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Betelvine (*Piper betle* L.) as a promising medicinal plant: Insights into phytochemistry, pharmacology and therapeutic applications

P. Sarvesh, T. Prabhu◆, S. Shenbagavalli*, K. Nageswari and P. Geetharani*****

Department of Spices and Plantation Crops, Horticultural College and Research Institute, Periyakulam, Theni-625604, Tamil Nadu, India
** Department of Natural Resource Management, Horticultural College and Research Institute, Periyakulam, Theni-625604, Tamil Nadu, India*
*** Department of Vegetable Science, Horticultural College and Research Institute, Periyakulam, Theni-625604, Tamil Nadu, India*
**** Agricultural Research Station, Vaigaidam, Theni-625562, Tamil Nadu, India*

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Abstract

Piper betle L., generally known as betelvine, is a medicinally important plant of the Piperaceae family, extensively cultivated and utilised throughout South and Southeast Asia. The leaves are a rich source of bioactive constituents, including phenolic compounds, flavonoids, alkaloids, essential oils such as eugenol, chavicol and hydroxychavicol, which underpin its diverse pharmacological effects. Traditionally, betel leaves have been used to maintain oral hygiene, enhance digestion and treat respiratory and inflammatory ailments. Recent scientific investigations have demonstrated a various property of physiological activities, like anti-inflammatory, antimicrobial, antidiabetic, antioxidant, anticancer and gastroprotective activities. These activities are primarily associated with the plant capacity to regulate inflammatory responses, oxidative stress and key metabolic pathways. Furthermore, *P. betle* shows considerable promise as a therapeutic agent for managing chronic diseases and promoting overall health. Additionally, betel leaves possess significant nutraceutical value due to the presence of vitamins, minerals and bioactive secondary metabolites. The plant has gained increasing attention in the pharmaceutical and food industries because of its potential use in developing herbal formulations, natural preservatives and functional foods. This review provides an integrated overview of its phytochemical profile, pharmacological activities and therapeutic potential, highlighting its significance as a natural resource for drug development and complementary medicine.

1. Introduction

Betelvine (*Piper betle* L.), a member of the family, Piperaceae, is originated in Eastern Malaysia, Sumatra and possibly Java. The crop is widely cultivated across several Asian countries including the Philippines, Myanmar, Indonesia, Bhutan, Nepal, Sri Lanka, India and Bangladesh (Mahalakshini *et al.,* 2019). Betelvine is a dioecious perennial climber (Punuri *et al.,* 2012). Betelvine is known by various regional names, including Tambula in Sanskrit, Villayadela in Kannada, Vetrilai in Tamil, Vettilakkoti in Malayalam, Tamalapaku in Telugu, Nagarbel in Gujarati, Tanbol in Arabic and Burg-e Tanbol in Persian, Videch-pan in Marathi and Pan in Bengali (Thomas *et al.,* 2013). The plant holds significant economic, medicinal, cultural and traditional value worldwide (Punuri *et al.,* 2012). In India, betel leaves are consumed extensively by an estimated 21-25 million people. These leaves are appreciated for their role as a natural mouth freshener and mild stimulant and are popularly referred to as "paan" in Hindi. They are traditionally used during various cultural, social and religious festivals including marriages, pooja ceremonies and shraddha rituals performed after cremation (Mahalakshimi *et al.,* 2019). Betel leaves are mainly consumed across South Asia and among Asian immigrant communities around the world, typically as part of betel chew or paan preparations combined with tobacco or areca nut with slaked lime (Saraswat *et al.,* 2020; shah *et al.,* 2021; Sahu *et al.,* 2021).

Corresponding author: Dr. T. Prabhu
Associate Professor and Head, Department of Spices and Plantation Crops, Horticultural College and Research Institute, Periyakulam, Theni-625604, Tamil Nadu, India
E-mail: prabhu.t@tnau.ac.in
Tel.: +91-9941765042

Plant is a tropical, perennial evergreen climber that prefers shaded environments and can reach heights of around 3-4 meters. It grows best in warm and humid climates. The plant has simple, alternate leaves that are ovate and heart-shaped, with pointed tips, smooth edges and a bright yellow to bright green colour. It produces compact cylindrical male spikes and drooping female spikes. Adventitious roots develop at each node, enabling the vine to cling securely to supporting trees. Betel leaves range in colour from light yellowish green to deep green and have a shiny upper surface along with a distinctive, pleasant fragrance. Owing to the presence of essential oils, the leaves are highly aromatic and may taste sweet or pungent (Bhalerao *et al.,* 2013; Lakshmi and Naidu, 2010; Chauhan *et al.,* 2016). Nowhere in the world is betel leaf so greatly valued as in the Indian subcontinent and traditionally, this edible plant has been used for many medicinal purposes. Historically, *P. betle* leaves have been reported in ancient Ayurvedic treatises, likely Charaka Samhita and Sushruta Samhita (600 AD), as remedies for oral hygiene, digestive disorders, respiratory ailments, wound healing and aphrodisiac properties (Kumar, 2006). Traditional chinese medicine (TCM) and Unani systems similarly recognise the plant stomachic, carminative and analgesic virtues (Fazal *et al.,* 2014).

Betel leaves have extensive applications in the culinary sector, beauty industry and medicinal industries. They contain a diverse range of volatile compounds, the composition of which varies according to the landrace, cultivation region, environmental conditions and soil type (Malik, 2019). The characteristic aroma and biological properties of betel leaves are mainly attributed to the volatile constituents present in their essential oil (Islam *et al.,* 2020). The characteristic strong and pungent aroma of betel leaves is attributed to the presence of significant amounts of terpenes and phenolic compounds in their essential oil (Guga and Nandi, 2019; Bhoite *et al.,*2019; Roy and Guha, 2015). The essential oil extracted from betel leaves is somewhat slippery, greasy and viscous in nature at room temperature (Biswas *et al.,* 2022). Contemporary pharmacological research has revealed a complex and bioactive secondary metabolite profile in betel leaves, dominated by phenylpropanoids notably hydroxychavicol (allylpyrocatechol), eugenol, chavibetol and chavicol alongside flavonoids, terpenoids, steroids, and alkaloids (Rai *et al.,* 2011). These compounds have shown notable antimicrobial, antioxidant, antidiabetic, anticancer and immunomodulatory activities in various experimental studies. Betelvine is generally categorised into pungent and non-pungent varieties according to differences in the taste, bitterness, size and leaf blade's shape (Radhalakshmi *et al.,* 2025; Swain *et al.,* 2022). The morphological variation of betelvine leaves is given in figure 1.

Figure 1: Morphological variation among betel.

2. Phytochemical composition of betel leaves

2.1 Nutritional composition of betel leaves

P. betle leaves are very nutritious, not only containing bioactive compounds. It also contains substantial nutritional elements like minerals, vitamins, fat, fibre, macro and some micronutrients essential for our health. The composition is predominantly moisture content (85-90%), followed by protein (3-3.5%), fat (0.4-1.0%) and minerals (2.3-3.3%), along with fibre (2.3%). It also contains chlorophyll and small amounts of vitamins and bioactive compounds, including thiamine (10-70 µg/100 g), nicotinic acid (0.63-0.89 mg/100 g), vitamin C (0.005-0.01%), vitamin A (1.9-2.9 mg/100 g) and riboflavin (1.9-30 µg/100 g). The material also contains a small proportion of essential oil (0.08-0.2%) **(**Guha, 2006).

2.2 Essential oil constituents

The volatile fraction of *P. betle* leaves ranges approximately from 0.7% to 2.6% of fresh weight, depending on cultivar and environmental conditions and represents one of the most important chemically active components (Madhumita *et al.,* 2020). The leaf essential oil contains major constituents are eugenol, chavicol derivatives, safrole and caryophyllene as identified through gas chromatography mass spectrometry evaluation. The gas chromatography mass spectrometry and gas chromatography flame ionization detection examination of the essential oil identified 38 compounds representing 94.1% of the total oil. Eugenol (18.8%), germacrene D (11.7%), chavibetol acetate (9.4%), â-caryophyllene (7.40%) and bicyclogermacrene (7.4%) were the major compounds in the oil (Idrus *et al.,* 2025). The *P. betle* oil was dominated by sesquiterpene hydrocarbons (19 compounds) and phenylpropanoids (five compounds), contributing 47.6% and 34.8% of the oil, respectively (Ahmad *et al.,* 2024).

2.3 Bioactive components

The major chemical constituents identified in *P. betle* include chavibetol (53.1%) and chavibetol acetate (15.5%). Other compounds detected in smaller quantities were allyl pyrocatechol diacetate (0.71%), camphene (0.48%), chavibetol methyl ester (0.48%), eugenol (0.32%), α-pinene (0.21%), β-pinene (0.21%). In addition, the hexane fraction obtained from the leaf stalks gave four purified aliphatic constituents: methyl hexacos-7-enoate, pentadecyl 6-hydroxytride-canoate, pentatriacontanol and 6,9-heptacosadiene (Dwivedi and Mehta, 2011). The major chemical constituents identified in *P. betle* include polyphenolic compounds such as eugenol, chavibetol, chavicol, catechol, carvacrol, allylpyrocatechol and vitamin C have been reported to possess strong antioxidant properties (Mahalakshmi *et al.,* 2019). The major reported constituents betel leaf oil along with their molecular formulas and applications are presented in Table 1 and the chemical structure are presented in Figure 2.

Table 1: Bioactive constituents of betel leaf and their uses

Bioactive constituents	Chemical formula	Uses
β-ocimene	$C_{10}H_{16}$	Aromatic compound
Chavibetol	$C_{10}H_{12}O_2$	Spicy aromatic compound
Sabinene	$C_{10}H_{16}$	Antimicrobial activity
Myrcene	$C_{10}H_{16}$	perfumery and culinary additive
α-terpinene	$C_{10}H_{16}$	Skin care and culinary industries
β-phellandrene	$C_{10}H_{16}$	Self-care and cleaning products
α-pinene	$C_{10}H_{16}$	Anti-inflammatory
Terpinolene	$C_{10}H_{16}$	Aromatic and culinary additive
Globulol	$C_{15}H_{26}O$	Antimicrobial activity
Caryophyllene	$C_{15}H_{24}$	antioxidant
1,8-cineole	$C_{10}H_{18}O$	Anti-inflammatory
Iso-safrole	$C_3H_5C_6H_3O_2CH_2$	Perfumery industry
β-bourbonene	$C_{15}H_{24}$	Flavour and aromatic agents
β-elemene	$C_{15}H_{24}$	Anticancer activity
Methyl eugenol	$C_{11}H_{14}O_2$	Perfumery ingredient
Allylpyrocatechol diacetate	$C_{13}H_{14}O_4$	Antimicrobial activity
Aromadendrene	$C_{15}H_{24}$	Antiageing properties
β-farnesene	$C_{15}H_{24}$	Natural pest control agent
Spathulenol	$C_{15}H_{24}O$	Antibacterial activity
Methyl isoeugenol	$C_{11}H_{14}O_2$	Flavour and fragrance
Germacrene-d	$C_{15}H_{24}$	Analgesic properties
β-selinene	$C_{15}H_{24}$	Antimicrobial properties
α-selinene	$C_{15}H_{24}$	Aroma compound
α-farnesene	$C_{15}H_{24}$	Plant defence
Hydroxychavicol	$C_9H_{10}O_2$	Antimutation effect
Eugenyl acetate	$C_{12}H_{14}O_3$	Antivirus potential
α-cadinene	$C_{15}H_{24}$	Anticancerous activity
Eugenol	$C_{10}H_{12}O_2$	Disinfecting and numbing agent
Germacrene-b	$C_{15}H_{24}$	Antimicrobial
Nerolidol	$C_{15}H_{26}O$	Flavouring agent
Camphene	$C_{10}H_{16}$	Perfumery and culinary additive
Cis-sabinene	$C_{10}H_{16}$	Antifungal agents

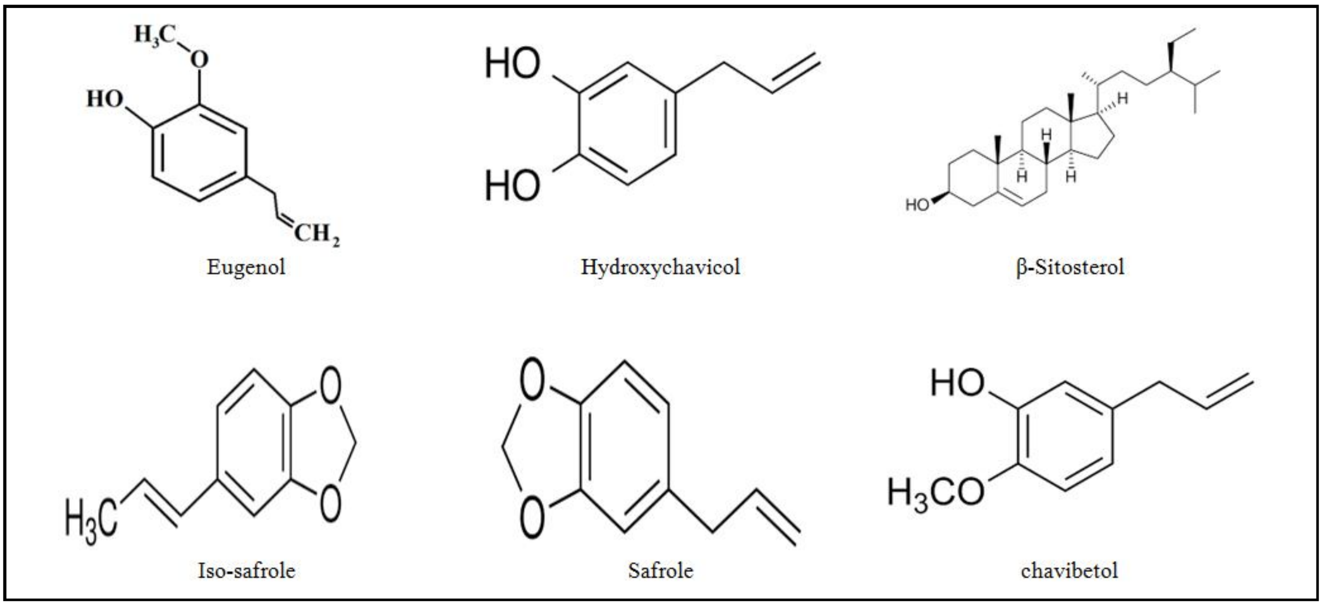

Figure 2: Chemical structure of phytochemicals.

3. Traditional and ayurvedic uses

In traditional and ayurvedic medicine, betel leaves are widely used for various therapeutic purposes. The application of oil-coated betel leaves on the breasts is traditionally believed to stimulate breast milk secretion during lactation (Fazal *et al.*, 2014). Due to their diuretic properties, betel leaf juice mixed with diluted milk and sugar has been used to relieve difficult or infrequent urination. The leaves are also valued for their cooling and analgesic effects, making them useful when applied topically to soothe severe headaches. For respiratory support, especially in children and elderly individuals, betel leaves treated with warm mustard oil are traditionally applied to the thorax to help relieve cough and respiratory discomfort. A juice prepared from betel leaf and mixed with some amount of honey is considered a nerve tonic and it is used to treat nervous exhaustion and relevant disorders.

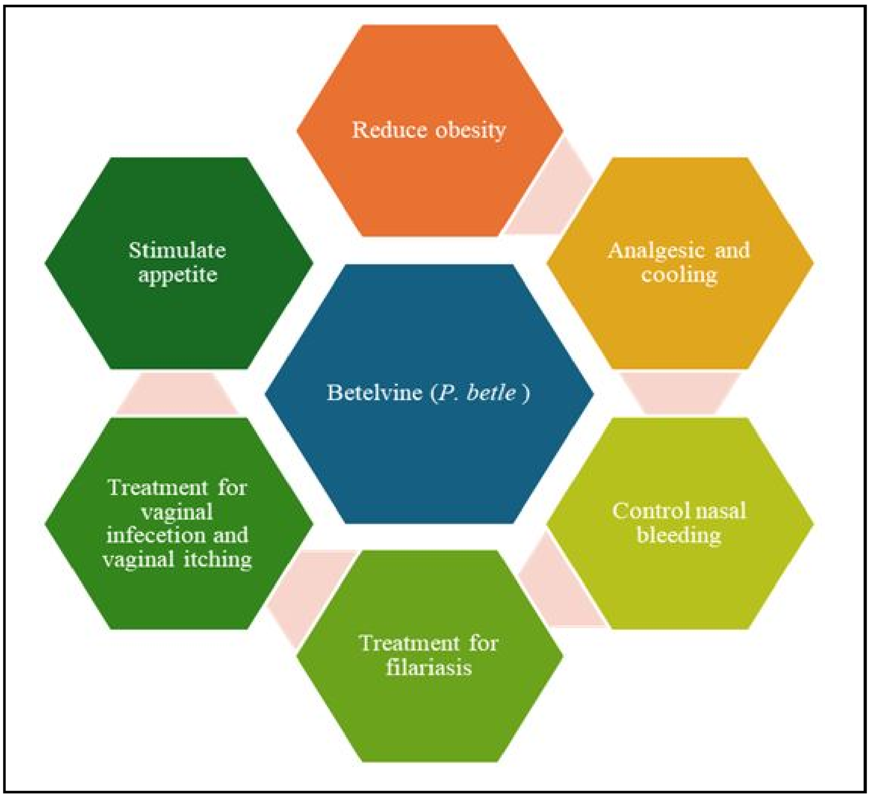

Figure 3: Medicinal application of betel leaves.

In pediatric constipation, the stalk of the betel leaf smeared with castor oil is traditionally used as a suppository to provide quick relief. Betel leaves are also associated with wound healing, as the juice is applied directly to wounds, which are then covered with a whole leaf and bandaged, a practice believed to promote healing within two days after a single application. For throat and cough relief, betel leaves are externally applied to soothe sore throats, while honey mixed with crushed fruits is used to treat cough. In the treatment of boils, a warm softened betel leaf coated with castor oil is placed over the affected area to promote maturation, rupture, and drainage, with the leaf being replaced periodically for effective results. Additionally, contraceptive properties of the leaves and roots of betel vine have also been reported. Traditionally, the root is mixed with black pepper and used by women as a contraceptive. Piperolactam A isolated from betel vine has shown affinity towards estrogen and progesterone receptors in *in silico* studies, indicating its potential as a non-steroidal lead compound for contraceptive development (Amin *et al*., 2017). Medicinal application of betel leaves given in Figure 3.

4. Pharmacological profile and application of betelvine

4.1 Oral care

Betel leaf contributes significantly to oral hygiene owing to its antiseptic and antimicrobial activities (Tarmale *et al.,* 2024). The presence of phenols helps reduce the mouth pathogens and supports the maintenance of healthy gums (Tarmale *et al.,* 2024; Kumar *et al.,* 2019; Sarella and Mangam, 2024). Dental caries is a long-standing infection that develops from the normal microorganisms present in the oral cavity. It begins with the demineralisation of enamel and can progress to dentin, mainly due to acids formed by tooth surface bacteria when they metabolise dietary carbohydrates. Among these microorganisms, *Streptococcus mutans* is the primary contributor to dental decay in humans. Streptococci are broadly classified into four groups: *S. mutans, S. salivarius, S. anginosus* and *S. mitis*. Additionally, *Lactobacillus acidophilus* also contributes although, to a lesser extent, to acid production within oral biofilm (Baviskar *et al.,* 2017).

The sticky nature of oral biofilm is due to dextran, which is formed when *S. mutans* ferments dietary sucrose. These bacteria also metabolise sugars such as fructose to produce lactic acid, which lowers the pH in the oral environment and leads to enamel demineralisation, particularly when the pH drops to around 5.5 or below. Thus, the interaction between plaque microorganisms and dietary carbohydrates serves a vital role in the initial stages of enamel caries (Al- Hosniyah, 2023). Certain highly cariogenic strains of streptococci, especially *S. mutans* can synthesise glucan from sucrose through the action of glucosyltransferase enzymes (Baviskar *et al.,* 2017). This process enhances their ability to adhere to tooth surfaces and establish themselves within oral biofilm.

Studies have shown that aqueous extracts of certain natural substances can inhibit a range of acid-producing oral pathogens and may alter the ultrastructure and properties of enamel. These pathogens include *streptococci, Treponema denticola, lactobacilli, staphylococci, corynebacteria* and *Porphyromonas gingivalis*. Such natural substances, commonly consumed in Asia as part of the daily diet, are considered beneficial for maintaining good oral hygiene (Bissa *et al*., 2007).

4.2 Gastroprotective activity

Betelvine extracts have been reported to exhibit gastroprotective activity by several mechanisms, including (i) enhancing the secretion of mucus and bicarbonate (ii) reducing gastric acid secretion and (iii) lowering gastric acidity (Arawwawala *et al.,* 2014; Ahmed *et al.,* 2021). The antiulcer effects of these constituents are also associated with their protein-protective and blood pressure modulating properties. In addition, strong gastroprotective activity has been demonstrated (Berenguer *et al.,* 2006). These defence effects may largely be attributed to the presence of secondary metabolites like alkaloids, tannins, flavonoids, saponins and other phenolic compounds (Barbosa *et al.,* 2019). The hot water extract was shown to significantly increase the amount of mucus lining the gastric mucosa. This mucus layer is essential for protecting the stomach lining from internal irritants such as gastric acid and also plays a vital role in supporting the repair process (Bhardwaj *et al*., 2022). Although, excessive acid secretion is considered a major contributor to the formation of gastric lesions, administration of high doses of the aqueous hot extract did not produce a significant reduction in stomach acid level, nor did it cause notable changes in the pH of gastric fluid (Arambewela *et al.,* 2011).

This suggests that the gastric protective action of *P. betle* is not due to a reduction in acid secretion, but rather its ability to enhance mucus production, thereby strengthening the stomach's natural defence system. Interestingly, at higher doses, the protective effect of the hot water extract was found to be greater than that of misoprostol (Rahmatullah *et al.,* 2009). Studies have also emphasised the significant role of antioxidants in safeguarding the gastric mucosa and inhibiting the progression of ulcer formation. Ulcer development is often driven by damage caused by free-radicals and compounds that neutralise these radicals can help promote quicker healing. The bioactive compounds also inhibit lipid peroxidation and protect the gastric mucosa from ulcerogenic agents (Majumdar *et al.,* 2003; Arambewela *et al.,* 2004). Allylpyrocatechol, a key bioactive compound, has demonstrated strong antioxidant activity in various *in vitro* studies. It has been shown to accelerate ulcer healing, partly by increasing mucus production, which helps protect the damaged area from harsh gastric secretions like hydrochloric acid and pepsin, ultimately supporting more effective tissue repair (Bhattacharya *et al.,* 2007).

4.3 Antidiabetic activity

Extracts of betel leaves have demonstrated promising antidiabetic activity through multiple mechanisms. Experimental studies have shown that the extracts improve the body ability to regulate blood sugar and increase responsiveness to insulin. The bioactive compounds found in the leaves helps to control glucose levels and safeguard pancreatic β-cells against damage caused by oxidative stress (Arambewela *et al.,* 2005; Pin *et al.,* 2010). Recent investigations have also revealed that eugenol, a phenolic constituent commonly found in plant essential oils, exhibits significant antidiabetic activity in diabetic animal models, further supporting its strong therapeutic potential against diabetes. Research findings have further demonstrated that eugenol possesses strong antidiabetic capacity in high-fat diet/streptozotocin-induced diabetic rats by modulating swelling and free radical-induced stress and enhancing insulin sensitivity. The study also found that eugenol markedly lowered elevated blood glucose levels in HFD/STZ-induced diabetic rats (Al-Trad *et al.,* 2019). The antidiabetic property of eugenol may be partly attributed to its ability to restore the activity of key enzymes involved in glucose metabolism and storage. In addition, both hot water and crude ethanolic extracts of betel leaves are known to exhibit safe antidiabetic activity.

4.4 Anticancer activity

Anticancer compounds that also have antioxidant properties can help maintain a balance of reactive oxygen species (ROS) in the body. This balance is important because it prevents uncontrolled cancer cell growth, especially in situations where the normal process of programmed cell death (apoptosis) is disrupted (Abrahim *et al.,* 2012). Administration of drinking water mixed with betel leaf extract significantly inhibited benzo(a)pyrene-induced tumour formation in the forestomach (Gundala and Aneja, 2014). Overall, the presence of bioactive compounds with antiproliferative and protective properties indicates that betel leaf extracts may possess potential therapeutic value in the management of various cancers, including lung cancer (Banerjee and Shah, 2014).

Furthermore, both experimental and clinical investigations have demonstrated that chronic inflammation plays a crucial role in the pathogenesis of several diseases, including cancer (Kangralkar and Kulkarni, 2013). *P. betle* has traditionally been used to alleviate irritation and inflammation of the oral cavity. Earlier studies reported that external use of betel leaf extract restrains pinene-induced oral cancer in hamsters (Toprani and Patel, 2013). Furthermore, the combined use of turmeric and betel leaf extracts in dietary supplements was found to enhance their therapeutic benefits. Moreover, betelvine has been reported to have cancer-preventive properties in several studies (Kudva *et al.,* 2018; Shukla *et al.,* 2018; Malkani *et al.,* 2021; Chowdhury and Markus, 2022). Leaf extract also helps prevent skin cancer. 75% of skin carcinoma is originated by basal cells and 15% accounts for squamous cell carcinoma. Studies show that by external use of leaf extracts, α-tocopherol and β-carotene, tumour formation can be reduced effectively. Moreover, betel leaf also has preventive effects in mammary cancers.

4.5 Antioxidant activity

Generation of reactive species during the radiolysis of water is capable of attacking the fatty acid chains present in membrane lipids. When a reactive species possesses sufficient power to remove an allylic hydrogen atom from the methylene group of polyunsaturated fatty acids, it triggers the lipid peroxidation process. Leaf extracts express strong antioxidant activity through several mechanisms. This process is mainly attributed to the presence of phenolic compounds and flavonoids, which efficiently neutralise free radicals and alleviate oxidative stress. Experimental studies using DPPH and ABTS assays have demonstrated the significant antioxidant potential of these extracts, with compounds such as eugenol and hydroxychavicol identified as major contributors to the observed antioxidant activity (Rathee *et al.,* 2006; Manigauha and Maheshwari, 2009). The extracts were able to reduce the Fe^{3+} ions and demonstrated strong reducing power (Dasgupta and De, 2004). Also exhibited strong scavenging activity against hydroxyl and superoxide anion radicals, performing comparably to standard compounds like Butylated Hydroxytoluene and ascorbic acid (Baviskar *et al.,* 2017; Rathee *et al.,* 2006; Sarkar *et al.,* 2008).

4.6 Anti-inflammatory

Inflammation is a complex physiological response of vascularized tissues to harmful stimuli, including pathogens, damaged cells, toxins and environmental irritants. It serves as a protective mechanism aimed at eliminating injurious agents, preventing the spread of damage, and initiating the healing and repair process. The inflammatory response involves the activation of immune cells, the release of chemical mediators and increased blood flow to the affected area, often resulting in redness, swelling, heat, pain and loss of function. Although, acute inflammation is beneficial and essential for tissue recovery, prolonged or chronic inflammation can contribute to the development of various diseases such as arthritis, cardiovascular disorders, diabetes and cancer. Studies have also reported that hydroethanolic extracts possess nitric oxide scavenging activity *in vitro* (Pawar *et al*., 2007). The leaf is traditionally used as a natural remedy for inflammation of the mouth. The crude extract of betelvine leaf is reported to possess anti-inflammatory activities, mediated by allylpyrocatechol present in the leaf (Pradhan *et al.,* 2013). Eugenol, a major bioactive constituent of betel leaf has demonstrated significant anti-inflammatory activity in various animal models induced by different inflammatory agents. Alcoholic extracts of *P. betle* have also been reported to exhibit considerable anti-inflammatory effects at safer concentrations. Studies revealed that betel leaf extract reduced inflammatory activity and decreased cellular inflammatory responses by 29% compared to the control (Pawar *et al*., 2007). The results show that selected varieties of *P. betle* can be used as natural antioxidants and as complementary remedies for inflammatory conditions (Hemalata *et al.,* 2025).

4.7 Antimicrobial activity

Betel exhibits significant antimicrobial activity against a wide range of microbes. It has been reported to be effective against pathogens such as *Staphylococcus aureus*, *Proteus vulgaris*, *S. pyogenes, P. aeruginosa and E. coli.* In addition, leaf extract expresses bactericidal activity against uropathogens, including *Citrobacter freundii*, *Citrobacter koseri*, *Klebsiella pneumonia and Enterococcus faecalis* (Chakraborty and Shah, 2011; Scherrer and Gerhardt, 1971). The antibacterial properties of betel leaf are associated with the presence of bioactive constituents such as sterols which occur abundantly in the extracts. These compounds are though to exert their antimicrobial action by interacting with bacterial cell walls and membranes causing structural damage, pore formation and subsequent breakdown of cellular components. In addition, sterols have been reported to impair the cell membrane permeability barrier in microbes (Baviskar *et al.,* 2017; Scherrer and Gerhardt, 1971). Moreover, Gram-positive bacteria are usually more sensitive to the antimicrobial activity of betel leaf extract because of their relatively simple cell wall structure, which lacks the outer protective membrane present in Gram-positive bacteria (Baviskar *et al.,* 2017). In contrast, Gram-negative bacteria possess a complex multilayered cell wall that acts as an additional barrier limiting the penetration of larger molecules (Ali *et al.,* 2010; Surucic *et al*., 2025).

4.8 Antifungal activity

The betel leaf posed the antifungal effect against many fungal infections (Panda *et al.,* 2019). One of them is dermatophytosis. It is a disease of the cornified tissues (skin, hair and nail) of the body caused by three genera (*Epidermophyton, Trichophyton and*

Microsporum) of highly specific fungi called the dermatophytes (Baviskar *et al.,* 2017). The chloroform extract of *P. betle* exhibited greater antifungal activity against dermatophytes than the methanolic fraction. This enhanced efficacy may be attributed to the presence of non-polar bioactive compounds in the chloroform extract, which are more effective in inhibiting the growth of dermatophytic fungi. In contrast, the methanol fraction contains relatively more polar constituents that may possess lower antifungal potential against these organisms (Chatterjee and Parkashi, 1995). Hydroxychavicol, a secondary metabolite comes under phenols obtained from the chloroform fraction of hydrophilic extract of *P. betle*, was evaluated for its antifungal potential against 124 different fungal strains. The compound demonstrated significant inhibitory activity against several clinically important fungal species, indicating its broad-spectrum antifungal properties. These findings suggest that hydroxychavicol may serve as a promising natural antifungal agent for the management of fungal infections caused by pathogenic microorganisms (Shah *et al*., 2016). Results suggest that hydroxychavicol is a potential for skin infection, as well as a gargle for oral infections (Shah *et al*., 2016; Arawwawala *et al.,* 2014).

5. Therapeutic properties of betel leaf

5.1 Thyroid regulating

Crude extracts of betelvine leaves confirmed to exhibit thyroid-inhibitory activity (Pullaiah, 2023). Thyroid hormones, specifically thyroxine (T_4) and its biologically active form triiodothyronine (T_3) are known as the two primary thyroid hormones plays essential role in regulating growth, development, differentiation and metabolism functions. Among them T_3 is considered more physiologically active than T_4. Overproduction of thyroxine can result in thyrotoxicosis, a condition characterized by increased thyroid hormone levels along with suppression of thyroid-stimulating hormone (THS). Studies have reported ameliorative effects of allyl pyrocatechol, isolated from betel vine leaves, in T4-induced hyperthyroid rats. These results indicate the potential therapeutic application of betel vine leaves in the management of thyrotoxicosis (Prabhu *et al.,* 1995).

5.2 Pancreatic lipase stimulant and digestive stimulant

In the traditional Indian system of medicine, betelvine leaves have long valued for their digestive stimulant and pancreatic lipase enhancing properties (Chang *et al.,* 2007; Budiman *et al.,* 2018). Traditionally, the leaves are used as digestive, stimulant and carminative effects. Although, they have little influence on bile secretion or bile composition. Studies have shown that betel leaves significantly increase pancreatic lipase activity. Moreover, these agents enhance the activity of key gastrointestinal enzymes, including amylase, lipase and disaccharidases, thereby facilitating the breakdown of fats, carbohydrates and complex sugars. This enzymatic stimulation contributes to more efficient nutrient digestion and absorption, ultimately supporting and improving overall gastrointestinal function and digestive health.

5.3 Platelet inhibition activity

Hydroxychavicol (HC) has been investigated for its antiplatelet activity and was found to effectively inhibit platelet aggregation. Studies have shown that HC suppresses the cyclooxygenase activity, scavenges reactive oxygen species and reduces platelet calcium mobilization as well as thromboxane B_2 synthesis. These effects collectively contribute to the inhibition of platelet aggregation indication its effective role of safeguard and cure of peripheral artery disease and other cardiovascular diseases. The therapeutic benefits of HC linked to its anti-inflammatory, antiplatelet properties without significantly interfering with normal haemostatic function (Amin *et al.,* 2017).

5.4 Antitumor/antioxidant

In Swiss albino mice, alcoholic extracts and fractions of betel leaves were assessed for their antitumor activity against Ehrlich ascites carcinoma (Shah *et al*., 2016). The findings revealed significant antitumour effects were likely associated with the enhancement of endogenous antioxidant defence mechanisms.

5.5 Antiacne activity

Acne is an inflammatory skin disease commonly linked to the blockage of sebaceous follicles and is associated with *Staphylococcus aureus* and *Propionibacterium acnes*. For assess the anti-acne potential of betelvine*,* a cream formulation containing ethanolic leaf extract was tested against these bacterial strains using the disc diffusion method and the minimum inhibitory concentration (MIC) was determined. The extract demonstrated notable antibacterial activity with MIC values of 4.5% and 4.0%, respectively (Biswas *et al*., 2022).

6. Future prospects

Future research on *P. betle* should focus on detailed investigation of its bioactive compounds and their molecular mechanisms. More *in vivo* studies, toxic evaluations and clinical trials are required to confirm its therapeutic efficacy and safety in humans. Standardization of extraction methods, formulation and quality control is essential for pharmaceutical and nutraceutical application. In addition, the use of nanotechnology and advanced drug delivery systems may improve the therapeutic potential of betel compounds. *P. betle* also has promising application in herbal medicine, functional foods, oral care products and natural preservatives. Future studies should emphasize sustainable cultivation, genetic improvement and conservation to support its long-term medicinal and industrial utilization.

7. Conclusion

The betelvine (*P. betle*) leaf emerges as a high valuable medicinal plant with significant pharmacological and therapeutic potential. This review highlights that its rich phytochemical composition particularly phenolic compounds such as eugenol and hydroxychavicol which plays a crucial role in imparting various physiological activities. They include strong antioxidant, antibacterial, anticancer, antidiabetic and gastroprotective effects which collectively contribute to its effectiveness in managing a wide range of health conditions. Beyond its pharmacological properties, betel leaf also contributes nutritional benefits, as it contains essential vitamins, minerals and other bioactive components that promote overall wellbeing. Overall, *P. betle* has strong potential as a natural, affordable and multifunctional plant that can contribute meaningfully to human health and the future of modern medicine.

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Conflict of interest

The authors declared no conflicts of interest relevant to this article.

References

Abrahim, N. N.; Kanthimathi, M. S. and Abdul-Aziz, A. (2012). *P. betle* shows antioxidant activities, inhibits MCF-7 cell proliferation and increases activities of catalase and superoxide dismutase. BMC Complementary and Alternative Medicine, 12(1):220.

Ahmad, F. S.; Mohamed, S. M.; Jamil, M. and Jani, N. A. (2024). Chemical composition, antibacterial activity, and ADME studies of leaf essential oil of *P. betle*. Malaysian Journal of Chemistry, 26(3):456-464.

Ahmed, S. R.; Rabbee, M. F.; Roy, A.; Chowdhury, R.; Banik, A.; Kubra, K. and Baek, K. H. (2021). Therapeutic promises of medicinal plants in Bangladesh and their bioactive compounds against ulcers and inflammatory diseases. Plants, 10(7):1348.

Ali, I.; Khan, F. G.; Suri, K. A.; Gupta, B. D.; Satti, N. K.; Dutt, P. and Khan, I. A. (2010). *In vitro* antifungal activity of hydroxychavicol isolated from *P. betle* L. Annals of Clinical Microbiology and Antimicrobials, 9(1):7.

Al-Hosniyah, K. S. (2023). Effectiveness of cancer educational program in Oman: A mixed-method study of School students, Teachers and Policymakers. Sultan Qaboos University (Oman).

Al-Trad, B.; Alkhateeb, H.; Alsmadi, W. and Al-Zoubi, M. (2019). Eugenol ameliorates insulin resistance, oxidative stress and inflammation in high fat-diet/streptozotocin-induced diabetic rat. Life Sciences, 216:183-188.

Amin, S. A.; Bhattacharya, P.; Basak, S.; Gayen, S.; Nandy, A. and Saha, A. (2017). Pharmacoinformatics study of Piperolactam A from *P. betle* root as new lead for non-steroidal anti fertility drug development. Computational Biology and Chemistry, 67:213-224.

Arambewela, L. S. R.; Arawwawala, L. D. A. M.; Kumaratunga, K. G.; Dissanayake, D. S.; Ratnasooriya, W. D. and Kumarasingha, S. P. (2011). Investigations on *P. betle* grown in Sri Lanka. Pharmacognosy Reviews, 5(10):159.

Arambewela, L. S. R.; Arawwawala, L. D. A. M. and Ratnasooriya, W. D. (2004). Gastroprotective activities of Sri Lankan *P. betle* leaf extracts in rats. SLAAS. 60th Annual Session, 117pp.

Arambewela, L. S. R.; Arawwawala, L. D. A. M. and Ratnasooriya, W. D. (2005). Antidiabetic activities of aqueous and ethanolic extracts of *P. betle* leaves in rats. Journal of Ethnopharmacology, 102(2):239-245.

Arawwawala, L. D. A. M.; Arambewela, L. S. R. and Ratnasooriya, W. D. (2014). Gastroprotective effect of *P. betle* Linn. leaves grown in Sri Lanka. Journal of Ayurveda and Integrative Medicine, 5(1):38.

Banerjee, D. E. V. J. A. N. I. and Shah, B. (2014). Anti-proliferative activity of *Piper betel* leaf extracts on human lung cancer cell line (A549). International Journal of Pharmacy and Pharmaceutical Sciences, 6(1):432-435.

Barbosa, J. A. P.; Santana, M. A. N.; Leite, T. C. C.; de Oliveira, T. B.; Mota, F. V. B.; Bastos, I. V. G. A. and da Silva, T. G. (2019). Gastroprotective effect of ethyl acetate extract from *Avicennia schaueriana* Stapf and Leechman and underlying mechanisms. Biomedicine and Pharmacotherapy, 112:108582.

Baviskar, H. P.; Dhake, G. T.; Kasai, M. A.; Chaudhari, N. B. and Deshmukh, T. A. (2017). Review of *P. betle*. Research Journal of Pharmacognosy and Phytochemistry, 9(2):128.

Berenguer, B.; Sánchez, L. M.; Quilez, A.; López-Barreiro, M.; De Haro, O.; Galvez, J. and Martin, M. J. (2006). Protective and antioxidant effects of Rhizophora mangle L. against NSAID-induced gastric ulcers. Journal of Ethnopharmacology, 103(2):194-200.

Bhalerao, S. A.; Verma, D. R.; Gavankar, R. V.; Teli, N. C.; Rane, Y. Y.; Didwana, V. S. and Trikannad, A. (2013). Phytochemistry, pharmacological profile and therapeutic uses of *P. betle* L.: An overview. Journal of Pharmacognosy and Phytochemistry, 1(2):10-19.

Bhardwaj, K.; Devi, A.; Mishra, R. and Rana, S. (2022). A review on anti-inflammatory potential of *P. betle*. World journal of Pharmaceutical and Medicinal Research, 8(2):83-90.

Bhattacharya, S.; Banerjee, D.; Bauri, A. K.; Chattopadhyay, S. and Bandyopadhyay, S. K. (2007). Healing property of the *Piper betel* phenol, allylpyrocatechol against indomethacin-induced stomach ulceration and mechanism of action. World Journal of Gastroenterology: WJG, 13(27):3705.

Bhoite, V. S.; Kamble, D. K. and Patil, Y. N. (2019). Effect of different levels of *Piper betel* leaves on physico-chemical attributes of ice-cream. Int. J. Chem. Stud., 7(5):168-171.

Bissa, S., Songara, D. and Bohra, A. (2007). Traditions in oral hygiene: chewing of betel (*P. betle* L.) leaves. Current Science, 92(1):26-28.

Biswas, P.; Anand, U.; Saha, S. C.; Kant, N.; Mishra, T.; Masih, H. and Dey, A. (2022). Betelvine (*P. betle* L.): A comprehensive insight into its ethnopharmacology, phytochemistry, and pharmacological, biomedical and therapeutic attributes. Journal of Cellular and Molecular Medicine, 26(11):3083-3119.

Budiman, A.; Rusnawan, D. W. and Yuliana, A. (2018). Antibacterial activity of *P. betle* L. extract in cream dosage forms against Staphylococcus aureus and Propionibacterium acne. Journal of Pharmaceutical Sciences and Research, 10(3):493-496.

Chakraborty, D. and Shah, B. (2011). Antimicrobial, antioxidative and antihemolytic activity of *Piper betel* leaf extracts. International Journal of Pharmacy and Pharmaceutical Sciences, 3(3):192-199.

Chang, M. C.; Uang, B. J.; Tsai, C. Y.; Wu, H. L.; Lin, B. R.; Lee, C. S. and Jeng, J. H. (2007). Hydroxychavicol, a novel betel leaf component, inhibits platelet aggregation by suppression of cyclooxygenase, thromboxane production and calcium mobilization. British Journal of Pharmacology, 152(1):73-82.

Chatterjee, A. and Parkashi, S. (1995). The treatise of Indian medicinal plants, volume IV. New Delhi: Publication and Information Directorate CSIR.

Chauhan, E. S.; Aishwarya, J.; Singh, A. and Tiwari, A. (2016). A review: Nutraceuticals properties of *Piper betel* (Paan). Am. J. Phytomed. Clin. Ther., 4(2):28-41.

Chowdhury, C. R. and Markus, A. F. (2022). Level of oral cancer awareness among Indian rural population: A possible research model using knowledge, attitude and practice (KAP) intervention and its utilisation in low resource settings of LMICs. Journal of Oral Biology and Craniofacial Research, 12(1):154-160.

Das, S.; Parida, R.; Sandeep, I. S.; Nayak, S. and Mohanty, S. (2016). Biotechnological intervention in betelvine (*P. betle* L.): A review on recent advances and future prospects. Asian Pacific Journal of Tropical Medicine, 9(10):938-946.

Dasgupta, N. and De, B. (2004). Antioxidant activity of *P. betle* L. leaf extract *in vitro*. Food Chemistry, 88(2):219-224.

Dwivedi, B. K. and Mehta, B. K. (2011). Chemical investigation of aliphatic compounds of *P. betle* (leaf stalk). J Nat Prod Plant Resour, 1(2):18-24.

Fazal, F.; Mane, P. P.; Rai, M. P.; Thilakchand, K. R.; Bhat, H. P.; Kamble, P. S. and Baliga, M. S. (2014). The phytochemistry, traditional uses and pharmacology of *Piper betel*. linn (Betel Leaf): A pan-asiatic medicinal plant. Chinese Journal of Integrative Medicine, pp:1-11.

Guha, P. (2006). Betel leaf: the neglected green gold of India. Journal of Human Ecology, 19(2):87-93.

Guha, P. and Nandi, S. (2019). Essential oil of betel leaf (*P. betle* L.): A novel addition to the world food sector. In Essential oil research: trends in biosynthesis, analytics, industrial applications and biotechnological production (pp:149-196). Cham: Springer International Publishing.

Gundala, S. R. and Aneja, R. (2014). *P. betel* leaf: a reservoir of potential xenohormetic nutraceuticals with cancer-fighting properties. Cancer Prevention Research, 7(5):477-486.

Hemalata, S. W.; Mardhekar, A. A. and Krishna, B. K. (2025). *P. betle*: An herbal plant: A review. International Journal of Food Science and Nutrition, 10(1):27-35.

Idrus, S. N. W.; Salleh, W. M. N. H. W.; Salihu, A. S.; Ab Ghani, N. and Abed, S. A. (2025). Discovering the therapeutic potential of piper Essential oils: Chemistry and Bioactivities. Journal of Basic and Applied Research in Biomedicine, 11(1):8-19.

Islam, M. A.; Ryu, K. Y.; Khan, N.; Song, O. Y.; Jeong, J. Y.; Son, J. H. and Kim, K. S. (2020). Determination of the volatile compounds in five varieties of *P. betle* L. from Bangladesh using simultaneous distillation extraction and gas chromatography/mass spectrometry (SDE-GC/MS). Analytical Letters, 53(15):2413-2430.

Kangralkar, V. A. and Kulkarni, A. R. (2013). *In vitro* antitumor activity of alcoholic extract of *Piper betel* leaf. Research Journal of Pharmaceutical Biological and Chemical Science, 4(4):1558-1561.

Kudva, A. K.; Rao, S.; Rao, P.; Periera, R.; Bhandari, G.; Mathew, J. M. and Baliga, M. S. (2018). *P. betle* Linn. in cancer: Past, present, and future. In: Anticancer plants: Properties and Application: Volume 1(pp.327-347). Singapore: Springer Singapore.

Kumar, S. (2006). Health Beneficial Properties of Betelvine. Journal of Human Ecology, 19:87-93.

Kumar, S.; Sharma, S. and Vasudeva, N. (2019). Review on ethnobotany, phytochemistry and pharmacological aspects of *P. betle* Linn. Journal of Pharmacy Research, 3(10):2378-2387.

Lakshmi, B. S. and Naidu, K. C. (2010). Comparative morphoanatomy of *P. betle* L. cultivars in India.

Madhumita, M.; Guha, P. and Nag, A. (2020). Bioactives of betel leaf (*P. betle* L.): A comprehensive review on extraction, isolation, characterization, and biological activity. Phytotherapy Research, 34(10):2609-2627.

Mahalakshmi, M.; Chitra, R.; Rani, P. J. and Janaki, D. (2019). Effect of organic manures and nutrients on growth and yield of betelvine (*P. betle* L.). IJCS, 7(3):288-291.

Majumdar, B.; Chaudhuri, S. R., Ray, A. and Bandyopadhyay, S. K. (2003). Effect of ethanol extract of *P. betle* Linn. leaf on healing of NSAID-induced experimental ulcer: A novel role of free radical scavenging action. Indian Journal of Experimental Biology, 41(4):311-315.

Malik, S. (Ed.). (2019). Essential Oil Research: Trends in Biosynthesis, Analytics, Industrial Applications and Biotechnological Production. Springer.

Malkani, N.; Kazmi, S. and Rashid, M. U. (2021). Epidemiological assessment of oral cancer burden in Pakistan. Cancer Investigation, 39(10):842-853.

Manigauha, A.; Ali, H. and Maheshwari, M. U. (2009). Antioxidant activity of ethanolic extract of *Piper betel* leaves. J. Pharm. Res., 2(3):194-95.

Panda, S.; Sikdar, M.; Biswas, S.; Sharma, R. and Kar, A. (2019). Allylpyrocatechol, isolated from betel leaf ameliorates thyrotoxicosis in rats by altering thyroid peroxidase and thyrotropin receptors. Scientific Reports, 9(1):12276.

Pawar, S., Bhane, P. and Jha, U. (2021). Review on betel pepper leaf for anti-inflammatory activity. World J. Pharm. Res., 11(2):1196-1208.

Pin, K. Y.; Chuah, A. L.; Rashih, A. A.; Mazura, M. P.; Fadzureena, J.; Vimala, S. and Rasadah, M. A. (2010). Antioxidant and anti-inflammatory activities of extracts of betel leaves (*P. betle*) from solvents with different polarities. Journal of Tropical Forest Science, pp:448-455.

Prabhu, M. S.; Platel, K.; Saraswathi, G. and Srinivasan, K. (1995). Effect of orally administered betel leaf (*P. betle* Linn.) on digestive enzymes of pancreas and intestinal mucosa and on bile production in rats. Indian Journal of Experimental Biology, 33(10):752-756.

Pradhan, D.; Suri, K. A.; Pradhan, D. K. and Biswasroy, P. (2013). Golden heart of the nature: *P. betle* L. Journal of Pharmacognosy and Phytochemistry, 1(6).

Pullaiah, T. (Ed.). (2023). Phytochemical Composition and Pharmacy of Medicinal Plants:2-Volume Set.

Punuri, J. B.; Sharma, P.; Sibyala, S.; Tamuli, R. and Bora, U. (2012). *P. betle*-mediated green synthesis of biocompatible gold nanoparticles. International Nano Letters, 2(1):18.

Radhalakshmi, V.; Raman, M. and Joy, M. R. (2025). Betel leaf bioactive compounds as a source of functional ingredients for food, nutraceutical and pharmacological applications in India. Next Research,100988.

Rai, M. P.; Thilakchand, K. R.; Palatty, P. L.; Rao, P.; Rao, S.; Bhat, H. P. and Baliga, M. S. (2011). *Piper betel* Linn (betel vine), the maligned Southeast Asian medicinal plant possesses cancer preventive effects: Time to reconsider the wronged opinion. Asian Pac. J. Cancer Prev., 12(9):2149-2156.

Rahmatullah, M.; Ferdausi, D.; Mollik, M. A. H.; Jahan, R.; Chowdhury, M. H. and Haque, W. M. (2009). A survey of medicinal plants used by Kavirajes of Chalna area, Khulna district, Bangladesh. African Journal of Traditional, Complementary and Alternative Medicines, 7(2):91.

Rathee, J. S.; Patro, B. S.; Mula, S.; Gamre, S. and Chattopadhyay, S. (2006). Antioxidant activity of *Piper betel* leaf extract and its constituents. Journal of Agricultural and Food Chemistry, 54(24):9046-9054.

Roy, A. and Guha, P. (2015). Development of a novel cup cake with unique properties of essential oil of betel leaf (*P. betle* L.) for sustainable entrepreneurship. Journal of Food Science and Technology, 52(8):4885-4894.

Sahu, A. K.; Kar, S. S.; Kumari, P. and Dey, S. K. (2022). An overview of Betel vine (*P. betle* L.). Advances in Horticultural Science, 36(1):63-80.

Saraswati, N.; Pillay, R.; Everett, B. and George, A. (2020). Knowledge, attitudes and practices of South Asian immigrants in developed countries regarding oral cancer: an integrative review. BMC Cancer, 20(1):477.

Sarella, P. N. K. and Mangam, V. T. (2024). Enhancing nutraceutical bioavailability with bilosomes: A comprehensive review. Asian Journal of Pharmacy and Technology, 14(3):271-280.

Sarkar, D.; Saha, P.; Gamre, S.; Bhattacharjee, S.; Hariharan, C.; Ganguly, S. and Chatterjee, M. (2008). Anti-inflammatory effect of allylpyrocatechol in LPS-induced macrophages is mediated by suppression of iNOS and COX-2 *via* the NF-κB pathway. International Immuno pharmacology, 8(9):1264-1271.

Scherrer, R. and Gerhardt, P. (1971). Molecular sieving by the Bacillus megaterium cell wall and protoplast. Journal of Bacteriology, 107(3):718-735.

Shah, S. K., Garg, G., Jhade, D. and Patel, N. (2016). *P. betle*: Phytochemical, pharmacological and nutritional value in health management. Int. J. Pharm. Sci. Rev. Res., 38(2):181-189.

Shah, S.; Boucree, T. S. and Chang, E. I. (2021). Betel quid chewing in the Mid-Atlantic United States: Any consequence. Res. Rep. Oral Maxillofac. Surg., 5:049.

Shukla, D.; Johri, J.; Srivastava, S. and Singh, P. C. (2018). Assessment of anticancer properties of betelvine. In: Anticancer plants: Properties and Application: Volume 1(pp:195-206). Singapore: Springer Singapore.

Suruèiæ, R., Travar, M., Kundakoviæ Vasoviæ, T., Radoviæ Selgrad, J., Suruèiæ, L., Momèiloviæ, M. and Škrbiæ, R. (2025). *In vtro* and *in silico* Analysis of Differential antibacterial activity of pomegranate polyphenols against Gram-positive and Gram-negative bacteria. Antibiotics, 14(9):912.

Swain, S.; Jena, B. R. and Ghose, D. (2022). Pandemic corona virus vs. epidemic and endemic virus diseases: Present, past, and future directions (1st ed.). IP Innovative Publication Pvt. Ltd. ISBN 978-93-91208-61-5.

Tarmale, V. A.; Wankhede, S.; Sen, A. K. and Uppalwar, S. V. (2024). Pharmacological properties, and traditional applications of Betel Leaf (*P. betle* L.). Journal of Pharma Insights and Research, 2(6):131-141.

Thomas, U. C.; Chandini, S. and Thomas, A. (2013). Integrated nutrient management studies in betelvine (*P betle* L.). Int. J. Appl. Res., Stud., 48:2-7.

Toprani, R. and Patel, D. (2013). Betel leaf: Revisiting the benefits of an ancient Indian herb. South Asian Journal of Cancer, 2(3):140.

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