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A Comprehensive Review on Phytochemical and Pharmacological Properties of Wood Apple (Feronia Limonia)

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Abstract: ***Wood Apple (Feronia limonia L.), a member of a Rutaceae family, is an underutilized yet nutritionally and medicinally important fruit widely found in India and other tropical regions. Traditionally regarded as a "poor man's fruit", it has gained attention due to its rich phytochemical composition and diverse therapeutic properties. The fruit grows in semi-arid and dry climates, demonstrating high adaptability and draught tolerance. Despite its abundance, its commercial cultivation and utilization remain limited. Pharmacological studies have reveled multiple biological activities of wood apple, including antidiabetic, antimicrobial, anticancer, antioxidant, hepatoprotective, antiulcer, and anti-inflammatory effects. Experimental studies demonstrate its ability to reduce blood glucose level, improve lipid profiles, and enhance antioxidant enzyme activity. Additionally, extracts of wood apple have shown inhibitory effects against several pathogenic microorganism, supporting its antimicrobial potential.***

Keywords: ***Wood Apple (Feronia limonia), phytochemicals, antioxidant activity, pharmacological properties, antidiabetic activities, nutraceuticals potential.***

I. INTRODUCTION

Most popular underutilized fruit crop in India is the wood apple, a prickly tree. Its botanical name is Feronia (F. limonia L.), and it is a member of the Rutaceae family [1]. Before processing the methods were established in the mid-1950s, wood apple fruit was considered a "poor man's food" in India [2]. The tree is given the genus Feronia in honor of the Roman goddess of forests [3]. Since elephants like it, it is sometimes known as monkey fruit or elephant apple in addition to wood apple. Other common names for wood apples include "curd apple," "golden apple," "stone apple," and so on; these names usually depend on the language, place, and culture. Rural residents believe that the animal's digestive tract has a special capacity to break down the fruit's insides without sacrificing its hard exterior. Consequently, when the animal excretes, the fruit appears whole[4,5].Other dialect names in Thailand include ma-khwit, Kramsang in Cambodia, Ma-fi in Loas, Gelingggai or Belinggai in Malaysia, pomme d'elept, hanpomme de bois, or citron des mois in French, Tuffâhh elfîl in Arabic, Kathbelin in Bangladesh, Thibin, Thanaka, and Tha nap-hkain Burmese, mu ping guo, mu ping kuo in Chinese, elefantaeble in Danish, olifantsapple in Dutch, kabeet, and Vakandra in Hindu, and Elefantenapfel in German.It is referred to by various names in

India, including Kayatbael, Kavataleal, Kavita in Bengali, Askotha, Kondhu in Gujarati, Kaitha in Hindi, Kavatha in Marathi, Vilamaram, Vilangai in Tamil, and Kaith in Urdu, among others. One tropical tree is the wood apple [7,8]. With the exception of India's chilly and high-altitude regions, it is one of the hardiest fruits to grow in semi-arid and dry environments. When unripe, fruit has an acidic quality, but when ripe, it has a nice flavor [9]. This deciduous tree features oddly pinnate leaves and globose, orange-sized fruits with a hard, woody rind. It belongs to the orange subfamily Citratae of the Rutaceae family, which also contains the genera Feroniella, Aegle, Chaetospermum, Balsamocitrus, and Aeglopsis. It is a common hard-shelled citrus fruit. Wood apple trees can be effectively grown in regions with mean annual temperatures of 20 to 350 degrees Celsius and mean annual rainfall of 25 to 60 centimeters. The wood apple is typically grown from seeds, which germinate 7–14 days after sowing. However, seedlings need at least 8–10 years to develop fruit, thus grafting and budding are used in commercial propagation to ensure precociousness. Planting trees is typically done during the rainy season, but if irrigation is available, it is best to plant them in February or March because that is when they grow the fastest. For maximum yield, grafted plants should be spaced 8 m by 5 m [10]. Wood apples can be kept year-round for human use as processed foods like jam, chutney, and jelly. They are a cheap, highly nutrient-dense, easily perishable, and seasonally available fruit [11]. It is widely valued for its medicinal qualities in Ayurveda, where it is supposed to heal liver problems, diarrhea, dysentery, respiratory problems, and piles. With its remarkable ability to satisfy thirst, wood apple juice has a lot of potential to grow into a significant crop in the beverage production sector.

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Fig No. 1. Wood Apple (Feronia Lmonia)

Wood apples are typically consumed raw in Indian homes because of their remarkable flavor and perfect ratio of tartness to sweetness. Herbal treatments are made from the bulk of the tree's parts. Diarrhea, dysentery, and dyspepsia can all be treated with the roots. The stem and root bark aqueous formulations are utilized topically to treat Wood fever, jaundice, eczema, urticaria, and malaria. Fruit extract is used to treat dysentery and diarrhea because it may reduce cholesterol [12]. Numerous microorganisms that cause illnesses in humans have Wood apple fruits are resistant to essential oils, which can be utilized to treat ear conditions such earaches. Wood apple fruit pulp can significantly raise hepatic glycogen, hexokinase, and HDL levels while lowering lipid profiles and hepatic glucose-6phosphatase levels [13]. C. albicans, A. tumefaciens, B. subtilis, P. fluorescens, and Escherichia coli are all inhibited by fruit extracts [14]. It exhibits anti-cancer properties as well. In pharmacological tests, the fruit and root showed hypoglycemic and antiamoebic qualities. Aegline, Marmesin, Marmin, and Marmelosin (also known as Imperatorin), a significant chemical component of wood apples with anticancer, antibacterial, and antiinflammatory properties, are among the plant's many alkaloids [15,16,17]. Two compounds that were isolated from seeds and had notable antiulcer effects were luvangetin and pyranocoumarin. The essential oil from the leaf has antifungal qualities. Cattle are fed the leaves, which have an anise-like scent [17].

II. HISTORY

In 1753, Linnaeus gave the wood apple its scientific name, Schinus limonia. In 1747, Linnaeus published his Account of Hermann’s Herbarium of Ceylonese Plants, which included a fairly detailed description. Under Limonia Acidissima, there are four citations. The common lime Citrus aurantifolia (Christmas.) Swing is most likely one of the two or more species found in Burman’s Thesaurus Zeylanicus. His own Flora Zeylanica is referenced in the second source, which undoubtedly relates to the wood apple. The wood apple or a nearly related species, Rumphius Herbarium Amboinense, is mentioned in the third citation. The fourth reference is Hesperethus acrenulata (Roxb.), Rheede, and Hortus Malabaricus. The next oldest generic name must be used as Limonia is therefore invalid. Published by Corrêa in 1800, this is Feronia, the name that is currently widely used. Feronia limonia (L.) n. comb is the oldest recognized name for the wood apple since Linnaeus initially described it as Schinus limonia in 1753. Similar to Roktogota (Haematocarpus validus), the wood apple (Limonia acidissima L.) is one of Bangladesh’s lesserknown fruits [18].

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III. ORIGIN AND DISTRIBUTION

The wood apple originated in Sri Lanka and South India. The parched plains of Bangladesh and the Pakistan are home to the wood apple, which is also commonly grown in Ceylon and India. The wood apple is found in west Africa ,Indo-China, and the philippine Island.Additionally Penang Island, Northen Malaysia, and Southest Asai all grow it. In Shrilnka and India, it is planted beside roads, on field boarders, and occasionally in orchards. In Malaysia and Indonesia, it is grown in parks and communities. The tree can reach a height of 450 meters above mean sea level (MSL) in the western Himalayas and the western Ghats, which are known for their high biodiversity [20]. It seems to be drought-tolerant and thrives on light soils. In India, a well-planted wood apple orchard is a rare occurrence. There is no information known about the acreage and productivity of this fruit crop in India. Typically, scattered trees can be found in homestead gardens, communal land on field bunds and road sides, and woodlands. In addition to being found in jungles, the tree is frequently cultivated as a border plant [22]. The tree may grow up to 450 meters above mean sea level (MSL) in the very biodiverse western Himalayas and western Ghats. It grows well in light soils and appears to be drought-tolerant. A well-planted wood apple orchard is uncommon in India. The productivity and acreage of this fruit crop in India are unknown. Scattered trees are typically found in woodlands, communal land on field bunds and road sides, and homestead gardens. The tree is commonly grown as a border plant in addition to being found in jungles. It is also said to exist in the woods of Chattisgarh, the Vidhyan hills of Uttar Pradesh, and some parts of Jharkhand's Hazaribagh, Palamau, and Chota Nagpur. It is dispersed throughout several districts in Uttar Pradesh, including Hardoi, Sitapur, Ayodhya, Bahraich, Gonda, Barabanki, Lucknow, Kushinagar, Etawah, and Kanpur. The wood apples in the Rajshahi and Gazipur regions are rather huge. The Indian region of Bundelkhand has a high biodiversity for wood apples, although being infrequently used. The agroclimatic conditions of Bundelkhand are quite promising for commercial farming. In Milkipur Tehsil, Faizabad, particularly in Ratapur village, fruits from wood apple trees were collected. Fresh wood apple fruit was sold in the local market in the Hardoi areas of Uttar Pradesh (U.P., India) [23,24].

IV. PHISICOCHEMICAL PROPERTIES

Beta carotene, a precursor to vitamin A, is abundant in wood apple pulp. It also contains substantial vitamin content, and it had little Ascorbic acid content amounts The pulp that has been scooped out can be consumed raw with or without sugar, or it can be mixed with coconut milk and palm sugar syrup and frozen as ice cream. Wood apples are consumed for breakfast in Indonesia after being combined with honey. India uses wood apple pulp to make savory chutneys. Despite all of these advantages, this fruit is largely overlooked in India and is thought to be a minor fruit crop.

However, in the majority of the tribal areas of central India, it is readily available in large quantities and can be easily turned into chocolate. Fruits are used in India and have a strong therapeutic value. In traditional medicine, unripe fruits are used as an astringent remedy for dysentery and diarrhea, and as a liver and cardiac tonic. It works well to cure gum disease, sore throats, and hiccups. The fruit has therapeutic qualities as well, making it one of India's useful medicinal plants. Essential oil derived from wood apple fruits was found to have antimicrobial action and to be effective against twelve human pathogenic microorganisms.The brown pulp has scattered seeds and is resinous, astringent, fragrant, and acidic or sweet. The fruit could be little and acidic or big and sweet.Because wood apples are inexpensive and may cure thirst, they are used as a good supply of juice during the harvest season. The wood apple apples are used to make a homemade beverage called "sarbat." The full fruit's flesh Indigestion, diarrhea, and piles can be effectively treated using a blend of cardamom, honey, and cumin seeds. Additionally, wood apple pulp was utilized to make the powder. The product is dehydrated and has incredibly extended shelf life with no noticeable changes. The nutritive value also rose with the inclusion of ginger and aonla powder. Wood apples were found to have an average chemical composition of 10.67 to 14.33 °Brix for TSS, 1.04 to 4.50% for acidity, and 4.08 to 4.47% for total sugar. The fresh wood apple fruits' nutritional and chemical characteristics 6.3g protein, 15.6g titrable acidity, 2.6 mg/100g vitamin C, 235 mg/100g total phenol, and 1412.55µg/g total antioxidant capacity were found in it.Fruits' perishable nature and seasonality in production necessitate their preservation for year-round human consumption, given their importance as a major contributor to human well-being and as a more affordable and superior source of protective foods[25].

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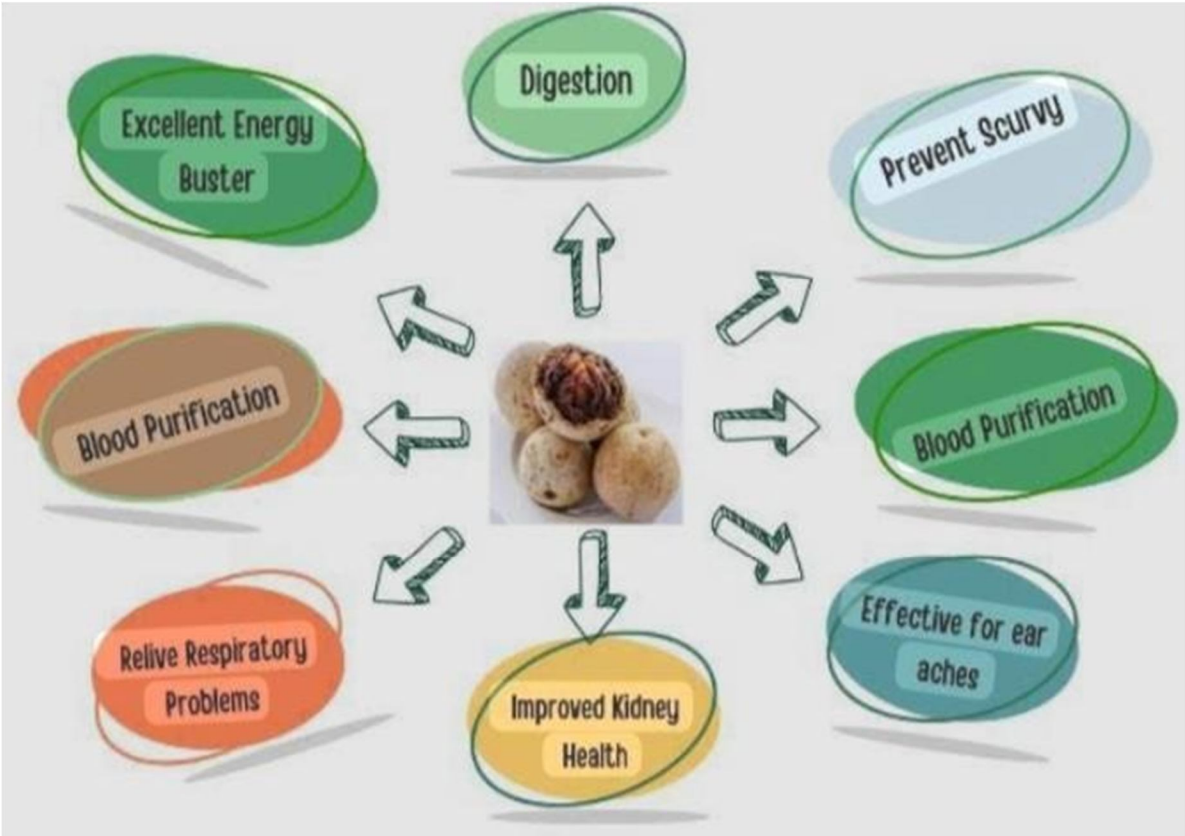


Fig No. 2. Physicochemical Properties

V. PHYTOCHEMICAL AND ANTIOXIDANT PROPERTIES OF WOOD APPLE

Plants are known to have naturally occurring chemical compounds that are physiologically active, protect plants, and improve human health. Since phytochemicals and their byproducts are antioxidants. They might be able to stop chronic illnesses. Sugars, amino acids, proteins, purines, pyrimidines, alkaloids, terpenes, and phenolics are among the phytochemicals. Carotenoids, flavonoids, cinnamic acids, benzoic acids, folic acid, ascorbic acid, and tocopherols are among the antioxidants found in wood apples. The wood apple's edible portions are abundant in phytochemicals and antioxidants, which are the main types of these substances [26,27,28].

Table.1. Some phytochemical and antioxidants contents of wood apple [28,29]

Phytochemical and Antioxidant	Quantity	Unit
Alkaloids	36	g.100g^-1 of dry matter
saponins	0.16	g.100^-1 of dry matter
Total phenols	35.72	Ug GAE.mg^-1
Flavonoid	35.51	Uggae.mg^-1
Ascorbic acid	0.45	ug. g^-1
Beta Carotene	0.04	ug. g^-1
Riboflavin	0.23	Ug. g^-1

VI. PHARMACOLOGICAL PROPERTIES

A. *Anticancer Properties*

Wood apple leaf essential oils have cytotoxic and antioxidant properties. shown that 89.19µg/ml of essential oil reduces DNA fragmentation in the human cancer cell line MCF-7 (Michigan Cancer Foundation-7). Similarly, ethanolic fruit extracts are evaluated for their antineoplastic activity on human breast cancer cell lines (SRBR3 and MDA-MBA435), with effective dose ED50 values of 56.1 and 30.6 µg/ml, respectively. The in vitro anti-tumor activity of fruit methanolic extracts at an oral dose of 570 mg/kg body weight on a mouse model of Dalton's Ascitic Lymphoma (DAL) cell revealed that treatment with extract increased the number of nonviable cells in peritoneal exudates and decreased the number of viable cells. This could be due to the extract being absorbed by viable cells, which ultimately led to cell lysis through macrophage activation or the production of cytokines. RBC and hemoglobin content were also restored by the extract [30,31]. Flavonoids may be responsible for the fruits' anticancer properties [32].

B. *Antidiabetic Properties*

95% ethanolic extracts' ability to prevent diabetes When unripe wood apple fruits were administered at a dose of 250 mg/kg body weight to rats with streptozotocin-induced diabetes, the animals' blood glucose levels were significantly reduced. Alloxan-induced diabetic rats also show hypoglycemic symptoms [33]. Methanolic extract works well to prevent hyperglycemia at 1.75g/kg body weight. A 21-day study using 200 mg/kg of wood apple bark 400 mg of methanolic extract per kilogram of body weight lowers blood sugar by 54.5 and 39%, respectively [34]. Alloxan-induced rats had a comparable effect, which was measured by blood serum levels as well [35]. After drinking fruit juice for ninety days, there was a notable reduction in blood sugar levels while fasting and after meals [36].

C. *Antihyperlipedimic Activity*

Fruit powder administered at 2.5, 5, and 10 g/kg body weight for 28 days significantly enhances hepatic glycogen, hexokinase, and HDL while lowering the lipid profile and hepatic glucose-6phosphatase. Fibers, flavonoids, polyphenols, saponins, phytosterols, and ascorbic acid may be the cause of it [37].

D. *Antioxidant Activities*

Water, petroleum ether, chloroform, ethyl acetate, and methanol extracts were used to assess the antioxidant activity of wood apple pulp [38]. They found significant antioxidant activity using assays for 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, hydroxyl radical scavenging (HRSA), ferric reducing antioxidant power (FRAP), nitric oxide radical (NO) scavenging, Trolox equivalent antioxidant capacity (TEAC), and total antioxidant activity (TAA). Antioxidant activity of petroleum ether, methanolic extract, and chloroform in vitro DPPH was used to determine the wood apple leaf the results of the radical scavenging activity, nitric oxide radical scavenging activity, and hydrogen peroxide scavenging activity technique show that every extract has adequate antioxidant qualities [39,40,41]. Additionally, methanolic extract was successful in combining antioxidant enzymes including catalase, superoxidase, and dismutase [42]. Enzymatic antioxidants such as glutathione, superoxide dismutase (SOD), catalase (CAT), and peroxidase were shown to be more active after 30 days of oral treatment of ethanolic leaf extract at 200 mg/kg body weight [43].

E. *Hepatoprotective Activities*

The hepatoprotective effect of pulp methanolic extracts was assessed against rats' liver damage caused by carbon tetrachloride (CCl4) [32]. They discovered that rats treated with 100, 200, and 400 mg/kg i.p. for three days had higher levels of hepatic enzymes, particularly aspartate transaminase (AST), alkaline phosphatase (AST), total protein (TP), total bilirubin (TB), and gamma glutamyltransferase (GGT), and lower levels of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and glutathione (GSH). Another study found that aqueous leaf extract increases the levels of alkaline phosphatase (ALP), aspartate aminotransferase (AST), and alanine transaminase (ALT) in the serum. Additionally, compared to the normal control, it raises the levels of urea, creatinine, potassium, and sodium in the phenyl hydrazine-induced anemic non-treated rats [44].

F. *Diuretic activity*

Urine production has been significantly increased by the leaves' methanolic extract. The extraction method determines the degree of urination and electrolyte excretion, specifically sodium, potassium, and chloride ions. It was discovered that Bath Sonicator extraction (BSE) is less active than Microwave Assisted Extraction (MAE) [45].

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G. Antiulcer and Wound Healing Properties

Wood apple fruit pulp has been shown to be effective against rats' stomach ulcers caused by indomethacin. By lowering the concentration of stomach HCl, it prevents gastric ulcers at 500 mg/kg. by raising the pH within the stomach [46]. At 400 mg/kg of the extract, the woundbreaking strength was tightened, the epithelization period was shortened, the wound contraction was raised, and the granulation tissue weight and hydroxyproline concentration increased [36]. By reducing mucosal lesions in a dose-dependent manner, acidissima extracts considerably shield the stomach mucosa from damage caused by ethanol. At 400 mg/kg leaf extract, the fruit's phenolic chemicals provide protection against gastric wall ulcers and leucocyte infiltration in submucosal layers [47].

H. Analgesic Activities

Analgesic activity against writhing mice generated by acetic acid was reported to be 60.53% on methanol, 59.65% on fruit peel acetone extracts, and 78.07% on the common medication Diclofenac Na [48].

I. Neuroprotective Activities

An evaluation of wood apple's neuroprotective properties revealed that it reduces ischemia at 250 mg/kg and 500 mg/kg body weight. Brain damage caused by reperfusion in rats [49].

J. Spermatotoxic Activities

The wood apple fruit's antispermatogenic properties by administering ethanolic extracts at 250 and 500 mg/kg for 55 days, pulp in adult male rats was found to be the cause of the decrease in sperm count, motility, and viability. Additionally, they decreased testicular protein content by 29.86% and increased the fraction of aberrant sperm by 24.58%, respectively [50].

K. Antidiarrheal activity

Wood apple aqueous bark extract was shown to have significant antidiarrheal and gastrointestinal motility-reducing effect by lowering average feces weight and GI motility [51]. The data was similar By Thomas technique on diarrhea brought on by castor oil Peel extracts containing 500 mg/kg of methanol and acetone and found inhibitions of 47.13% and 44.83% [48].

L. Antimicrobial Activity

At 250 mg/kg, the methanol and acetone fruit peels extract exhibits moderate effectiveness, inhibiting Klebsiella oxytoca, Vibrio metschnikovii, Escherichia coli, Bacillus subtilis, and Staphylococcus aureus by 34.45% and 35.63%, respectively [48]. Z-anethole (22.1%), E-anethole (8.1%), Methyl chavicol (12.0%), and -pinene (28.4%) are among the essential oils found in wood apple leaves. It has antibacterial properties against eight Gram-negative bacteria (Escherichia coli, Klebsiella pneumonia, Serratiamarcescens, Proteus mirabilis, P. vulgaris, Pseudomonas aeruginosa, Salmonella Typhimurium, Enterobacter aerogenes) and five Gram-positive bacteria (Staphylococcus aureus, Micrococcus flavus, M. luteus, Bacillus subtilis, and Candida albicans).
Additionally, the oils have minimal inhibitory concentration values of 0.31, 0.52, 0.20, and 0.26 Mg/ml against Micrococcus luteus, Proteus mirabilis, Penicillium chrysogenum, and Aspergillus niger, respectively [52]. Agar well was also used to evaluate antibacterial activity. Diffusion technique against a gram negative bacterium (Proteus mirabilis) and three gram positive bacteria (Staphylococcus aureus, Bacillus subtilis, and Staphylococcus epidermidis). The plant's various sections contain essential oils that have antimicrobial properties [53]. MIC is the minimum inhibitory concentration on leaf extract in methanol, hexane, and chloroform and demonstrate adequate activity [54]. Staphylococcus aureus, Bacillus cereus, Enterococcus faecalis, Escherichia coli, Salmonella Typhi, and Pseudomonas aeruginosa were tested against biosynthesized silver and zinc oxide nanoparticles, and the results showed 2021 44 effectiveness [55]. Additionally, antimicrobial activity against Salmonella typhi, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella pneumonia was assessed using the well diffusion method [56]. Another study indicated that the highest zone of inhibition for S. aureus, S. typhi, and P. aeruginosa was 15.16, 15.5, and 13.33 mm, respectively, when silver and zinc oxide nanoparticles were applied at 400 µg/ml. Even so, zinc oxide nanoparticles have less activity than silver nanoparticles [57]. At 12.5 µg/ml, these nanoparticles are also efficient against M. tuberculosis [58]. In Thailand, the wood apple has long been used to cure throat and mouth infections. assesses the antibacterial activity of 500 mg/ml of dried pulp and rind against Bacillus subtilis, Proteus mirabilis, Staphylococcus aureus, and Staphylococcus epidermidis. Other researchers have also reported that wood apples have antimicrobial properties [59].

M. Antifungal Activity

Wood apple fruit shells contain antifungal substances as osthenol, xanthotoxin, psoralene, and 2, 6-dimethoxy benzoquinone [30]. Using cup plate techniques, the antifungal activity of leaf ethanolic extracts was tested on M. gypseum, T. tonsurans, T. mentagrophytes, C. albicans, and least T. rubrumon in a dose-dependent manner [60].

N. Larvicidal Activities

With a 90% death rate at 3% aqueous extract, wood apple leaf is effective against Culexquinque fascist larvae. Additionally, the methanol and chloroform extract exhibits 95% mortality at a concentration of 100 ppm [61]. The presence of terpene in wood apple leaves, which inhibits Aedesaegypti eggs, larvae, and pupae, was discovered to have mosquitocidal activity. The larvicidal and pupicidal properties of the extracts are excellent. L. acidissima hexane extract exhibits ovicidal action against Cx eggs at concentrations of 79.2% and 60% at 500 ppm. Ae. and Quinquefasciatus [62,63].

VII. PRECAUCTION, SIDE EFFECTS AND DISADVANTAGES

Although wood apple have many nutritional and therapeutic benefits, eating them should be done with caution as they may have negative effects. Some of these are listed i.e. Constipation, bloating flatulence, upset stomach, and other digestive disorders can result form consuming too much wood apple juice. Pregnant women and nursing mothers should generally avoid it because it may have negative health effects. Those who have digestive issue should stay away from it. Some people may develop allergies as a result, which needs to be addressed. Shouldn't be consumed on a daily basis. Without interruption since it can interfere with the intestinal peristaltic motions. Tannis found in leaves have long term carcinogenic effects and can causes abortions in pregnant women. It could significantly reduce blood sugar level. If someone on hypoglycemic medication consumers large amounts of it. A person with a thyroid condition should stay away from it [64].

VIII. MARKETING

Kaith fruit have significant market demand, especially during summer. They sell for 5-10 per fruit, and a mature, significant-yielding tree can generate 1,500-2,000 annually. Some inventive kaith growers earn more than 10,000 per plant.

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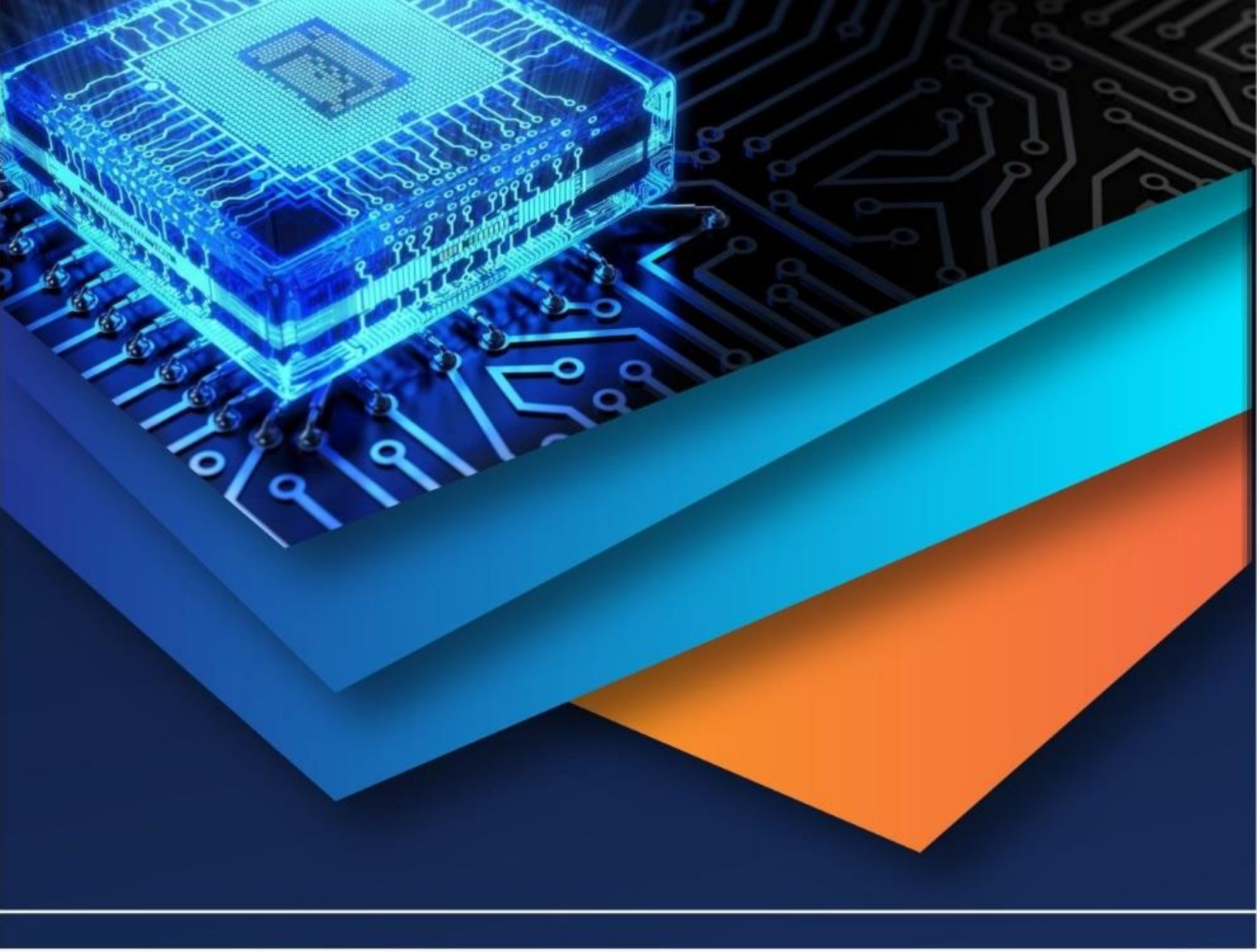
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