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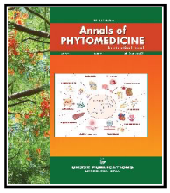

Review Article : Open Access

Recent insights into the therapeutic profile and holistic application of Wood apple in biomedicine and food industry

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Abstract

Pharmacological and ethnomedicinal sciences have recently flourished in empirical research with regard to the utilization of underexploited fruit crops for their vast medicinal properties and prospective health applications. It is now well acknowledged by medical professionals that integration of nutrition and drug therapy may provide the most effective outcomes in combating diseases. The phytochemical active constituents found in versatile minor fruit crops are being studied for their potential application as novel therapies, owing to their preventive effects. Wood apple (*Limonia acidissima* Groff.) is one among the Indian fruit crops with immense medicinal potential that has long been utilized in traditional medicines. Ayurveda medicine makes significant use of fruits, leaves, bark, seeds, and roots that contain biochemicals; namely, phenolic acids, coumarins, quinones, lignans, flavonoids, sterols, alkaloids, triterpenoids, and volatile oils, which extensively treat severe diseases like laxatives, peptic ulcers, chronic diarrhoea, and dysentery. This paper delivers an overview of the pharmaceutical characteristics wood apple to foster innovation and make significant improvements in the fields of research and industry.

1. Introduction

Nature has offered a whole treasury of remedies to cure human ailments. Approximately 80% of world's population relies entirely or partially on traditional therapies to get their main healthcare requirements (Gangadhar *et al.*, 2012). The exploration of herbal remedies remains a crucial aspect of pharmaceutical studies, motivated by the desire to discover novel therapeutic agents from nature's gifts. Among those natural treasures, wood apple stands out as a fascinating botanical life form, valued for its complex medicinal potential and ancient traditional applications.

Wood apple scientifically known as *Limonia acidissima* Groff., is an underutilized and indigenous crop belonging to family of Rutaceae, native to India (Pandey *et al.*, 2014).Wood apple is a spiritual, religious and medicinal plant native to India and Bangladesh and spread throughout Southeast Asia. It is mostly prevalent in West Bengal, Chhattisgarh, Uttar Pradesh, Madhya Pradesh, Maharashtra, and the Western Himalaya in India (Singhania *et al.*, 2020). This fruit is exclusively referred to as monkey fruit, curd apple, and elephant apple in English, and as koyito, kothbel, kaitha, pushpaphala and volaga in India (Murakonda *et al.*, 2022).The plants can withstand difficult soil conditions and climates because of their deep-rooted, sturdy roots. The fruit was considered as a "poor man's food" in India (Hiwale, 2015). The fruit's hard shell gives its name, "wood apple," and its shape resembles an apple (Rodrigues *et al.*, 2018). It has a unique appearance, like a rotten coconut on the outside and soft pulp inside. The pulp presents a sour taste and peculiar flavor that mixes well with sugar in dessert and toasty spices in savory meals (Parvez and Sarker, 2021). The entire wood apple tree is incredibly beneficial and useful; for example, the leaves have antimicrobial and diuretic activities and can help avoid stomach based disorders in children.

Fresh wood apple contains approximate moisture content (79.26 to 79.58%), fat (1 to 2.010%), protein (8.31 to 8.35%), ash (0.986 to 1.82%), total sugars (6.41 to 6.43%), total soluble solids (17.60 to 17.80%), reducing sugar (5.2 to 5.6%), acidity (4.5 to 4.7%) and ascorbic acid (5.12 to 5.121%) (Waghmare *et al.*, 2021). Amino acids, saponins, polyphenols, coumarins (including osthenol, bergapten, demethylsuberosin, psoralen, and isopimpinellin), phytosterols, triterpenoids, and tyramine derivatives are among the essential and phytochemical compounds that are rarely found in several other fruits (Poongodi Vijayakumar *et al.*, 2013).

Currently, wood apple is gaining popularity due to its numerous health benefits and traditional use in Ayurveda. Its rich nutritional profile, digestive benefits, skin health advantages, and immune-boosting effects contribute to its popularity. By utilizing this versatile fruit into the daily life, people can experience its benefits and explore its traditional wisdom, contributing to overall well-being and a deeper connection with nature's offerings. These underutilized fruits are essential for meeting vitamins and mineral requirements in the

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poor inadequate diets of rural communities. This review primarily highlights the nutritional, dietary, and medicinal benefits of this undervalued fruit and envisions vast opportunities for additional pharmacological research, development of biomedicines and value added products in the future.

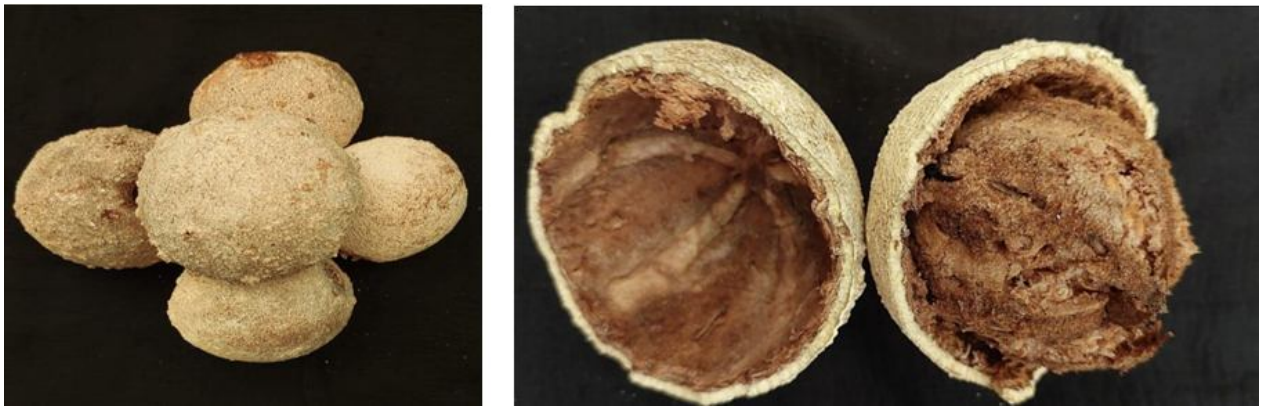
2. Phytogeography and origin

The wood apple is a monotypic species in the genus *Limonia*, is an undomesticated nutritional and therapeutic source which remains underutilized as because of a lack of knowledge about its significance and a methodical investigation of its diversity (Lamani *et al.*, 2022). It is indigenous to India, Vietnam, and Pakistan but also found in Malaysia, Sri Lanka, Thailand, Cambodia and also noticed in some regions of southern Asian countries (Tripti *et al.*, 2018). Through the crop is not commercially cultivated, but it holds religious significance in Southern India, particularly during the festival times which is regarded as sacred tree by Hindu people. It grows all across the arid regions of India.

The fruit is cultivated in Indian states that includes Andhra Pradesh, Maharastra, Karnataka, Tamil Nadu, Kerala, Madhya Pradesh, and the western Himalayas and these fruits are available in huge quantity during October to March. (Pareek, 2009). Although, wood apples can be found in the Western Himalayas, they are more prevalent in Maharashtra's Thane and Chandrapur districts and additionally, it has been reported in several areas of Jharkhand's Hazaribagh, Palamau, and Chota Nagpur (Hiwale, 2015). This tree is suitable for growing in wastelands, dry plains, roadsides, and orchards. It is a versatile plant that can well thrive in saline, neglected lands, and dry regions, and is resistant to pests and diseases because of its presence of antimicrobial compounds (Kumar and Deen, 2017). They have a high utility value and are regionally abundant but limited in their geographic dispersion (Mahato *et al.*, 2020).

3. Morphological description

The tree *L. acidissima* is erect, slow-growing, deciduous in nature, and features few upward-facing branches that bend outward near the apex, where they fell into narrow branch lets that droop at the terminals. Its fruit has a diameter of 5 to 12.5 cm and is round in shape. The rind is greyish-white in colour and appears 6 mm thick. In addition to being dark, mealy, aromatic, resinous, acidic, or sweetish, the pulp has lot of tiny white seeds throughout (Figure 1). Its sticky pulp can processed to make beverages, jams, jellies, and syrups. In India, wood apples are a seasonal fruit that ripens in October and is accessible until January. Plants have a maximum yield varies between 40.50 and 70.00 kg. The leaves are pinnate and have five to seven leaflets, each measuring 25 to 35 mm in length and 10 to 20 mm in width. When crushed, the leaflets release a citrus aroma. The flowers bloom with five petals and are white. The fruit, a berry with a diameter of 5 to 9 cm, can be sour or sweet. It looks greenish-brown on the exterior, has a tough rind that can be difficult to split open, and inside is sticky brown pulp with tiny white seeds (Kerkar *et al.*, 2020).



(a) (b)

Figure 1: Grayish white rind (a) sticky brown pulp of Wood apple (b)

4. Nutritional profile

4.1 Proximate analysis

The nutritional composition of wood apple was studied (Figure 2) and the results showed that the fruit has a high level of dietary fibre and moisture content (Table 1).The pulp is an important nutritional component that has a substantial impact on the human health and nutrition (Lamani and Anu-Appaiah *et al.*, 2022).

4.2 Polysaccharides

The Evaporative Light Scattering Detection (ELSD) based High-Performance Liquid Chromatography (HPLC) method has been used to examine free sugars and the results shown that defatted fruit pulp contains the total free sugar content as 31.59% dry weight (DW). Maltose (0.57%), sucrose (0.13%), and rhamnose (0.24%) made up the remaining amount. According to research, the fruit of wood apples varies in total sugar content between 7 and 9.6%, reducing sugar content between 1.04 and 4.09%, and non-reducing sugar content between 3.05 and 7.23% (Singh *et al.*, 2019).

4.3 Proteins

Nitrogen constitutes one of the macronutrients found in proteins, along with hydrogen, oxygen, carbon, and sulphur, and occasionally phosphorus, iron, and copper. Ulvie, (2022) reported that the fruit contains 4.3% protein can hydrolyze or break down into their individual components and similar compounds like fatty acids were

present. Another study indicates that wood apple had a 7.1% protein content and contains amino acids, including proline, serine, valine, histidine, threonine, glutamic acid, isoleucine, leucine, glycine, tyrosine, and phenylalanine (Murthy and Bapat, 2020).

Table 1: Nutritional composition of Wood apple pulp (100 g)

Nutrient value (%)		Vitamins (mg/100 g)		Minerals (mg/100 g)	
Water	64.2	Vitamin A	0.055	Sodium	8.5
Total dietary fibre	31.8	Vitamin B,	1.2	Manganese	0.7
Protein	1.8	Vitamin C	8.00	Zinc	386.3
Carbohydrate	31.8	Thiamine	0.13	Potassium	600
Fat	0.3	Riboflavin	0.03	Copper	0.21

Source: Baliga *et al*., 2011, Rodrigues *et al.*, 2018

4.4 Lipids

The fatty acid content of Wood apple pulp was examined and crude fat content of wood apple pulp was 0.99%; the description of fatty acid indicates greater proportion of unsaturated fatty acids. It has been found that α-linolenic acid (16.55%) and linoleic acid (10.02%) were the two most common polyunsaturated fats (PUFA) in the oil of wood apple pulp (Lamani and Anu-Appaiah *et al*., 2022).

4.5 Minerals and vitamins

The pulp of matured Wood apple is aromatic and sweet, and it also contains micronutrients such as iron(0.07%), phosphorus(0.08%), and 170 milligram riboflavin, along with 2 mg of the antioxidant vitamin C (Thakur *et al.*, 2020). Additionally, Wood apple has a notable amount of minerals, including calcium (15.9 mg), sodium (8.5 mg), iron (3.5 mg), phosphorus (46.5 mg), zinc (386.3 mg), manganese (0.7), and copper (0.8 mg)(Rodrigues *et al.*, 2018).

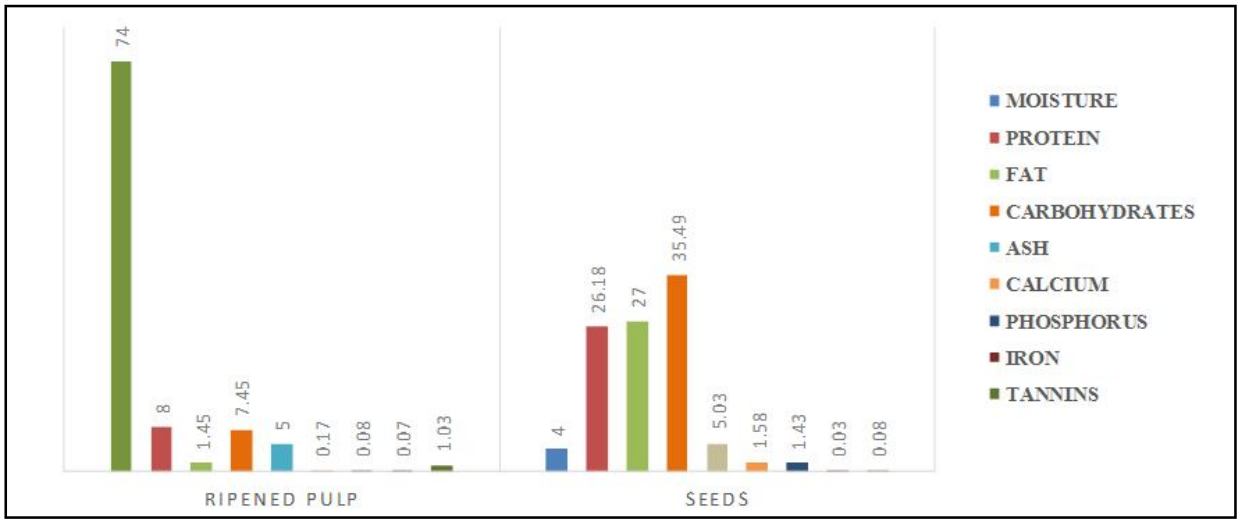


Figure 2: Nutritional composition of fruit pulp and seed of Wood apple.

5. Phytochemical profile of plant parts

Phytochemicals were compounds that occur naturally in plants and are considered vital nutrients, indicating human beings must consume them through diet in order to maintain normal physiological activities (Table 2). Phytochemicals that exist in wood apples include polyphenols, tri-terpenoids, amino acids, coumarins, saponins, amino acids, and tannins (Figure 3). In addition to being consumed by insects along with other living things, phytochemicals contain chemical substances that plants generate, usually to aid in their resistance to infestations by bacteria, fungus, and plant viruses.

5.1 Phenolic compounds

For plants to thrive, reactive oxygen species (ROS) need to be mitigated because they are detrimental to them. Additionally, phenols shield them from attack from insects, bacteria, and predators in addition to protecting against genetic damage. A research investigation was conducted to determine the total phenolic content (TPC) of pulp using the Folin-Ciocalteu (FC) method. The amount of phenolic yield ranged from 3.73 to 11.34 mg GAE/g, according to the results. (Pandey *et al*., 2014). A different investigation looked for TPC in dried wood apple fruit material. The results of the investigation showed that DW had a greater phenolic content, ranging from 3.01 to 7.23 mg GAE/ g (Kerkar *et al*., 2020).

5.2 Flavanoids

Their characteristics include the ability to suppress inflammation, inhibit oxidation, stop gene mutations, and ward off the growth of cancer. Additionally, they support the regulation of cellular enzyme activity (cell-stimulating proteins). According to another investigation, flavonoids demonstrate an extensive number of biological functions, such as extra bactericidal as well as antioxidant qualities, the induction of cell death, repression of enzymes in them, and suppression of cell growth. The extracts were shown to have a very high flavonoid content, with an average of 35.51 µg CE/mg (Pandey *et al*., 2014).

Table 2: Phytoconstituents present in different plant parts of Wood apple

Parts	Phytoconstituents	Reference
Leaves	**Flavones**: Orientin, vitexin	Murthy *et al.* (2020)
	Alkaloids: Psoralen, bergapten, saponins, essential oils, acidissimi and acidissiminol, gum and mucilage, fixed oils and fats, stigmasterol	Wakchoure *et al.* (2023)
Flowers	**Fatty acids:** Stigmasterol	Pitchai *et al.* (2012)
	Carbohydrate: Sucrose	Ulagi *et al.* (2011)
	Amides: N-(4-methoxy phenyl) acetamide, 1-[4-aminomethyl] (phenyl) ethanol, p- coumaric acid, N-phenylpropanamide, N-2- (methyl phenyl) acetamide	
	Alkaloid : quinone	
Fruit pulp	**Flavone glycoside:** 5, 4-dihydroxy-3-(3-methyl-but-2-enyl), 3, 5, 6-trimethoxy flavone-7-O-b-D-glucopyranoside	Dar *et al.* (2013)
Shell	**Volatiles:** Methyl hexanoate**,** ethyl-3-hydroxyhexanoate**,** butanoic acid.	
	Alkaloids: Coumarins, 2,6-dimethoxybenzoquinone, Osthenol, Psoralene**,** Xanthotoxin	
	Fatty acids: β-sitosterol, β-amyrin, palmitic, linoleic, oleic, linolenic, and palmitoleic acids	Wakchoure *et al.* (2023)
Bark	**Coumarins:** xanthotoxin, scopoletin, luvangetin, bergapten, psoralen, marmesin,	
	Osthol, 6, 7-dimethoxycoumarin and isoimperatorin.	
	Steroids: sitosterol-o-beta-d-glucoside	
	Flavones: 5, 7-dihydroxy-3', 4'-dimethoxy-6,8-di (3-methylbut-2-enyl) sitosterol -3-O-β-D-glucopyranoside, streptmasterol, tripterpenoids	Murthy *et al.* (2020)
Root	**Lactones:** Frenolin, lactone and geranylumbelliferone	
	Coumarin: Marmesin, aurapten, bergapten, osthol, osthenol, xanthotoxin, xanthyletin, 6-methoxy-7-geranyloxycoumarin.	
	Quinolone alkaloid: 1-methyl-4-methoxy-2-quinolone	Laphookhieo (2012)

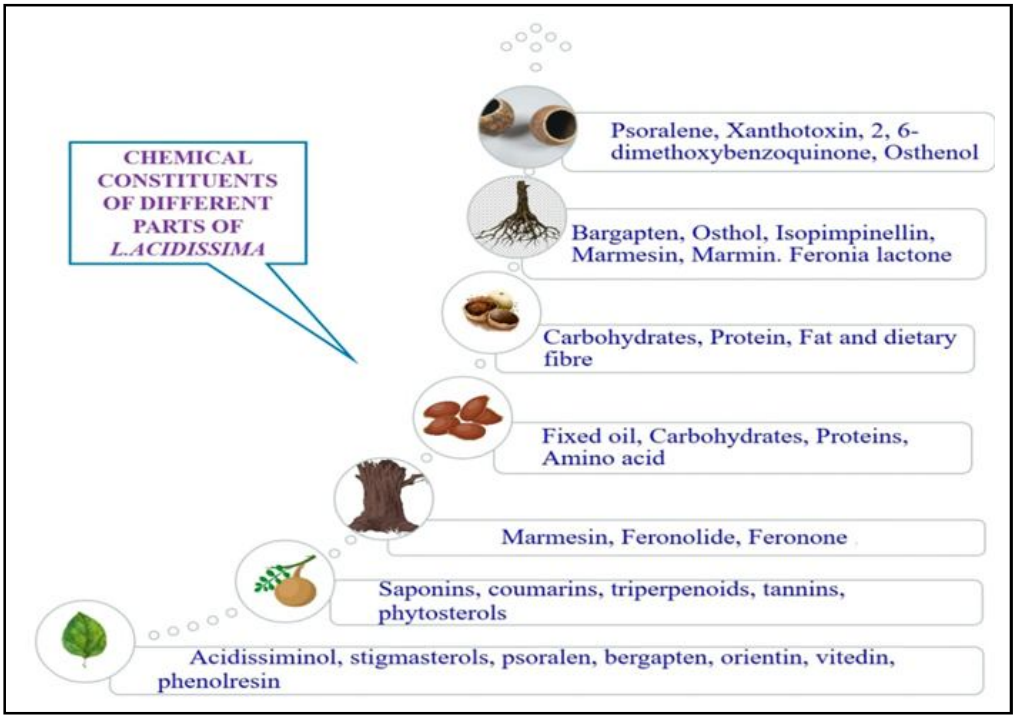


Figure 3: Chemical constituents present in different parts of Wood apple.

5.3 Alkaloids

Alkaloids were a class of chemical substances that exist naturally and predominantly consist of basic nitrogen atoms. Alkaloid compounds are crucial to the field of biomedical research. Their ability to operate as either hydrogen-donors or hydrogen-acceptors for hydrogen bonding, depending on the kind of amine functionality found in alkaloids, gives them a special quality. Alkaloids are chemical molecules with a smaller molecular weight that are found in nature and include nitrogen. The majority of them are produced by plants and animals as a defense mechanism (Pandey *et al*., 2014). In contrast, a different study discovered that wood apple fruit pulp has a respectable level of alkaloid (26.01 µg/mg).

5.4 Coumarins

In plants, the coumarins have antioxidants and enzyme-inhibition qualities. Additionally, they control the processes of photosynthesis and development and serve as the plant's defense against diseases. As a medicine, coumarin is employed for the treatment of excessive protein-induced lymphedema, enhance venous circulation, and has been investigated as an antineoplastic in clinical studies.

6. Pharmacological activity

Employing medicinal plants to cure illness has greatly assisted humanity since they are typically more secure, simpler to procure, and sometimes even more effective than synthetic drugs. Even though a number of traditional herbal remedies are currently receiving more attention, plant-based medicines are still an essential asset for healing severe ailments, especially in nations that are developing (Geddawy *et al*., 2023). The extracts and chemical compounds obtained from wood apples have demonstrated a range of pharmacological measures (Table 3), including antibacterial, anti-inflammatory, antitumor, antidiabetic, antioxidant, antimutagenic, analgesic, antimalarial, and hepatoprotective properties (Srivastava *et al*., 2019).

Table 3: Therapeutic properties of Wood apple

Variety/Region	Type of activity	Type of extract	Key findings	Reference
Wood apple	Anticancer activity	Ethanolic extract	Significant decrease in the proliferation of cancer cells	Shah *et al*. (2020)
Wood apple	Antioxidant activity	Glycoside extract	Phenolic glycoside extracts exhibited greater antioxidant action	Thakur *et al*. (2020)
Wood apple (Mysore)	Antioxidant activity	Methanolic extract	49.3-83.7% is the inhibition in DPPH, whereas 52.2-83.3% is the inhibition in ABTS, which assays	Illaiyaraja *et al*. (2015)
Wood apple (Uttar pradesh)	Antioxidant activity	Methanolic extract	IC_{50}-0.7 mg/ml	Pandey *et al*. (2014)
Wood apple	Neuroprotective activity	Methanolic extract	Extract from fruit showed a significant improvement in the neurobehavioral parameter	Thakur *et al*. (2020)
Wood apple	Antimicrobial activity	Methanolic extract	Highest antibacterial activity against *S. epidermidis*	Pandey *et al*. (2014)
Wood apple	Hepatoprotective activity	Methanolic extract	Reduction in the levels of hepatic markers	Murthy *et al*. (2021)
Wood apple	Antidiabetic activity	Methanolic extract	Significant protection against kidney damage rats	Thakur *et al*. (2020)
Wood apple	Anti-inflammatory activity	Aqueous extract	Inhibits protein denaturation	Sujitha *et al*. (2021)
Wood apple	Antispermatogenic activity	Ethanolic extract	Reduction in testicular protein content	Parvez and Sarker (2021)
Wood apple	Antiulcer activity	Methanolic and acetone extract	Protects the stomach mucosa and reduced the mucosal lesions	Parvez and Sarker (2021)
Wood apple	Analgesic activity	Methanolic and aqueous extract	Analgesic activity found	Islam *et al*. (2020)

6.1 Antioxidant effect

A diet rich in antioxidants may lower the chance of developing a number of illnesses, such as heart disease and several types of cancer. Antioxidants prevent or lessen oxidative damage by scavenging free radicals from cells in the body. Worldwide research on the preventive properties of antioxidants is still ongoing. Hydrolysed seed protein from *L. acidissima* may be a valuable source of antioxidant peptides (Sonawane and Arya, 2017). An investigation was carried out to assess the antioxidant ability of phenolic compounds found in the pulp of mature wood apple and it was measured using the Folin-Ciocalteu technique, and the antioxidant activity was ascertained using the 2, 2-diphenyl-1-picrylhydrazyl (DPPH) method. The results, demonstrated that the extract of phenolic glycosides had higher antioxidant activity than the traditional antioxidants such as Butylated hydroxytoluene (83.2%) with trolox (64.6%) (Thakur *et al*., 2020). Higher levels of HRSA (hydroxyl radical scavenging activity) were noted in the

methanolic extract of fruit. However, it turned out that the fruit's ethyl acetate infusion possessed ABTS [2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate)] Assay radical elimination abilities. When contrasted with other solvent-based extracts, the fruit's pure water extract additionally displayed possible elevated nitric oxide elimination of radical efficiency. Furthermore, there is an effective correlation between the phenolic and flavonoid content in these extracts from fruit and overall antioxidant ability (Shermin *et al.*, 2012).

6.2 Antidiabetic effect

Approximately 422 million individuals globally suffer from diabetes, with the majority residing in low- and middle-income nations. The disease is directly accountable for the 1.5 million fatalities that occur each year. In the previous decades, there has instance of ongoing increase in both the number of cases and the incidence of diabetes. Natural supplements and herbal medicines featuring fewer side effects are being proven as possible diabetes treatments that may enhance patient quality of existence (Sanjeev *et al.*, 2021). Ninety five percentage ethanolic extract of an unripened fruit was examined for their antidiabetic potential at 250 mg/kg body weight on streptozotocin-induced diabetic rats. The results revealed that the extract substantially decreased the levels of glucose in blood of the rats in both the fed and starved conditions. By encouraging insulin secretion, the fruit extract probably lowered blood glucose levels (Gupta *et al.*, 2009). In another study, the antidiabetic ability of wood apple was investigated in rats who had been given streptozotocin-induced diabetes and methanolic extracts of wood apples contained a considerable amount of flavonoid components, according to the initial stage of phytochemical screening. After 30 days of treatment with 200 and 400 mg/kg of the extract, the blood sugar and serum cholesterol levels of the diabetic rats significantly decreased. Moreover, there was an impact on the rat's capacity to gain weight. Results shown that in rats with diabetes induced by streptozotocin, methanolic pericarp extracts of wood apple provided significant protection against kidney damage in addition to having a considerable antihyperglycemic and antihyperlipidemia effect (Thakur *et al.*, 2020). The antidiabetic effect was tested on Wistar rats given alloxan using a methanol extract of pulp and it indicated that, when compared to the control, the extract significantly enhanced the rats' ability to tolerate glucose in cases of alloxan-induced diabetes. The extract reduced the glucose level in a dose-dependent manner. Furthermore, the extract considerably raised the amount of total protein in treated rats while dramatically lowering blood levels of urea and creatinine.

6.3 Antitumor effect

After cardiovascular problems, cancer is another leading cause of death. Genetic changes in DNA lead a natural cell to distort, resulting in beginning of cancer. This aberrant cell reproduces asexually, indicating that it ignores signals that control the proliferation of nearby cells, obtaining invasion characteristics and altering the tissues within its nearby vicinity. More attention should be given to the quick advancement in plant phytochemical research, which is gaining popularity due to its anticancer properties. The essential oils from the leaves of wood apple have cytotoxic and antioxidant properties. The 3-[4,5-dimethylthiazol-2-yl]-2,5 diphenyl tetrazolium bromide assay (MTT) and DNA fragmentation assay were used in the study to assess the anticancer activity of *L. acidissima's* fluid extract over the MCF7 cell lines at various doses and the outcomes demonstrated that 52.01% cell viability and 47.99% cytotoxicity at a dose of 15.6 µ/ml. These results shown that *L. acidissima* fruit flesh has a significant amount of cytotoxic capability against the breast cancer cell MCF7 (Sujitha and Venkatalakshmi, 2021). The findings of *in vitro* research demonstrated the many health benefits associated with wood apple, including its anti-inflammatory, antioxidant, and anticancer capabilities. Therefore, including this fruit into our diet on a regular basis is recommended to reap the benefits for this unvalued fruit.

6.4 Antidiarrheal effect

A gastrointestinal illness known as diarrhea distinguished by frequent passage of gastric contents through the intestine, abnormal fluidity, and frequent fecal evacuation, usually of partially solid or watery fecal matter, three or more times per day. Although, diarrhea isn't necessarily an indication of a serious illness, persistent diarrhea can be more dangerous. Senthilkumar *et al.* (2010) investigated the effects of an aqueous extract of bark on diarrhea and gastrointestinal motility, and they reported a significant reduction in diarrheal activity by lowering the average weight of faeces and GI motility.

6.5 Antimicrobial effect

Recently, there exists an ongoing search for new antibiotic compounds among natural plant products due to the growing issue of antibiotic resistance to drugs by pathogenic microbes during the previous decades. Both positive and negative effects can be attributed to many consumable food ingredients. Positive aspects include their antibacterial properties against various oral cavity microbes. The effectiveness of natural products as a source of antimicrobial agents against a range of pathogens has been assessed. Three gram positive bacteria (*S. aureus*, with a zone of inhibition of 18.3 mm, *S. epidermidis*, 25.3 mm, and *B. subtilis*, 15 mm) were used in a study to assess the antibacterial property of dried pulp and the result shown that higher-phenolic-content samples were more effective in preventing bacterial growth and produced a zone of clearance with a larger diameter (Pandey *et al.*, 2014). Antimicrobial action against *Salmonella typhi*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Klebsiella pneumoniae* has been shown by the protein hydrolyte of seeds at 300 mg/ml. Since psoralen, 2, 6-dimethoxybenzoquinone, osthenol, and xanthotoxin are antifungal compounds that are present in fruit shells contains antifungal properties, shells are effective against both types of bacterial cells (Gram-positive and Gram-negative) (Purwar, 2023).

6.6 Antiulcer effect

Although children are susceptible to peptic ulcer disease at any stage of life, it is typically diagnosed in teenagers between the ages of 12 and 17. Parental intervention and ongoing medical care is necessary due to the severity of this disease. The study revealed that fruit pulp is capable of preventing stomach ulcers in rats caused by indomethacin. By raising the intra-gastric pH and lowering the gastric HCl concentration up to 500 mg/kg, it helps to prevent stomach ulceration (Mishra *et al.*, 2009). By reducing mucosal lesions in a dose-dependent manner, *L. acidissima* extracts considerably protect the gastrointestinal mucosa from ethanol-induced damage. The leaves contain a wide range of phytochemical elements with distinct pharmacological effects. The literature analysis revealed that the entire plant contains glycosides, tannins,

and alkaloids. According to the recent study, rat models of ulcers caused by ethanol showed antiulcer efficacy when exposed to ethanolic extracts of wood apple leaves. The findings of using an ethanol-based leaf extract on Albino rats at doses of 200 mg and 400 mg/kg body weight revealed a substantial increase in the pH of the gastrointestinal juice of the rats that caused ulcer due to ethanol (Aneesha *et al.*, 2018).

6.7 Analgesic and anti-inflammatory effect

Anti-inflammatory activity plays a vital role in the process of wound healing. Cytokines and anti-inflammatory primary immune organs function as mediators to bring about the healing phenomenon. Additionally, these mediators regulate the biochemical process and inhibit the spread of illnesses. The analgesic effectiveness was shown against wriggling mice generated by acetic acid and was 60.53% on methanol and 59.65% on fruit peel acetone extracts, compared to 78.07% on the prescribed drug Diclofenac Na (Islam *et al.*, 2020). Employing an albumin denaturation inhibition test, the anti-inflammatory properties of an aqueous wood apple extract at five different concentrations of 200, 400, 600, 800, and 1000 g/ml of water-soluble extracts were evaluated for their ability to suppress protein denaturation. At a dosage of 1000 µg/ml, wood apple significantly reduced protein denaturation by 74.55% while this activity enhanced with an increase in extract concentration (Sujitha and Venkatalakshmi, 2021). Numerous medications, including immunosuppressants and nonsteroidal anti-inflammatory agents, are on the market in order to reduce or combat this kind of inflammation. Use the lowest effective dose of certain medications because prolonged use can cause side effects (Rahul *et al.*, 2023).

6.8 Antihistaminic effect

Among the most prevalent inflammatory mediators is histamine, which primarily promotes acute inflammation through the H1 histamine receptor, triggering allergic reactions. Histamine synthesis is effectively inhibited by an ethanolic extract including Polar components that are isolated from leaves of wood apple (Akhter *et al.*, 2008).

6.9 Antidandruff and antiacne effect

Human scalps that have dandruff suffer dryness and itchiness. Approximately 50% of people are impacted by it, particularly those under the age of twenty. For those with dandruff, one of the primary issues is a loss of hair and one of the inflammatory diseases affecting the skin's pilosebaceous unit is acne. It impacts over 85% of teenagers worldwide. A study conducted to dock with the target enzymes, *M. globosa* lipase-1 and the beta-keto acyl synthase-III of Cutibacterium acnes. Remarkably, the docking experiments revealed that the target enzymes comprising *C. acnes* beta-keto acyl synthase-III and *M. globosa* lipase-1, respectively, had the greatest atomic contact energy (ACE) for isopimpinellin and saponarin, respectively. As a result, this latest finding provides novel perspectives on the potential of the 11 selected ligands of *L. acidissima* as effective antiacne and antidandruff medicines (Vishnupriya *et al.*, 2024).

6.10 Antibilious effect

Bilious is a word from the 1800s and 1900s used to describe excessive emissions (passing gas), discomfort in the stomach, constipation, and poor digestion. The tree's bark has antibilious properties which can be consumed either as a decoction or as a powder. The juice of leaves also applicable directly to rashes on the skin brought on by biliousness (Jayakumar and Geetha, 2012).

6.11 Antihepatotoxic effect

By lowering the level of oxidative stress, eradicating viral infection, blocking cell development, and blocking or regulating metabolic processes, botanical medicines or phytonutrients were effective against liver disorders (Nadeem *et al.*, 2022).An investigation into the prospect of hepatoprotective benefits of pulp methanolic extract on the liver injury brought on by carbon tetrachloride administration in rat animal models and the research outcomes revealed a rise in performance of antioxidant enzymes, including glutathione peroxidase (GP), catalase (CAT), glutathione dismutase (SOD) and glutathione (GSH). Rats were administered different doses of extracts for three days, which led to decreased levels of hepatic biochemical markers and elevated levels of antioxidants (Murthy and Paek, 2021).

6.12 Diuretic effect

Experimental mice showed a diuretic response to methanol extracts from fruit prepared by the methods of bath sonicator extraction (BSE) and microwave-assisted extraction (MAE). It was also found that within five hours of delivery, a noticeably higher production of urine was observed as well as rise in levels of excretions of potassium, sodium, and chloride ions observed in the urine. The presence of triterpenoids, flavonoids, glycosies, coumarin, and polyphenols in the methanolic extracts (obtained using MAE and BSE) may be the cause of the diuretic property of *Feronia limonia* (Parial *et al.*, 2009).

6.13 Antihyperlipidemic effect

Wood apple fruit powder provided with 2.5, 5, and 10 g/kg body weight for 28 days lowers the levels of hepatic glucose-6-phosphatase, lipid profile, and substantial rises in HDL, hexokinase, and hepatic glycogen. Ascorbic acid, fibers, saponins, phytosterols, polyphenols, and flavonoids might be contributing factors to it (Rupal *et al.*, 2013).

6.14 Antifertility effect

The pulp extracted with ethanol inhibits spermatogenesis, which can hinder male rat reproductive functions. Moreover, seminal vesicular fructose levels were lowered, which might have an impact on sperm motility. The pulp from fruits might have transient antisteroidogenic as well as antispermatogenic properties effects. The antispermatogenic capacity of pulp were investigated in male adult rats were given treatment using ethanolic extracts at 500 and 250 mg/kg for 55 days, which resulted in the number, motility, and viability of sperm declined (Dhanapal *et al.*, 2012).

6.15 Immune modulatory effect

The ability of leucocytes, or white blood cells, to generate antibodies in response to an assortment of disease-causing infections essentially keeps our immune system functional. Consequently, the demand for foods that enhance immunity has emerged in recent years. The primary compound that have been found as saponins, glycosides, tannins from the fruit which contains hydroxyl groups, phenolic substances have the ability to either trigger or depress the immune system. These groups also have the ability to alter the electron-

transferring system or a metabolic enzyme, which can have an immune modulatory effect, particularly on the phagocytic process (Tripathy *et al.*, 2014).

6.16 Antiageing effect

Wood apple contains vitamin C, which promotes the human body's natural production of collagen. It supports the prevention of UV-sun exposure-induced oxidative injury and preserves the appearance of the skin for decades. So, it is especially effective at promoting the antiageing effects of diets rich in antioxidant components (Yadav *et al.*, 2018).

6.17 Rejuvenating effect

The wood apple is abundant in β-carotene, which is the precursor of vitamin A. It also has an adequate amount of vitamin B, which includes thiamine and riboflavin, and trace amounts of ascorbic acid, or vitamin *C. Collagen* is impacted by thiamine during the healing process (Sharma *et al.*, 2024). It was just revealed that riboflavin deficiency slows the process by which wounds heal and reduces the maturity of collagen. Enforcing the wound-breaking strength, reducing the epithelial growth duration, enhancing the wound contraction, and raising the weight of the tissue granulation at the level of hydroxyproline at 400 mg/kg contributed to the wound rehabilitation activity (Ilango and Chitra, 2010).

6.18 Antidermatophytosis

A fungal super infection particularly the ring worm infection's severity can vary from moderate, scaly lesions to erythematous, exudative infections. Numerous phytochemicals, including psoralen, vitexin, bergapten, orientin, and saponarin, have been identified in wood apple seeds and are used to cure several kinds of illnesses, including ringworm (Intekhab and Aslam, 2009).

6.19 Detoxifying effect

Wood apple is an excellent approach to detoxify the body since they include compounds like thiamine and riboflavin. It is recommended to take the juice of a wood apple (50 mg/l) with sugar and warm water to aid in detoxification by purification of blood and removing toxins from the body (Vasant and Narasimhacharya, 2011).

6.20 Antinoxious effect

Both the pulp and the powdered rind are prepared as plaster to apply to harmful insect wounds and stings. Fruit pulp, bark, leaves, and roots are all used to prevent snakebites. The bark is administered to poisonous wounds after being chewed along with Barringtonia bark. Crushed bark is applied to venomous wounds and contains aurapten, 0.016% marmesin, bergapten, and other coumarins (Sivakkolundu and Loganathan, 2013).

6.21 Antiasthmatic effect

People of all ages are susceptible to the chronic lung disease asthma which causes swelling and narrowing of the muscles lining the airways, making inhaling harder. The study demonstrated that the fruits had a strong relaxing effect on the tracheal tubes of guinea pigs, surpassing theophylline at the concentrations applied. However, it is confirmed that the ethanol-based extract of plant pulp, which contains glycosides, alkaloids, flavanoids, sterols, saponins, tannins, and polyphenols, may be the cause of the antiasthmatic impact on tracheal networks of Guinea Pigs (Mahapatra *et al.*, 2014).

6.22 Antihyperuricemic and antigouty effect

The primary fatty acid group in *L. acidissima* possess the ability to regulate the function of proteins related to the expulsion of uric acid and the inhibitory pathway. By boosting uric acid excretion through the kidneys and preventing the inflammatory cascade, the ethanol extract of fruit may be able to alleviate a high level of uric acid production and gouty arthritis. The fruit of *L. acidissima* contains terpenoids, sterols, and fatty acids that may be used to treat gout arthritis (Yusnaini *et al.*, 2023).

6.23 Effect on muscle relaxation

Wood apple leaves were used in both the actophotometer and rotarod methods to determine the muscle relaxant activity. According to the results of the study, the mice's muscular coordination had significantly decreased. The presence of proteins, amino acids, and saponin was demonstrated by the ethanolic and aqueous extracts. The muscle relaxant may be due to the existence of these compounds (Praveen *et al.*, 2015).

6.24 Effect on cardiovascular system

Wood apples contain potassium, which is beneficial for heart health. Potassium helps in controlling blood pressure, lowers the risk of high blood pressure and cardiovascular illnesses, regulation of nerve impulses, muscle contractions and the equilibrium of fluids. Wood apple have a high potassium content (58.24 mg/100 g) having ability to lower blood pressure, prevent stones in the kidneys, lessen salt sensibility, and protect from stroke (Dyuti *et al.*, 2022).

6.25 Effect on nervous system

The effects of methanolic extract from wood apple and ischemia produced by vitamin E were examined in a study on neurobehavioral parameters. The findings of the study demonstrated that wood apple having neuroprotective properties against ischemia-reperfusion-induced brain damage in rats by altering certain biochemical markers in their brains (Thakur *et al.*, 2020). One of the main causes of death for which there is presently no effective treatment that is brain stroke. However, it has been demonstrated that *L. acidissima* possesses strong antioxidant activity and is neuroprotective against brain injury brought on by ischemia-reperfusion. When rats receiving fruit methanolic extract treatments were examined using neurobehavioral metrics, such as motor function, there was a statistically significant improvement. Enzymatic antioxidants like SOD, the superoxide dismutase and catalase had considerably greater activity in the neurons of rats than in the biochemical parameters measuring total nitrite and lipid peroxidation (Shah *et al.*, 2020).

7. Applications of Wood apple in ethnomedicine

The wood apple is known for its therapeutic qualities, making it an important plant for medicinal purposes in India (Table 4). All components of the wood apple are utilized in Ayurveda therapies for venomous insect strings. Wood apple being a good source of beta-carotene, are also beneficial for liver issues. This fruit is utilized in cardiovascular tonics and contains thiamine and riboflavin, which have been shown to promote liver health (Thakur *et al.*, 2020).

Table 4: Ethnomedicinal properties of Wood apple

Plant parts	Ethnomedicine	Reference
Fruits and leaves	Combating scurvy, chronic constipation, influenza, dysentery, and capillary bleeding	Parvez and Sarker (2021)
Unripe fruits	Therapy for itchiness, pharyngodynia, and constipation in the traditional medical system	Diengngan and Hasan (2015)
Ripe fruits	Venomous strings	Parvez and Sarker (2021)
	Useful in the role of "liver tonic" as well as a curative medication for tumor and asthmatic	Parvez and Sarker (2021)
Fresh juice	Treatment for earache	Parvez and Sarker (2021)
	Treatment of various cardiac disabilities, such as gastric ulcers, hiccups, anorexia, indigestion, diarrhea, flatulence, vomiting, and cardio tonic disorders	Parajapati *et al.* (2003)
Leaves	Treatment for respiratory illnesses, progesterone shortage, infertility, fever, and breast and uterine cancer	Jayakumar and Geetha (2012)
Seeds	Treatment for heart ailments	Senthilkumar *et al.* (2010)
Spines	Menorrhagia treatment	Parvez and Sarker (2021)
Gum	Constipating, eliminating diarrhea, and preventing hemorrhoids	Jayakumar and Geetha (2012)

8. Contribution of Wood apple to nutritional and economic security

India is experiencing serious issues with food security, unemployment, and degradation of the environment due to the population explosion of the nation. In the coming years, staple crops will face significant challenges; hence, diversifying the crop composition to reduce dependence on staples will be crucial to attaining food production security. Consumer awareness of the nutritional value and overall wellness of their food basket is growing in modern times. There is a trend away from synthetic and processed foods and toward obtaining nourishment from natural sources. These neglected fruits are the primary sources of income for the underprivileged and are crucial in combating the issue of malnutrition. Wood apple is differentiated by its high value for use, local abundance, restricted geographic variation, wide adaptability to agro-ecological nooks and marginal areas, insufficient scientific information, and confined current application compared to their prospective value to the economy. These fruits are still consumed and traded in relatively small amounts, and commercial production of such minor fruits is not yet accomplished or extensively produced. This fruit crop has an immense amount of economic potential and is important because it provides the underprivileged in rural areas with a supplementary diet full of nutrients and a source of additional income. Many millions of people, primarily in poor nations, depend extensively on the production of these indigenous plants for their survival and revenue. This fruit gives non-indigenous people supplemental nourishment, acts as a source of income alternative for indigenous people, and is a primary food supply for them. It is believed that the abundance of these fruit plants in their natural habitat can be easily cultivated for commercial purposes. Under such circumstances, it is possible to produce nutritious fruit products like juice, jam, jelly, and pickles to increase the income of underprivileged rural residents and increase their standard of living (Srivastava *et al.*, 2017).

9. Application of Wood apple in beverage industry

Pharmacological and dietary components have been separated by the complex interactions between cell membranes, the matrix, and individual cells. Whole, fresh foods work with the digestive tracts of people to progressively break down the complex carbohydrates. This raises the knowledge of medical professionals by enabling whole foods to deliver nutrients and other beneficial components to different parts of the gut (Vaidya *et al.*, 2022). Because of their remarkable flavour and nutritional value, wood apple have distinctive phytonutrients composition and a significant potential to bring value for fruits, especially in the beverage industry. Reports indicate that while there are not several commercial products on the market, a drink developed with fruit has a refreshing and cooling effect (Thakur *et al.*, 2020). Since many of the food products made from wood apples are novel to customers, it is therefore necessary to bring additional products onto the market and assess their economic worth. Foods that promote health are gaining popularity among consumers. This has further influenced customer preference for plant-based products and raised demand for foods packed with nutrients and healthy foods that can improve society's overall well-being (Chhikara *et al.*, 2018). This will promote the expansion of the wood-apple processing industry in addition to providing new chances to maximize the exploitation of robust fruit with high yields.

10. Utilization of Wood apple in food industry

Because apple presents versatile applications in the food industry due to its distinct flavor profile and nutritional advantages. Its inherent sweetness and high pectin concentration make it ideal for setting and thickening jams without requiring additional additives. In desserts, wood apple pulp can be incorporated into ice creams, sorbets, and yogurt, offering a refreshing citrus-like flavor that contrasts well with creamy textures. Moreover, its high fibre content makes it a valuable component in bakery items such as cakes, muffins, and bread, where it not only enhances nutritional worth but also contributes to the texture and moisture of the final product. Wood apple extracts and concentrates can be used as natural flavourings and additions in sauces, dressings, and beverages in addition to their use in direct food products (Poongodi Vijayakumar *et al.*, 2013). It is a desired ingredient for improving the nutritional profile of these products and may have health advantages due to its

antioxidant capabilities. As consumer preferences shift towards natural and functional foods, wood apple provides food manufacturers with an opportunity to innovate and differentiate their products in the market, appealing to health-conscious consumers seeking wholesome and sustainable food choices.

10.1 Candy and snack Items

Wood apple pulp can be used to make preserves, jams, and jellies. It can be thickened because of its high pectin content. The pulp of the fruit can be used to make candy and chews, which are frequently made with flavors or other fruits added.

10.2 Confectionary

Wood apple pulp is occasionally utilized in the production of these desserts. These frozen sweets get a tropical twist from its distinct flavor. The fruit has a unique flavor that goes well with other ingredients when used as a filling for pies and tarts.

10.3 Sauces and dressings

Wood apple can be used in savory sauces, especially in fusion cuisine where its tartness balances rich flavors. Its flavor profile makes it suitable for crafting unique salad dressings, adding a touch of exotic taste**.**

10.4 Traditional and regional cuisine

In South Asian cuisine, wood apple is often used in chutneys and pickles. Its tangy taste pairs well with spices and other ingredient. It can be incorporated into curries and stews, where its flavor complements a range of spices and ingredients.

10.5 Health food

Wood apple is rich in dietary fiber, vitamins, and minerals. It can be processed into powder or capsules for use as a nutritional supplement. Due to its potential health benefits, such as aiding digestion and having antioxidant properties, wood apple is explored in functional food products.

11. Preserved products

Consumers who are concerned about their well-being are currently encouraging the development of functional foods that are high in bioactive substances, including polyphenols, antioxidants, and prebiotics, that improve health and diminish the risk of disease. Future health relies on this trend, and to counteract growing healthcare expenditures, further studies and technological advances will be required. Consequently, the fruit pulp has been utilized to make plenty of food products, including jam, jelly, wine, fruit bars, chutney, pulp powder, and sherbet (Poongodi Vijayakumar *et al.*, 2013) (Table 4). In addition to giving a dairy-based product different flavors with prolonged shelf-life, fewer calories, the addition of wood apple powder would improve the appeal of this valuable fruit. If appropriately directed, the value-added products of these fruits are anticipated to capture both domestic and foreign markets (Figure 3). However, only a finite amount of fruit is used in the manufacturing of products.

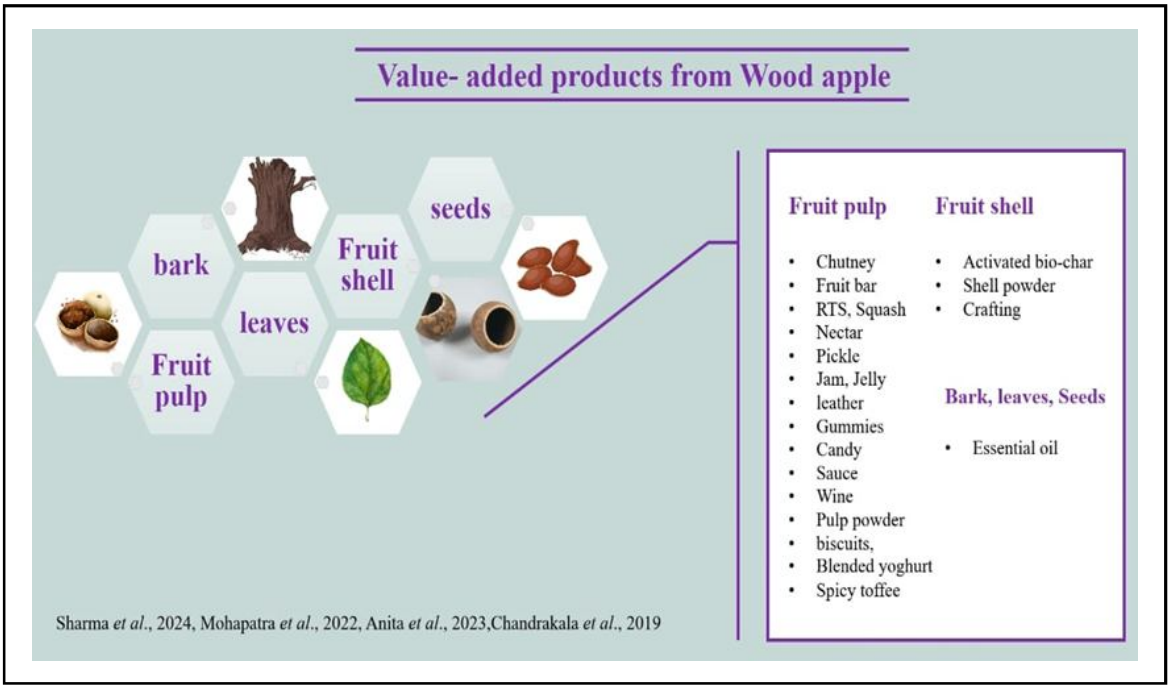


Figure 3: Value added products from different parts of Wood apple.

12. Conclusion

Based on scientific research, it may be inferred that many edible plant species include unique qualities that could be developed into new ingredients with beneficial health effects or used to make dietary supplements or healthcare foods. Due to the prohibitive price of synthetic medications and their adverse reactions, these plants are becoming increasingly significant at the global level, in both industrialized and underdeveloped countries. Due to their affordable price and lack of adverse effects, herbal medications are widely accepted. The demand for functional food items is expanding due to people's changing views on nutritious eating and their own health.

Thus, a number of ethno botanical goals have been investigated in relation to the study of underutilized plants and their products. The wood apple has been utilized traditionally to treat several kinds of ailments in people. The fruit is well-suited to be developed as a super-food due to its nutritional composition and several bioactive components. The fruit is currently underappreciated and has only been used locally, despite its numerous health benefits. In addition to investigating the potential for utilizing various plant components for medicinal purposes, commercial promotion of the manufacturing of various functional products from fruits is necessary. It might be developed as a functional food product in future generations that contributes significantly for maintenance of healthy lifestyle.

Future prospects

The wood apple is expected to have a significant impact on sustainability and health in the future. Investigating its molecular details may lead to advanced therapeutic applications and improve its ability to regulate a range of physiological functions, especially those related to its anti-inflammatory and antioxidant characteristics (Sujitha and Venkatalakshmi, 2021). In addition, the challenges engaged in the creation of functional foods and nutraceuticals, like dealing with patents and supporting health claims, may provide possibilities for innovation and lead to the development of products derived from wood apples that have been shown to have positive health effects (Dixit *et al.*, 2023). The shell is biodegradable that has ecofriendly applications like reinforcing material for natural fiber (Murthy and Bapat, 2020).The pharmaceutical and cosmetic industries may also use the essential oil produced from wood apple since it includes a variety of health-promoting substances (flavonoids, polyphenols, and phytosterols). Cultivation of wood apple trees promotes biodiversity and provides economic opportunities in rural areas. research continues to unveil its medicinal properties, including its antimicrobial and antioxidant effects, wood apple is poised to emerge as a versatile resource for both biomedical applications and innovative food products. In the food industry, wood apple could serve as a natural flavoring agent or additive, enhancing nutritional profiles and promoting health benefits. Future research and innovation on wood apples will be part of the comprehensive strategy that also understands the fruit's potential to benefit industry, advance health, and contribute to the sustainability of the environment.

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Conflict of interest

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

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