**PHYTOCHEMISTRY OF WOOD APPLE: AN OVERVIEW OF BIOACTIVE COMPOUNDS AND THEIR MEDICINAL POTENTIAL**

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**ABSTRACT**

**Limonia acidissima**, commonly known as the Wood apple, is a tropical fruit from the Rutaceae family. Native to regions like Sri Lanka, India, and Myanmar, it is widely cultivated across Southeast Asia. This fruit has been deeply valued in traditional medicine, particularly for its remarkable nutritional and therapeutic properties. The pulp of the wood apple is rich in β-carotene, which the body converts into vitamin A, and is also a good source of essential B vitamins such as riboflavin and thiamine, with small amounts of ascorbic acid (vitamin C) present as well. Wood apple's health-promoting benefits are attributed to a diverse array of bioactive compounds, which include antioxidants, hepatoprotective agents, antimicrobials, neuroprotective substances, antidiabetic agents, anti-inflammatory compounds, and more. These properties are linked to its phytochemical profile, which contains polyphenols, saponins, phytosterols, tannins, triterpenoids, coumarins, amino acids, tyramine derivatives, and vitamins. Studies have also shown that wood apple exhibits promising anticancer potential by inhibiting the growth and proliferation of cancer cells. Beyond its health benefits, the wood apple is widely used in commercial food products, including ready-to-drink beverages, syrups, jellies, chutneys, and other culinary applications. This review delves into the nutritional and phytochemical content of the wood apple, emphasizing its antioxidant, anti-inflammatory, and anti-diabetic effects, and discusses its potential for development into value-added products. However, while the fruit demonstrates substantial health benefits, it is important to note that the molecular mechanisms underlying these properties remain insufficiently explored. To fully integrate wood apple into the food, cosmetics, and pharmaceutical industries, comprehensive clinical trials and toxicity studies are essential. Such research could foster innovation and contribute significantly to both scientific and commercial progress.

**Keywords:** Wood apple, Phytochemicals, Anticancer, Nutrition, Essential oils.

1. **INTRODUCTION**

*Limonia acidissima* Groff, commonly referred to as the 'Wood apple,' is a tropical fruit from the Rutaceae family, classified as an underutilized tree species [1]. It is predominantly grown in India (particularly in the semi-arid and arid regions), Sri Lanka, Penang Island, and other Southeast Asian countries. In India, it is primarily found in states such as Uttar Pradesh, Madhya Pradesh, Maharashtra, West Bengal, Chhattisgarh, and parts of the Western Himalayas [2]. The wood apple is known by various regional names, including Elephant apple, Curd apple, Monkey fruit, Kothbel, Koyito, Pushpahala, and Kaitha [3].

The tree itself is slow-growing and deciduous, producing spherical-shaped fruits with a diameter ranging from 5 to 12.5 cm. These fruits have a hard, woody outer shell and a sour pulp that distinguishes them from many other tropical fruits [4]. In India, wood apple is a seasonal fruit that typically ripens in October and remains available until January. The yield per plant varies, ranging from 40.5 to 70 kg on average [5].

Wood apple fruits are a rich source of tannins, glycosides, flavonoids, saponins, and several vitamins, including ascorbic acid, riboflavin, vitamin B, and β-carotene. These nutrients, alongside a range of minerals, set wood apple apart from many other fruits. Additionally, it contains unique bioactive compounds such as amino acids, polyphenols, coumarins (including osthenol, psoralen, demethylsuberosin, bergapten, and isopimpinellin), triterpenoids, phytosterols, and tyramine derivatives [6]. Given these attributes, wood apple has been found to exhibit substantial free radical scavenging activity, positioning it as a potential antioxidant agent. Both ripe and unripe fruits are recognized for their therapeutic benefits, with mature fruits being particularly effective in treating liver disorders [7].

1. **NUTRITIONAL PROFILE OF WOOD APPLE**

Wood apple (Limonia acidissima) is a highly nutritious fruit, rich in essential vitamins, minerals, and bioactive compounds, making it a valuable addition to the diet. The fruit is particularly celebrated for its high content of β-carotene, a precursor to vitamin A, which is essential for maintaining healthy vision, skin, and immune function. Wood apple also provides significant amounts of vitamin B complex, including riboflavin (vitamin B2) and thiamine (vitamin B1), both of which play crucial roles in energy metabolism, nerve function, and overall cellular health. Additionally, the fruit contains vitamin C (ascorbic acid), contributing to immune system support and antioxidant protection [8].

**Key Nutrients in Wood Apple:**

1. **Vitamins**:
	* **Vitamin A (β-carotene)**: A potent antioxidant that supports eye health and skin vitality.
	* **Vitamin B Complex**: Includes **riboflavin (B2)**, **thiamine (B1)**, and **niacin (B3)**, which are involved in energy production and nervous system function.
	* **Vitamin C (Ascorbic acid)**: An antioxidant that enhances immune defense and promotes skin and tissue health [8].
2. **Minerals**:
	* **Calcium**: Contributes to bone health and muscular function.
	* **Iron**: Essential for red blood cell formation and oxygen transport in the body.
	* **Potassium**: Regulates fluid balance, nerve signals, and muscle contractions.
	* **Magnesium**: Supports muscle function, nerve transmission, and energy production [9]
3. **Phytochemicals**:
	* **Polyphenols**: Antioxidant compounds that protect the body from oxidative stress and may help reduce the risk of chronic diseases.
	* **Tannins**: Have antimicrobial and anti-inflammatory properties, contributing to the fruit’s therapeutic effects.
	* **Flavonoids**: Known for their antioxidant, anti-inflammatory, and cardioprotective effects.
	* **Saponins**: Possess antimicrobial and immune-boosting properties, and may help in reducing cholesterol levels.
	* **Coumarins**: These compounds, including osthenol, psoralen, and bergapten, have been shown to have anticancer and anti-inflammatory properties [10].
4. **Fiber**:
	* The fruit is rich in dietary fiber, particularly soluble fiber, which aids in digestion, promotes gut health, and helps regulate blood sugar levels. Fiber is also beneficial for reducing cholesterol and maintaining a healthy weight [11].
5. **Amino Acids**:
	* Wood apple contains a variety of **essential amino acids**, which are vital for protein synthesis, muscle repair, and overall cellular function [12].
6. **PHYTOCHEMICAL PROFILE OF *Limonia acidissima***

The phytochemical profile of wood apple (Limonia acidissima) is characterized by a diverse array of bioactive compounds with therapeutic potential:

**Major Phytochemical Classes**

1. **Polyphenols:** Includes phenolic acids and flavonoids, with total phenolic content ranging from 3.01–35.72 mg GAE/g (dry weight), depending on extraction methods and fruit maturity. Methanol extracts show the highest phenolic content (335.12 mg GAE/100g).
2. **Flavonoids:** Total flavonoid content varies between 1.59–4.39 mg RE/g in pulp, with specific compounds like orientin, vitexin, and isovitexin identified in leaves.
3. **Coumarins:** Includes bergapten, psoralen, imperatorin, and isopimpinellin, which contribute to antimicrobial and anti-inflammatory properties.
4. **Saponins & Phytosterols:** Implicated in cholesterol modulation [13].
5. **HEALTH BENEFITS LINKED TO ITS NUTRITIONAL PROFILE:**

Wood apple (*Limonia acidissima*) has been widely recognized for its wide array of health benefits, which are primarily attributed to its rich nutritional profile, including vitamins, minerals, and bioactive compounds. These properties make wood apple not only a nutritious fruit but also a potential natural remedy for various health conditions. Below are some of the notable health benefits of wood apple:

1. **Rich Antioxidant Activity**

Wood apple is packed with **polyphenols**, **flavonoids**, and **vitamin C**, all of which are powerful antioxidants. These compounds help neutralize **free radicals**, reducing oxidative stress and the risk of developing chronic conditions such as **cardiovascular diseases**, **diabetes**, and **cancer**. The fruit’s antioxidant capacity can also contribute to delaying the signs of aging and protecting the body from harmful environmental factors like pollution and UV radiation [14].

1. **Supports Digestive Health**

The dietary fibre found in wood apple promotes gut health by aiding in digestion and preventing constipation. The fruit’s high soluble fibre content helps maintain regular bowel movements, improves the consistency of stools, and supports the growth of beneficial gut bacteria.

Wood apple has been traditionally used as a remedy for **indigestion**, **gastritis**, and **ulcers**. The **tannins** and **saponins** in the fruit have antimicrobial and anti-inflammatory properties, helping to soothe the stomach lining and reduce inflammation in the digestive tract [15].

1. **Liver Health (Hepatoprotective Properties)**

Wood apple has been found to have **hepatoprotective** (liver-protecting) effects. Studies have shown that its bioactive compounds, including **tannins** and **triterpenoids**, can help in the **detoxification** process by supporting liver function. It can also protect the liver from damage caused by toxins, alcohol, and certain medications, making it beneficial for individuals with **liver disorders** like **hepatitis** and **fatty liver disease** [14].

1. **Regulates Blood Sugar Levels (Anti-diabetic Effect)**

Preliminary research suggests that wood apple may help **regulate blood glucose** levels, making it potentially beneficial for individuals with **diabetes**. The fruit’s high fiber content can slow the absorption of sugars in the bloodstream, reducing spikes in blood sugar levels after meals. Additionally, the fruit’s **saponins** and **polyphenols** may help improve insulin sensitivity and support overall metabolic health [14].

1. **Anti-inflammatory Properties**

The **polyphenols**, **flavonoids**, and **triterpenoids** in wood apple have strong **anti-inflammatory** effects. These compounds can help alleviate symptoms of **inflammatory conditions** such as **arthritis**, **gout**, and **inflammatory bowel diseases** (IBD). Regular consumption of wood apple may help reduce swelling, pain, and stiffness associated with inflammation [15].

1. **Improves Skin Health**

The **antioxidant** and **anti-inflammatory** properties of wood apple are beneficial for **skin health**. It is commonly used in traditional medicine for treating **skin disorders** like **acne**, **eczema**, and **psoriasis**. The fruit’s rich **vitamin C** content helps in **collagen production**, which is crucial for maintaining skin elasticity and reducing wrinkles.

Additionally, wood apple’s antimicrobial and anti-inflammatory effects help prevent and heal **skin infections**, making it useful for cleansing and purifying the skin [14].

1. **Supports Immune Function**

Due to its high **vitamin C** and **antimicrobial** properties, wood apple strengthens the **immune system**, helping the body defend against infections and illnesses. Regular consumption of wood apple can support the body's natural defences, making it easier to fight off colds, flu, and other viral or bacterial infections [15].

1. **Cardioprotective Benefits**

The **fiber**, **potassium**, and **antioxidants** in wood apple contribute to **heart health** by supporting healthy blood pressure, reducing bad cholesterol (LDL), and improving overall cardiovascular function. **Potassium** helps regulate **electrolyte balance** and **blood pressure**, while **flavonoids** and **polyphenols** protect the blood vessels from oxidative damage, potentially reducing the risk of **heart disease** and **stroke** [16].

1. **Anticancer Potential**

Several studies have indicated that wood apple possesses anticancer properties due to its diverse range of bioactive compounds, including coumarins, polyphenols, and saponins. These compounds have been shown to inhibit the proliferation of cancer cells and reduce the formation of tumors in certain cancers. While more research is needed, the fruit holds promise as a natural adjunct in cancer prevention and treatment [14].

1. **Relieves Pain (Analgesic Effects)**

Wood apple has been traditionally used to treat pain and inflammation. The fruit’s analgesic properties may help alleviate discomfort caused by headaches, muscle pain, and joint pain. Some studies suggest that wood apple's compounds may influence pain receptors, offering a natural alternative to over-the-counter pain medications [16].

1. **Enhances Cognitive Function (Neuroprotective Effects)**

The **neuroprotective** properties of wood apple make it beneficial for **brain health**. The fruit’s high antioxidant and anti-inflammatory compounds help protect the brain from oxidative stress and inflammation, which are associated with neurodegenerative diseases like **Alzheimer’s disease** and **Parkinson’s disease**. Regular consumption may support better memory, focus, and overall cognitive function [15].

1. **CONCLUSION**

All Wood apple (Limonia acidissima), a lesser-known yet pharmacologically significant plant, exhibits a rich phytochemical profile comprising flavonoids, alkaloids, phenolics, tannins, and essential oils. These bioactive chemicals have a variety of therapeutic qualities, including antioxidant, anti-inflammatory, antibacterial, hepatoprotective, antidiabetic, and anticancer effects. The traditional use of various parts of the plant—pulp, leaves, bark, and roots—aligns with modern pharmacological findings, emphasizing its therapeutic value. Despite its promising bioactivity, more in vivo research, clinical trials, and extract standardization are required to confirm its safety and efficacy. Future research should focus on isolating novel compounds, understanding their mechanisms of action, and exploring their potential in drug development. Harnessing the full potential of wood apple could have a substantial impact on natural product-based treatments and integrative medicine.

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