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PHYTOCHEMICAL RICHNESS AND PHARMACOLOGICAL POTENTIAL OF SYZYGIUM CARYOPHYLLATUM (L.) ALSTON: AN INTEGRATIVE REVIEW

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ABSTRACT

Herbal medicine has gained global recognition due to its natural origin and reduced side effects. *Syzygium caryophyllatum*, commonly known as wild black plum, is an evergreen tree native to Sri Lanka and the Western Ghats of India. Traditionally, different parts of the plant have been used to treat diabetes, infections, inflammation, and gastrointestinal disorders. Modern studies have demonstrated antioxidant, antimicrobial, antidiabetic, larvicidal, anticancer, and anti-inflammatory activities. These pharmacological effects are attributed to phytoconstituents such as phenolics, flavonoids, tannins, alkaloids, saponins, glycosides, and essential oils rich in sesquiterpenoids. This review analyzing phytochemistry and pharmacology, and highlights the potential of S. caryophyllatum as a candidate for hepatoprotective research.

KEYWORDS: *Syzygium caryophyllatum*, phytochemistry, antioxidant, antimicrobial, antidiabetic, anti-inflammatory, hepatoprotective potential.

INTRODUCTION

The genus Syzygium comprises more than 1200 species, many of which are valued for their edible fruits and medicinal properties. *Syzygium caryophyllatum* (L.) Alston, commonly known as wild black plum, is an evergreen tree native to Sri Lanka and distributed in parts of the Western Ghats of India. It is considered endangered due to habitat loss and overexploitation. Traditionally, its bark and seeds have been used for diabetes, leaves for antibacterial remedies, and roots for inflammation. Fruits are consumed by tribal communities.[1] Phytochemical investigations reveal a rich profile of secondary metabolites, including phenolics, flavonoids, tannins, alkaloids, saponins, glycosides, anthocyanins, and essential oils. These compounds are known to mediate antioxidant, antimicrobial, antidiabetic, and anti-inflammatory effects.[2] Tribal people consider this plant as a boon of nature and it is consumed by Paniya tribal community of Waynad district, Kerala, India.[3,4]

Given the central role of oxidative stress and inflammation in the progression of chronic diseases, the pharmacological profile of *Syzygium caryophyllatum* provides a strong rationale for exploring its hepatoprotective potential. Previous studies have demonstrated promising activities across multiple domains, yet comprehensive evaluation and clinical validation remain limited. This review consolidates an integrative understanding of the phytochemical richness and pharmacological versatility of S. caryophyllatum. By highlighting consistent trends, comparative analyses, and gaps in current research, the article aims to establish the species as a candidate for future drug discovery and nutraceutical development, while also emphasizing the importance of conservation due to its endangered status.[5]

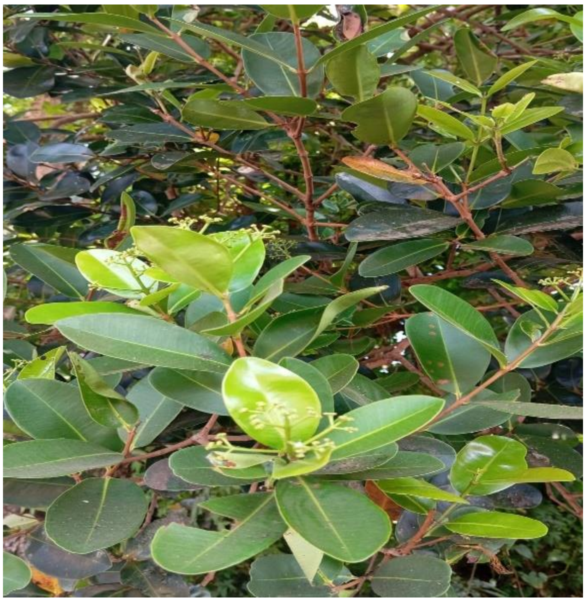

Fig. 1: ***Syzygium Caryophyllatum.***

PHYTOCHEMICAL PROFILE OF *SYZYGIUM CARYOPHYLLATUM*

Phytochemical investigations of *Syzygium caryophyllatum* have consistently revealed a rich and diverse array of bioactive compounds. These secondary metabolites are central to the plant's pharmacological activities, including antioxidant, antimicrobial, antidiabetic, anti-inflammatory, and anticancer effects. The phytochemical profile varies across plant parts leaves, bark, seeds, roots, and fruits and is influenced by extraction methods and solvents. This section highlights the chemical diversity and its biological relevance.

Leaves

Leaves of *S. caryophyllatum* are particularly rich in phenolics, flavonoids, and tannins. Quantitative assays reported phenolic content as high as 36.1 mg gallic acid equivalents per gram of extract, with flavonoid levels around 5.6 mg rutin equivalents per gram. Tannin content was also substantial, exceeding 36 mg tannic acid equivalents per gram. These values are significantly higher than those observed in fruit pulp, underscoring the leaves as a potent source of antioxidant compounds.[6]

Gas chromatography–mass spectrometry (GC-MS) analysis of leaf essential oil identified 24 compounds, accounting for nearly 90% of the oil composition. Major constituents included 8-cadinol (42.1%), 9-epi-β-caryophyllene (13.4%), and selin-11-en-4α-ol (5.4%). These sesquiterpenoids are known for antifungal and antibacterial properties, explaining the strong inhibition observed against *Candida albicans* and bacterial strains. The presence of cadinene type sesquiterpenes suggests potential for natural preservative applications.[7]

Bark

Bark extracts are similarly rich in phenolics and flavonoids, with values slightly lower than leaves but still substantial. Methanolic bark extracts demonstrated strong antioxidant activity, correlating with phenolic content. Bark also showed potent α-glucosidase inhibition, with activity exceeding 80% at 100 μg/ml, highlighting its relevance in antidiabetic therapy. Phytochemical screening confirmed the presence of tannins, alkaloids, and glycosides, which may contribute to antimicrobial and antidiabetic effects.[4]

Seeds

Seeds of *S. caryophyllatum* contain a diverse set of phytochemicals, including tannins, phenolics such as gallic acid and ellagic acid, flavonoids, and glycosides. Seeds demonstrated maximum α-amylase inhibition (78% at 500 μg/ml), supporting traditional use in diabetes management. The presence of phenolic acids and flavonoids suggests strong antioxidant potential, while glycosides may contribute to enzyme inhibition. Seeds also contain proteins and fatty acids, adding nutritional value.

Roots

Roots are characterized by flavonoids, tannins, alkaloids, saponins, phenols, and amino acids. These compounds collectively mediate anti-inflammatory activity, as demonstrated in protein denaturation assays. The presence of alkaloids and saponins suggests additional pharmacological potential, including antimicrobial and immunomodulatory effects. Comparative studies revealed that *S. caryophyllatum* roots contain higher levels of phenols and tannins than related species such as *S. densiflorum*, confirming superior phytochemical richness.[8]

Fruits

Fruit pulp contains carbohydrates, proteins, fats, and vitamin C, with methanolic extracts showing particularly high ascorbic acid content (847 mg/g). Anthocyanins contribute to the fruit's coloration and antioxidant activity. Fractionated extracts revealed strong radical scavenging activity, with ethyl acetate fractions showing highest potency. Hexane fruit fractions exhibited potent α-amylase inhibition, outperforming the standard drug acarbose. GC-MS analysis identified 58 volatile compounds, while ICP-MS revealed essential trace elements, adding depth to phytochemical characterization.[9]

Fig. 2: Fruit of *S. caryophyllatum*.

Comparative Phytochemistry

Across plant parts, leaves and bark consistently show highest phenolic and flavonoid content, correlating with strong antioxidant and antimicrobial activity. Seeds excel in antidiabetic activity due to enzyme inhibition, while roots uniquely exhibit anti-inflammatory potential. Fruits contribute nutritional and antioxidant value, with anthocyanins and vitamin C playing key roles. Essential oils, dominated by sesquiterpenoids, explain antifungal potency. Comparative studies with related species confirm that *S. caryophyllatum* is phytochemically superior in several respects.[6]

Solvent Influence

Extraction solvents significantly influence phytochemical yield. Methanol extracts consistently yielded higher phenolic and flavonoid content, correlating with stronger antioxidant and antimicrobial activity. Ethanolic extracts were generally more potent than aqueous extracts in antibacterial assays. Acetone extracts of roots showed higher phenolic content than methanol, highlighting the importance of solvent choice in maximizing bioactivity.[10]

Biological Relevance

The phytochemical diversity of *S. caryophyllatum* underpins its pharmacological potential. Phenolics and flavonoids mediate antioxidant and antimicrobial effects. Tannins contribute to antidiabetic and anti-inflammatory activity. Sesquiterpenoids in essential oils explain antifungal potency. Alkaloids and saponins add antimicrobial and immunomodulatory potential. Anthocyanins and vitamin C enhance antioxidant activity in fruits. Collectively, these compounds provide a strong rationale for therapeutic applications, including hepatoprotective potential. The phytochemical profile of *Syzygium caryophyllatum* is remarkably diverse, with each plant part contributing unique compounds and activities. Leaves and bark are richest in phenolics and flavonoids, seeds excel in antidiabetic activity, roots provide anti-inflammatory potential, and fruits add nutritional and antioxidant value. Essential oils are dominated by sesquiterpenoids, explaining antifungal activity. Solvent choice significantly influences phytochemical yield and bioactivity. This chemical richness underpins the plant’s broad pharmacological spectrum and highlights its potential as a source of novel therapeutic agents, including hepatoprotective drugs.[11]

PHARMACOLOGICAL ACTIVITIES OF *SYZYGIUM CARYOPHYLLATUM*

The pharmacological potential of *Syzygium caryophyllatum* has been explored across multiple domains, including antioxidant, antimicrobial, antidiabetic, anti-inflammatory, anticancer, and larvicidal activities. Each plant part such as leaves, bark, seeds, roots, and fruits contributes uniquely to this spectrum of bioactivity. The following subsections provide a detailed synthesis of findings from eight original studies, highlighting methodologies, results, and implications.

1. Antioxidant Activity

Antioxidant activity is one of the most consistently reported pharmacological properties of *S. caryophyllatum*. Free radicals and oxidative stress are implicated in the pathogenesis of numerous diseases, including cancer, diabetes, and liver disorders. The plant's rich phenolic and flavonoid content underpins its strong radical scavenging potential.

- Leaves and Bark: Methanolic extracts of leaves and bark demonstrated high phenolic and flavonoid content, correlating with strong antioxidant activity. DPPH assays revealed inhibition rates exceeding 80%, with bark extract showing up to 88% inhibition. ABTS assays confirmed similar potency.
- Seeds: Seed extracts also exhibited strong antioxidant activity, though slightly lower than leaves and bark. The presence of gallic acid, ellagic acid, and flavonoids contributed to radical scavenging.
- Fruits: Fruit pulp and fractions showed significant antioxidant activity. Ethyl acetate leaf fractions exhibited highest radical scavenging power, while fruit fractions demonstrated strong FRAP and ORAC activity. Anthocyanins and vitamin C enhanced antioxidant potential.
- Roots: Root extracts contained flavonoids and tannins, contributing to moderate antioxidant activity, though less studied compared to other parts.

Antioxidant activity is consistently strong across plant parts, with leaves and bark being most potent. Methodological diversity (DPPH, ABTS, FRAP, ORAC) strengthens the evidence base. However, most studies are limited to in vitro assays, and in vivo validation is needed to confirm therapeutic relevance.[12]

2. Antimicrobial Activity

Antimicrobial activity has been reported against a wide range of bacterial and fungal pathogens, highlighting the plant's potential in infectious disease management.

- Leaves: Ethyl acetate and methanolic leaf extracts inhibited *Staphylococcus aureus*, *Bacillus subtilis*, *Aeromonas hydrophila*, and *E. coli*. Essential oils showed strong antifungal activity against *Candida albicans*, with MIC values as low as 44 µg/ml.
- Bark: Bark extracts demonstrated antibacterial activity against *Staphylococcus hominis*, *Bacillus licheniformis*, and *Aerococcus viridians*.
- Seeds: Seed extracts inhibited *Aerococcus viridians*, *Bacillus cereus*, and *Staphylococcus aureus*.

- Fruits: Fruit pulp extracts showed moderate activity, with inhibition against *Staphylococcus aureus*.
- Comparative Solvent Analysis: Ethanolic extracts were generally more potent than aqueous extracts, with MIC values ranging from 0.075 to 0.625 mg/ml.

Antimicrobial activity is broad-spectrum, covering Gram-positive and Gram-negative bacteria as well as fungi. Essential oils, rich in sesquiterpenoids, explain antifungal potency. However, variability in extraction methods and test organisms complicates direct comparison. Future studies should standardize methodologies and explore synergistic effects with conventional antibiotics.[13]

3. Antidiabetic Activity

Antidiabetic activity is a major focus of *S. caryophyllatum* research, reflecting traditional use of bark and seeds in diabetes management.

- Seeds: Seed extracts demonstrated maximum α-amylase inhibition (78% at 500 μg/ml), supporting their role in reducing postprandial glucose levels.
- Bark: Bark extracts exhibited strong α-glucosidase inhibition (80.9% at 100 μg/ml), highlighting their potential in slowing carbohydrate digestion.
- Leaves: Leaf extracts showed moderate enzyme inhibition, contributing to overall antidiabetic potential.
- Fruits: Fruit fractions exhibited potent α-amylase inhibition, outperforming acarbose, a standard antidiabetic drug. Antiglycation assays confirmed efficacy against AGE formation, which is relevant in diabetic complications.

Antidiabetic activity is robust, with seeds and bark being most effective. Mechanistic insights suggest enzyme inhibition as the primary mode of action, though stimulation of insulin secretion and antiglycation effects may also contribute. In vivo studies are needed to confirm efficacy and safety.[2,12]

4. Anti-inflammatory Activity

Inflammation is a key contributor to chronic diseases, including arthritis and liver disorders. *S. caryophyllatum* roots have been traditionally used for inflammatory conditions, and modern studies validate this use.

- Roots: Aqueous root extracts inhibited protein denaturation in egg albumin assays, with activity comparable to diclofenac sodium. Phytochemical screening revealed flavonoids, tannins, alkaloids, and saponins, which likely mediated the activity.
- Leaves and Bark: While less studied for anti-inflammatory activity, their phenolic and flavonoid content suggests potential.

Anti-inflammatory activity is well-documented in roots, validating traditional use. However, studies are limited to in vitro assays, and in vivo validation is needed. Exploration of molecular mechanisms (e.g., COX inhibition, cytokine modulation) would strengthen the evidence base.[8]

5. Anticancer Activity

Anticancer potential has been reported in leaf extracts, though research is limited compared to other pharmacological domains.

- Leaves: Ethyl acetate leaf extracts demonstrated cytotoxicity against Hep2 carcinoma cells, reducing viability to less than 10% at high concentrations.
- Mechanisms: Activity is likely mediated by phenolics and flavonoids, which can induce apoptosis, inhibit proliferation, and modulate cell cycle.

Anticancer activity is promising but preliminary. Only one study has directly evaluated cytotoxicity, and further research is needed to confirm efficacy across cancer cell lines and elucidate mechanisms.[12]

6. Larvicidal Activity

Vector control is an important public health priority, and *S. caryophyllatum* has demonstrated larvicidal activity against mosquito species.

- Leaves and Bark: Essential oils and methanolic extracts caused significant mortality in *Aedes aegypti* and *Culex quinquefasciatus* larvae. Mortality was concentration-dependent, with effective LD50 and LD90 values confirmed by probit analysis.

Larvicidal activity highlights the plant's potential as an eco-friendly alternative to synthetic insecticides. However, field studies are needed to confirm efficacy and environmental safety.[2]

CONCLUSION

The pharmacological profile of *Syzygium caryophyllatum* is remarkably diverse, with each plant part contributing uniquely. Leaves and bark are richest in phenolics and flavonoids, seeds excel in antidiabetic activity, roots provide anti-inflammatory potential, fruits add nutritional and antioxidant value, and essential oils explain antifungal potency. Methodological diversity strengthens the evidence base but also introduces variability. Future research should focus on in vivo validation, isolation of active compounds, mechanistic studies, and clinical trials to fully realize the therapeutic potential of this endangered species.

The collective evidence establishes *Syzygium caryophyllatum* as a phytochemically rich and pharmacologically versatile species. Its antioxidant, antimicrobial, antidiabetic, larvicidal, anticancer, and anti-inflammatory properties highlight its potential in drug discovery and nutraceutical development. However, as an endangered species, conservation strategies are critical.

Leaves and bark are consistently rich in phenolics, flavonoids, and tannins, correlating with strong antioxidant and antimicrobial activity. Seeds demonstrate notable antidiabetic potential, particularly in α-amylase inhibition. Roots show unique anti-inflammatory activity, validated by protein denaturation assays. Essential oils are dominated by sesquiterpenoids, explaining antifungal potency. Methodological diversity ranging from phytochemical screening to GC-MS and bioassays strengthens the evidence base. Collectively, these studies establish *S. caryophyllatum* as a versatile medicinal plant with broad pharmacological promise.

Although none of the reviewed studies directly evaluated hepatoprotective activity, the evidence strongly suggests potential in this area. Antioxidant activity can mitigate oxidative stress, a major driver of liver injury. Anti-inflammatory properties can reduce hepatic inflammation, while antidiabetic effects can prevent metabolic disorders that contribute to fatty liver disease. Antimicrobial activity may protect against infections that exacerbate liver damage. Together, these findings provide a strong rationale for future hepatoprotective studies on *S. caryophyllatum*.

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