as flavonoids and phenolic compouns and these antioxidants helped in neutralizing free radicals in the body, thereby reducing oxidative stress and potentially offering protective effects against diseases.

Wound Healing

Traditionally, betel leaf was used for wound healing due to its antimicrobial and anti-inflammatory properties. It was applied topically to wounds to promote healing and prevent infections.

Anti-diabetic Potential

Some studies have suggested that betel leaf extracts may have antidiabetic properties by reducing blood glucose levels. This could be beneficial in managing diabetes, but more research is needed to establish its efficacy and safety.

Gastroprotective Effects

Betel leaf extracts have been investigated for their gastroprotective effects, potentially protecting the stomach lining and reducing the risk of gastric ulcers.

Anti-cancer Properties

There was an emerging research which indicated that betel leaf extracts had traces of anticancer properties where the studies suggested cytotoxic effects against cancer cell lines

Central Nervous System Effects

Betel leaf extracts showed some effects on the central nervous system, including potential analgesic (pain-relieving) properties and effects on neurotransmitter levels.

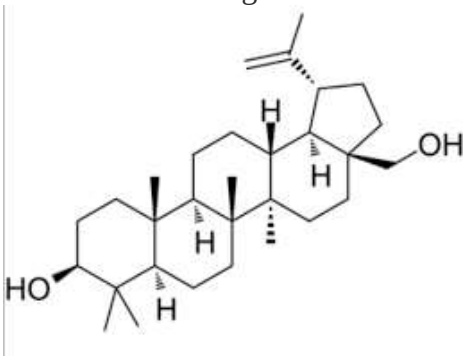
3. TRITERPINOIDS

Triterpenoids are a diverse class of naturally occurring organic compounds found abundantly in plants, fungi, and some marine organisms. They are characterized by their structural backbone consisting of six isoprene units, which can be modified and rearranged to produce a wide array of chemical structures and biological activities. These compounds play crucial roles in plant defense mechanisms, serving as deterrents against herbivores, pathogens, and environmental stressors. Additionally, triterpenoids contribute to the aroma, flavor, and color of many fruits, vegetables, and herbs, making them important constituents of the human diet. Triterpenoids exhibit a myriad of pharmacological properties, including anti-inflammatory, antioxidant, antimicrobial, antiviral, and anticancer activities. As such, they have attracted significant interest in pharmaceutical research for their potential therapeutic applications in various diseases and disorders.

In the context of alopecia treatment, certain triterpenoids have shown promise in promoting hair growth, reducing inflammation of the scalp, and protecting hair follicles from oxidative damage. Their multifaceted pharmacological properties make them valuable candidates for the development of novel treatments for hair loss[4,5].

3.1. Chemistry of Triterpinoids

Triterpenoids are structurally diverse compounds derived from the cyclization of the C30 precursor squalene, a linear hydrocarbon composed of six isoprene units. The cyclization process results in the formation of a triterpene backbone consisting of four fused rings: three six-membered rings and one five-membered ring.



This basic structure serves as the foundation for the remarkable structural diversity observed among triterpenoids. The chemical diversity of triterpenoids arises from modifications to the basic triterpene skeleton, including oxidation, reduction, rearrangement, and addition of functional groups. These modifications occur enzymatically within plants or through chemical reactions during extraction and isolation processes.

Triterpenoids are classified based on the number of carbon atoms in their structure, with the most common subclasses being the tetracyclic triterpenoids (containing 30 carbons) and the pentacyclic triterpenoids (containing 30 carbons and an additional side chain). Due to their complex structures, triterpenoids exhibit a wide range of biological activities and pharmacological properties. They are known for their anti-inflammatory, antioxidant, antimicrobial, and anticancer activities, among others. These properties make triterpenoids valuable compounds in various fields, including medicine, agriculture, and cosmetics[5].

3.2. Classification of Triterpinoids[12]

These compounds exhibit a wide range of biological activities and pharmacological properties, making their classification essential for understanding their roles in various fields such as medicine, pharmacology, and natural product chemistry. Here's an overview of the classification of triterpenoids.

1. Based on the Carbon Skeleton

Triterpenoids are classified into two main groups based on the number of carbon atoms in their structure: **Tetracyclic** and **Pentacyclic**. Tetracyclic triterpenoids contain a basic structure consisting of four fused rings, including three six-membered rings and one five-membered ring. Examples include oleanane and ursane skeletons. Pentacyclic triterpenoids contain an additional side chain along with the basic four-ring structure. Examples include lupane, hopane, and dammarane skeletons.

2. Based on Biosynthetic Origin

Triterpenoids are also classified according to their biosynthetic origin, which is determined by the cyclization of the precursor molecule, squalene. Squalene cyclizes to form the basic triterpene skeleton, which undergoes further modifications to produce various subclasses of triterpenoids, such as lupane, oleanane, ursane, and friedelane derivatives.

3. Based on Functional Groups

Triterpenoids can be further classified based on the presence of specific functional groups or side chains attached to the basic carbon skeleton. Hydroxyl groups, carbonyl groups, and epoxide rings are common functional groups found in triterpenoids, contributing to their diverse biological activities. Examples of functionalized triterpenoids include glycyrrhizin from licorice root (containing a glycoside moiety), betulinic acid from birch bark (containing a hydroxyl group), and asiaticoside from *Centella asiatica* (containing sugar moieties).

4. Based on Biological Activity

Triterpenoids can also be classified based on their predominant biological activity or pharmacological properties. For example, anti-inflammatory triterpenoids, such as boswellic acids from *Boswellia serrata*, are known for their ability to inhibit pro-inflammatory enzymes and cytokines. Anticancer triterpenoids, such as betulinic acid and ursolic acid, exhibit cytotoxic effects on cancer cells and are under investigation for their potential as anticancer agents.

3.3. Applications of Triterpinoids

Triterpinoid compounds exhibit diverse biological activities and pharmacological properties, making them valuable in medicine, pharmacology, agriculture, and cosmetics. Following are some of the notable applications of triterpinoids:

1. Medicinal uses- Triterpenoids have been extensively studied for their therapeutic potential in treating various diseases and disorders. They possess anti-inflammatory[17], antioxidant, antimicrobial, antiviral[18], and anticancer activities[19], among others. Examples of medicinal triterpenoids include boswellic acids from *Boswellia serrata* for treating inflammation and arthritis, asiaticoside from *Centella asiatica* for wound healing, and glycyrrhizin from licorice root for liver protection[13].

2. **Agricultural Applications**- Triterpenoids play a role in plant defense mechanisms against pests, pathogens, and environmental stressors. Some triterpenoids such as meliaceae act as allelochemicals, influencing plant interactions with neighboring organisms and ecosystems. Additionally, certain triterpenoids exhibit insecticidal and antifungal properties, making them potential candidates for developing environmentally friendly pesticides and fungicides[14].

3. Pharmacological Research- Triterpenoids are valuable compounds in pharmacological research, serving as lead molecules for drug discovery and development. Researchers investigate their potential as novel therapeutics for conditions such as cancer[19], diabetes[20], cardiovascular diseases, and neurodegenerative disorders[13]. Betulinic acid, for example, is being studied for its anticancer properties, while oleanolic acid derivatives show promise in treating metabolic disorders[15].

4. Cosmetic Industry- Triterpenoids are utilized in the cosmetic industry for their skin-conditioning, moisturizing, and anti-aging properties[21]. They help improve skin texture, promote collagen synthesis, and protect against UV-induced damage. Plant-derived triterpenoids such as lupeol, ursolic acid, and asiaticoside are commonly used in skincare products, including creams, lotions, and serums[16].

5. Nutraceuticals and Dietary Supplements- Triterpenoids present in fruits, vegetables, and herbs contribute to their nutritional value and health-promoting effects. Dietary supplements containing standardized extracts of triterpenoid-rich plants are marketed for various health benefits, including immune support, cognitive function, and overall well-being[5].

CONCLUSION

In conclusion, both *Aegle marmelos* and *Piper betle* leaf exhibit significant therapeutic potential, supported by traditional use and modern scientific evidence. Their bioactive compounds demonstrate a wide range of pharmacological effects, including antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. While research on these plants is still evolving, their incorporation into traditional medicine highlights their importance in complementary healthcare. Further clinical studies and rigorous trials are necessary to fully elucidate their mechanisms of action, efficacy, and safety. The promising results suggest that *Aegle marmelos* and *Piper betle* could offer valuable natural alternatives in modern therapeutic strategies.

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