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Review Article

Star fruit (*Averrhoa carambola* L.): Exploring the wonders of Indian folklore and the miracles of traditional healing

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Abstract: Herbal medicines have been used for centuries to treat various ailments and have now gained global importance for their therapeutic and economic implications. One such plant is *Averrhoa carambola* commonly known as star fruit, a tropical plant belonging to the Oxalidaceae family. With a rich history of traditional medicinal uses in India and Southeast Asia, it has been employed to treat various ailments, including urinary infections, hypertension, diabetes, and gastrointestinal issues. The fruit is popular for its sweet and sour taste and finds culinary use in salads, beverages, and garnishing. The therapeutic potential of *A. carambola* is attributed to its abundance of natural antioxidants and phenolic compounds such as gallic acid in gallotannin form, catechins, and epicatechins. These bioactive constituents contribute to its medicinal properties and health benefits. However, scientific investigations have revealed potential health risks associated with *A. carambola* consumption. High oxalic acid content in the fruit poses a risk of toxicity, particularly for individuals with renal impairments who consume excessive fruit juices. Additionally, the presence of caramboxin, a neurotoxin, can interfere with the GABAergic system, leading to neurotoxic effects. This review offers a comprehensive and well-organized examination of the current progress regarding the benefits, phytochemistry, pharmacology, and toxicity of *A. carambola*. The insights presented in this review have the potential to drive advancements and novel treatments involving star fruit in modern times. As interest in herbal medicines continues to rise, further research on *A. carambola* holds promise for exploring new therapeutic applications in the realm of natural remedies.

1. INTRODUCTION

In recent decades, there has been a significant shift in people's attitudes towards the modern medicinal system. Many individuals have become increasingly interested in exploring ancient healing systems such as Ayurveda, Siddha, and Unani. This shift is primarily driven by concerns about the adverse effects associated with synthetic drugs used in modern medicine. As a result, herbal drugs are gaining prominence and are seen as vital components of health care programs, especially in developing countries (Kamboj, 2000). Alternative medicine is not

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widely accepted in developed nations because of poor documentation and strict quality control. Properly documenting research on traditional medicines is crucial to build trust and integrate these practices into mainstream healthcare (Kirtikar & Basu, 2005). For traditional medicines India is one of the ancient heritages, and for folklore customs and conventional characteristics of medicinally significant secondary metabolites. India provides Materia medica with full of information. Materia medica of India provides approximately 2000 natural origin drugs list which are the derivatives of folklore and traditional systems. For the discovery of new pharmaceuticals historically natural products and plants that originated from higher plants played a pivotal role (Gupta *et al.*, 2001; Mukherjee, 2002). According to WHO (World health organization) eighty percent people of developing countries depend on traditional remedial system for their primary healthcare system (Chopra & Nayar, 1956; Gupta & Gupta, 2020). Around the world, 21000 plants species are used medicinally and in India around 2500 plant species are used indigenously (Yadav *et al*., 2006). About 400 families of flowering plant, out of which 315 are represented by India (Jain *et al*., 2006).

The plant *Averrhoa carambola* L., commonly known as star fruit or "Kamarakh," belongs to the Oxalidaceae family and is native to Malaysia. Its distinct star-shaped appearance is matched by its delightful sweet and sour flavor (Warrier, 1993). The Sanskrit term "Karmaranga" is derived from "*carambola*," signifying a culinary appetizer. *A. carambola* is a hardy, drought-resistant tree known for its longevity (Manda *et al*., 2012). It holds significant commercial value in India due to its versatile applications and the delectable nature of its fruit (Warrier, 1993). While the unripe fruit is employed as a vegetable, ripened fruits find their way into various forms such as jams, jellies, fermented and non-fermented beverages, and desserts (Patil *et al*., 2010).

Considering the potential of ethnobotany in future medicinal applications, *A. carambola* is gaining substantial attention. Various parts of the tree have been utilized in traditional folk medicine. Additionally, it serves as a rich source of essential nutrients including copper, potassium, folate, and pantothenic acid. The level of ascorbic acid in a ripe fruit is a determining factor for its taste, whether sweet or tart (Manda *et al*., 2012).

2. BOTANICAL STUDY

2.1. *Averrhoa carambola* (Oxalidaceae): Herbal Plant

The fruit scientifically known as *Averrhoa carambola* goes by various names in different languages. In English, it is commonly referred to as Star fruit or simply carambola. In Hindi, it is known as Kamrakh or Karmal, in Myanmar known as mak-hpung, zaung-ya while in Malay and Indonesia, it is called Belimbing. In Sanskrit, it is referred to as Karmaranga, in Bengali as Kamranga, and in Gujarati as Kamrakh. In Marathi, it is known as Karambal, and in Tamil, it goes by Thambaratham or Tamarattai (Nandkarni, 1976; Orwa *et al*., 2009).

Star fruit, scientifically known as *Averrhoa carambola*, belongs to the Plantae kingdom, which encompasses all plants. It falls under the category of vascular plants (Tracheobionta), indicating that it has specialized tissues for conducting water and nutrients. Further classification places it in the Spermatophyta division, denoting plants that produce seeds. Within this division, it is categorized as an Angiospermae, signifying that it produces flowers and encloses its seeds in fruits.

In terms of class, star fruit is classified as Magnoliopsida, which refers to a class of flowering plants. This class includes a wide range of familiar plants like roses, peas, and sunflowers. Within the order Oxalidales, star fruit finds its place. This order includes various families of plants, one of which is the Oxalidaceae family to which star fruit belongs. Oxalidales is a diverse order that encompasses several different plant families, each with its own unique characteristics.

Finally, within the genus *Averrhoa*, star fruit is identified by the species name *carambola* L., specifically referring to the *carambola* variety (Avinash *et al*. in 2012).

2.2. Botanical Description with Habitat and Distribution

A. carambola is a tiny, slow-growing, evergreen tree that grows to a height of 3–16 m. The leaves of *A. carambola* are alternating, spirally organised, and range in length from 15 to 25 cm.The under side of leaves is quite pale in colour, while the upper side is smooth and greenish. Leaves at night incline and curl but most active in daylight, so delicate to sudden jolt. Surface of leaves are glabrous, acute type of apex and base is oblique with characteristic taste and odor (Kirtikar & Basu ,1987; Dasgupta *et al*., 2013). Clusters of small, six-millimetre-wide flowers, crimson in color with purple-red hues, often reveal a delicate hint of pink or white on their backside. These blooms form tight clusters along the leaf axis, creating a visually stunning display. (Avinash *et al*., 2012). The versatile *A. carambola* fruits are both edible and multifunctional. These fruits are fleshy and start off as light green when unripe, transitioning to an orangish-yellow hue upon maturity. Their brown seeds are contained within a 5-6 edged, star-shaped cross-section, spanning 5-15 cm in length. With a crisp, waxy texture, their taste spectrum ranges from sour to sweet, emitting a fragrance reminiscent of oxalic acid shown in Figure 1 (Dasgupta *et al*., 2013). For centuries, *A. carambola* has been cultivated in Malaysian and various Southeast Asian nations. Originating from Ceylon and the Moluccas, this fruit has thrived and spread across these regions (Morton, 1987). This annual herbaceous plant is generally full-fledged in the warmer parts of India, Bangladesh, Brazil, Philippines, China, Malaysia, Indonesia, Israel, Florida, Thailand, Taiwan, Australia, and other divisions of world with similar climate (Ghani, 1998). It can tolerate wider range of climate and survive in both the subtropical countries and hot tropical areas together with Israel and Egypt and freezing temperatures as low as −3° C can tolerate. Ideally, they grow in humus rich soil with acidic pH range but also withstand with pH range of 8.5 also (Bircher & Bircher, 2000).

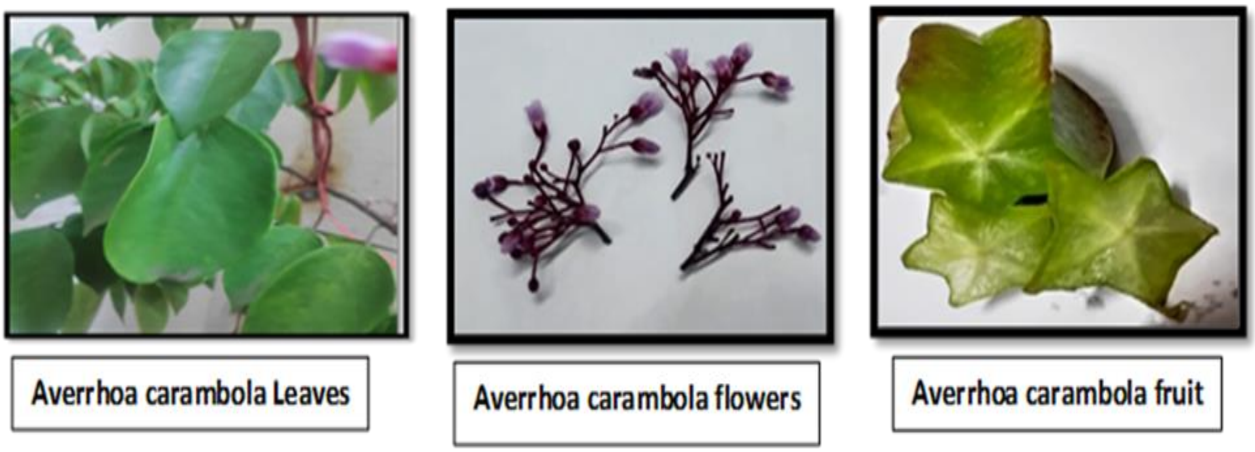

Figure 1. Pictorial representation of *Averrhoa carambola* plants parts.

3. TRADITIONAL AND POTENTIAL BENEFITS

3.1. Conventional Practices of *A. carambola*

For millennia, *A. carambola* has been employed in traditional medicine for a diverse range of ailments. This medicinal plant encompasses various components—roots, leaves, stems, fruits, flowers, and seeds—each offering distinct therapeutic properties in different regions such as Malaysia, Brazil, India, and China.

In India, the juice and ripe fruits of *A. carambola* have been used to address scurvy, boost appetite, act as an astringent, stimulate saliva production, alleviate fever, treat hemorrhoids, relieve thirst, and act as a purgative (Vasant & Narasimhacharya, 2014; Sheth, 2005).

Meanwhile, in Brazil, the ripe fruit is employed for urinary concerns, serving as a diuretic for bladder and kidney-related issues, and proving useful in managing hypertension and diabetes (Soncini *et al*., 2011). Sri Lanka recognizes *A. carambola* for its remarkable hypoglycemic effects, employing it in diabetes prevention (Abeysekera *et al*., 2015; Herbal Medicine Research Centre, 2002). In Malaysian traditional medicine, the fruit serves as a febrifuge, addresses recurrent aphthous ulcers, acts as an emetic, and aids in chest pain relief (Yang *et al*., 2020). Additionally, its leaves are utilized for treating ringworm, chickenpox, and headaches (Pang *et al*., 2017).

In Chinese medicine, ripe *A. carambola* fruits are employed for countering food poisoning from flesh consumption and for addressing an enlarged spleen (Carolino *et al*., 2005). They are also used to manage conditions like jaundice, diarrhea, throat infections, inflammation, toothaches, rashes, and strokes. Moreover, in women, it is utilized to stimulate milk secretion and, when the dosage is increased, to promote menstrual discharge. It is also known to enhance sexual desire in both males and females (Sung *et al*., 1998). Simultaneously, star fruit leaves find application in improving diabetes mellitus, alleviating emesis, addressing coughs, countering hangovers, and managing headaches (Ferreira *et al*., 2008; Thomas *et al*., 2008). Regarding the use of seeds, crushed seed decoctions are utilized to stimulate milk production, acting as a galactagogue. For colic pain and asthma, powdered seeds are applied. In Southeast Asia, *A. carambola* flowers are beneficial for skin inflammation and are also used as febrifuges, vermifuges, and for addressing malaria (Sheth, 2005; Sung *et al*., 1998).

3.2. Star Fruit Benefits as Food

There are numerous advantages and uses of *A. carambola* as a food. In different countries it has different uses from various parts of plant like flowers and leaves having sour and delicate taste unless used as salads. Due to its exotic flavor and unique shape, *A. carambola* finds application in crafting beverages and enhancing pastry presentations. Ripe, fresh fruit serves as a base for alcoholic drinks, achieved by fermenting it with *Saccharomyces cerevisiae* yeast. This yeast naturally converts the fruit sugars into alcohol and CO2 during a five-day fermentation process at 25°C, resulting in the creation of fruit wine (Napahde *et al*., 2010; Valim *et al*., 2016). Asian peoples used these fruits in different ways in cooking as sausages to cakes and jams to sauces while population of Malaysia generally prepare a sauce by boiling the fruit with sugar, cloves, and apples. Similarly Thai people used unripe fruit boiled with shrimp but the Chinese's people cooked the fish with the fruit. Also, in Taiwan and China star fruit is cut into strips and exported in boxes (Roopa *et al*., 2014). Even star fruit juice is used as energizing drinks or for its sour taste and also as condiments in dishes of fish. From the juice of star fruit an excellent frozen dessert can also be prepared by mixing the gelatin, sugar in the juice and kept its mixtures at low temperature for few hours (Ferrara, 2018). The unripe fruit serves as a key ingredient in jam-making, undergoing a process of marination with salt and vinegar, followed by maceration in honey overnight. After this, it is briefly cooked, transforming into jam, ready to be preserved in sterilized, sealed jars (Prati *et al*., 2002).

4. CHEMICAL COMPOSITION AND PHARMACOLOGICAL ACTIVITIES

4.1. Significant Phytochemical Constituents of *A. carambola*

When *A. carambola* analyzed for their phytochemical screening it showed the presence of alkaloid, phenylpropanoids, terpenes, saponins, phenols and flavonoids too. (Thomas *et al*., 2008). In the fruit major sterols found are, lupeol (a), Isofucosterol (b), β-sitosterol (c), and campesterol (d) apart of these sterols four major plant fatty acids are found – linolenic acid (e), linoleic, oleic and palmitic acid (f). (Gupta & Gupta, 2020; Nordby & Hall, 1979) The fruit edible portion is found to be rich source of dietary fibers, pectin, cellulose, reducing and non-reducing sugars, minerals, calcium, phosphorous, hemicellulose and carotenoid compositions

(Tiwari *et al*., 1979). The *A. carambola* fruit also includes gallic acid in gallotannin form, epicatechin (g), proanthocyanidins and L-ascorbic acid. Till now approximately 132 compounds are extracted and identified from *A. carambola* (Shui & Leong, 2004). Some of the extracted compound structures from *A. carambola* are shown in Figure 2.

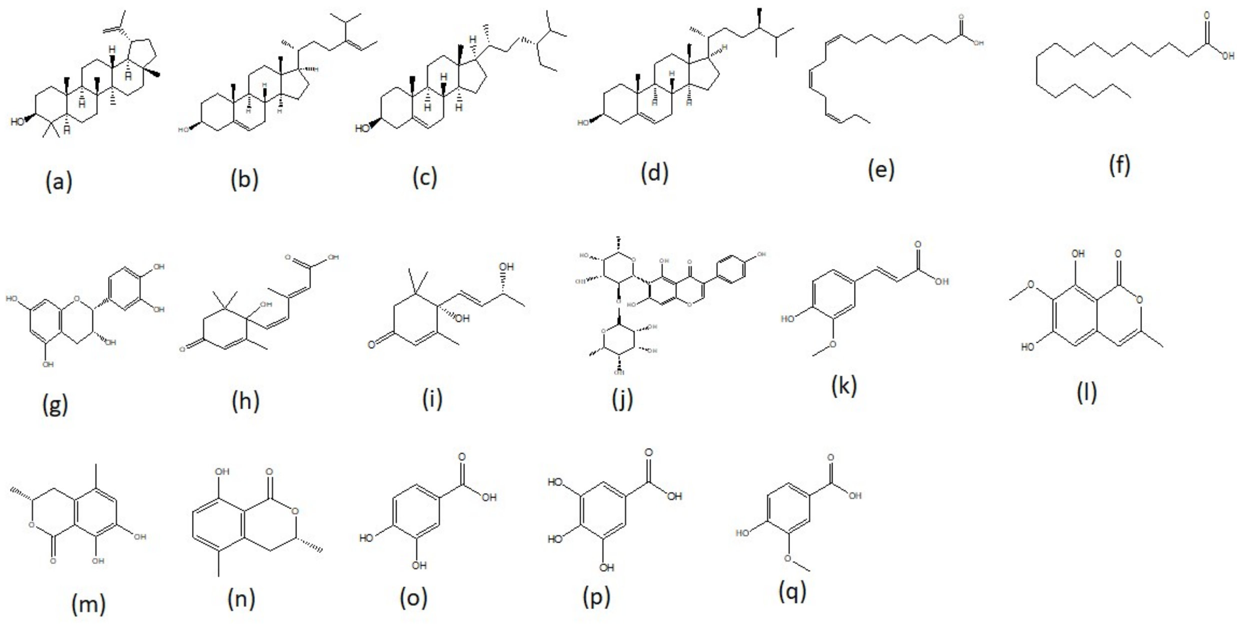

Figure 2. Chemical structures of some isolated compounds from *A. carambola*.

4.1.1. *Terpenes*

Terpenes are also called isoprenoids as isoprene is the building blocks of terpenes and it is found as the secondary metabolites in plants and specifically used for fragrances and pigmentation for plants, vegetables and fruits but apart from this, having lots of medicinal properties (Bahramsoltani *et al*., 2020; de Paulo Farias *et al*., 2020). About 29 terpenes have been identified and separated from *A. carambola* fruits using various spectroscopic techniques. The major terpenes found were cis and trans-abscisic acid (h), cis and trans-abscisic alcohol β-D-glucopyranoside, cis-abscisic alcohol β-D-glucopyranoside (6S,9R)-roseoside, and vomifoliol (i) (Gunawardena *et al*., 2015). Apart from this two components C_{13}- and C_{15}-norisoprenoids derived from *A. carambola* of terpenes massively intensify the flavor of fruits (Jia *et al*., 2019).

4.1.2. *Flavonoids*

Flavonoids have its place in class of natural products specifically as plant secondary metabolite with polyphenolic structures. Maqsood *et al*. (2020) identified a flavonoid in *A. carambola* that exhibits excellent pharmacological action, primarily in the area of radical scavenging and antioxidant activity, making it effective for the treatment or prevention of heart problems. From different organs of *A. carambola* plants like roots, leaves, fruits and stems around 51 flavonoids were isolated and characterized via various spectroscopic techniques viz Mass spectrometry (MS) and Nuclear magnetic resonance (NMR). Among these 51 compounds some are dihydrochalcone C-glycosides- Carambolaside R1-R3, Carambolaside A-H, Carambolaside I, Ia, Carambolaside J, Ja, Carambolaside M-Q, Carambolaside T1-T3, 3-Hydroxycarambolaside T1, Carambolaside S1-S2, 3-Hydroxycarambolaside P (Abeysekera *et al*., 2015; Jia *et al*., 2019; Yang *et al*., 2015) and other agents which exhibited radical scavenging activity against ABTS and DPPH are flavan-3-ols- Epicatechin-(5,6-bc)-4β-(p-hydroxyphenyl)-dihydro-2(3H)-pyranone,Epicatechin-(7,8-bc)-4α-(p-hydroxyphenyl)-dihydro-2(3H)-pyranone, Epicatechin-(7,8-bc)-4β-(p-hydroxyphenyl)-dihydro-2(3H)-pyranone, (–)-Epicatechin, 6-(R-2-pyrrolidinone-5-yl)-epicatechin, 6-(S-2-Pyrrolidinone-5-yl)-epicatechin, (+)-Epicatechin, 8-carboxymethyl-(+)-epicatechin methyl ester.(28, 38, 39) Other compounds are also found with multiple structures like Pinobanksin 3-O-β-D-glucoside, Helicioside A, Aromadendrin 3-O-β-D-glucoside, (+)-Catechin, Norathyriol, Taxifolin 3′-O-β-D-glucoside, Isovitexin, sovitexin 2″-O-α-L-rhamnopyranoside, Hovertichoside C, Cyanidin-3-O-β-D-glucoside, Cyanidin-3, 5-O-β-D-diglucoside, Apigenin 6-C-(2″-O-α-L-rhamnopyranosyl)-β-D-glucopyranoside, also Carambolaflavone A and B (j) with outstanding antihyperglycemic activity in animal model (Cazarolli *et al*., 2009; Cazarolli *et al*., 2012).

4.1.3. *Phenylpropanoids*

With a three-carbon propene tail of coumaric acid and an aromatic ring, phenylpropanoids are a class of chemicals that are produced by plants from the amino acids phenylalanine and tyrosine. It is an abundant supply of secondary metabolites from plants and is used in the manufacture of various other molecules, including lignans and flavonoids (Yao *et al*., 2020). During the spectroscopic analyses by^{13}C- NMR and^{1}H- NMR found around 18 phenylpropanoids compounds are productively isolated from fruits and roots of *A. carambola* plant. Out of total phenylpropanoids 12 lignans compounds are isolated from roots- (+)-isolariciresinol 3α-O-β-D-glucopyranoside, (-)-isolariciresinol 3α-O-β-D-glucopyranoside, Tarennanosides A, Fernandoside, (+) and (-)-lyoniresinol 3α-O-β-D-glucopyranoside, (+) and (−)-5′-methoxy-isolariciresinol 3α-O-β-D-glucopyranoside, 7α-[(β-glucopyranosyl) oxy]-lyoniresinol, and four compounds are simple phenylpropanoids- 1-O-feruloyl-β-D-glucose, (+) and (-)-lyoniresinol 9-O-β-D-glucoside, Ferulic acid (k) derived from fruits of *A. carambola* plant . Moreover, from fruits of *A. carambola* four coumarins compounds are isolated- reticulol that showed modest antioxidant capacity and 6-O-methyl-reticulol (l) that represented as iso-coumarin, 7-hydroxy-5- methylmellein (m) and 5- methylmellein (n) are Dihydroisocoumarins structurally (Sritharan *et al*., 2019).

4.1.4. *Polyphenols*

Phenolic compounds, derived from secondary pathways in plants, encompass tannins, flavonoids, lignans, phenolic acids, and coumarins. Within star fruit, these compounds are widely distributed across its fruits and roots, as highlighted by various studies (Wen *et al*., 2012; Jia *et al*., 2017; Yang *et al*., 2014; Liao *et al*., 2019; Gupta *et al*., 2021). Through techniques such as 1H-NMR, 13C-NMR, and FT-IR, researchers have isolated and characterized 16 phenolic compounds from the roots and fruits of *A. carambola*. These compounds exhibit remarkable radical scavenging capabilities. Notably, among these compounds are 8,9,10-trihydroxythymol, 3,4,5-trimethoxyphenol-1-O-β-D-glucopyranoside, Protocatechuic acid (o), Gallic acid (p), Vanillic acid (q), Methoxyhydroquinone-4-β-D-glucopyranoside. Within this array, alkylphenols such as 2,5-dimethoxy-3-undecylphenol, Carambolaside K, L, and 5-methoxy-3-undecylphenol stand out structurally (Pang *et al*., 2016).

4.1.5. *Additional compounds*

In addition to the previously mentioned compounds, various other chemical constituents have been investigated within *A. carambola*. Notably, quinone compounds such as 2-methoxy-6-nonyl-cyclohexa-2,5-diene-1,4-dione, 2-dehydroxy-5-O-methylembelin, 2-dodecyl-6-methoxycyclohexa-2,5-diene-1,4-dione, (+)-cryptosporin, and 5-O-methylembelin have been identified, alongside Heptyl vicianoside, Octyl vicianoside, cis-3-hexenyl rutinoside, and Methyl 2-O-β-D-fucopyranosyl-α-L-arabinofuranoside classified as alkyl glycosides. Furthermore, tetrahydroisoquinoline alkaloids like (1R*,3S*)-1-(5-hydroxymethylfuran-2-yl)-

3-carboxy-6-hydroxy-8-methoxyl-1,2,3,4-tetrahydroisoquinoline and (1S*,3S*)-1-methyl-3-carboxy-6-hydroxy-8-methyoxyl-1,2,3,4-tetrahydroisoquinoline have been identified.

Of particular interest is a compound derived from the roots of *A. carambola* plants, namely 2-dodecyl-6-methoxycyclohexa-2,5-diene-1,4-dione, exhibiting diverse bioactive properties. This compound has shown anti-inflammatory properties (Xie *et al*., 2016), anticancer effects (Gao *et al*., 2015; Chen *et al*., 2017; Gupta *et al*., 2022), neuroprotective activity (Wei *et al*., 2018), anti-obesity potential (Li *et al*., 2016), and antidiabetic properties (Lu *et al*., 2019).

4.2. Potential Medicinal Benefits of *A. carambola*

The *A. carambola* plant holds immense medicinal potential, showcasing a wide array of benefits such as anti-inflammatory, hepatoprotective, antimicrobial, antioxidant, neuroprotective, and antitumor activities, among others, as illustrated in Figure 3. In both Ayurvedic and Traditional Chinese Medicine (TCM), *A.carambola* is valued for its diverse medical advantages, addressing conditions such as coughs, dermal fungal infections, eczema, severe headaches, and diarrhea (Wang *et al*., 2016; Patel *et al*., 2015).

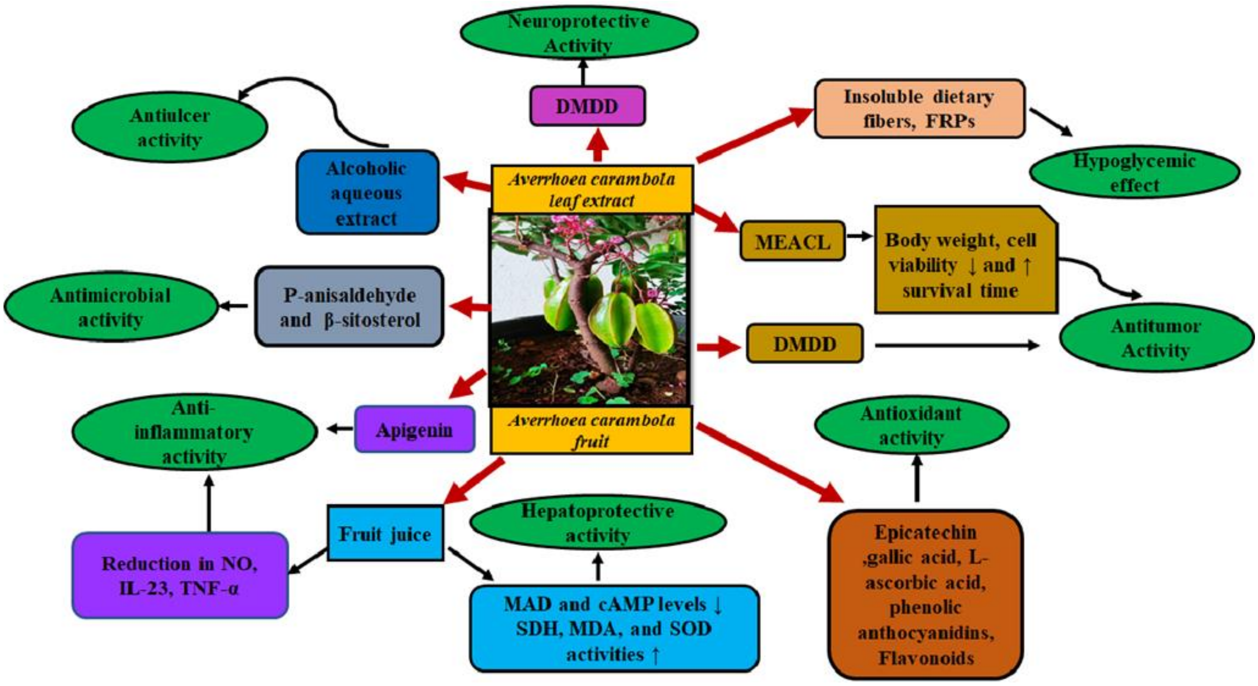

Figure 3. Diagrammatical representations of potential medicinal benefits of *Averrhoa carambola*.

4.2.1. *Antitumor activity*

Various studies have shown that an alcoholic extract from the stems of A. carambola was used against brain tumour cells, while an extract from the leaves was more effective against liver cancer cells (Tadros & Sleem, 2004). Methanol extract of *A. carambola* leaves (MEACL) at the dose of 25 and 50 mg/kg, i.p. once a day for 5 days substantially decreases the viability of cell and weight of the body, progressive change in hematologic estimations (Hgb, White Blood Cells, Red Blood Cells) and prolongs survival time in Ehrlich ascites carcinoma (EAC) cell-bearing mice (Siddika *et al*., 2020).

4.2.2. *Anti-inflammatory activity*

One study stated that *A. carambola* leaf ethanolic extract and butanol, ethyl acetate, and hexane fractions showed beneficial effects to diminishing the induced ear edema by croton oil and cellular migration in animal (Cabrini *et al*., 2011; Soncini *et al*., 2011). In another investigation, aqueous extract of *A. carambola* inhibited carrageenan-induced rat paw inflammation when given intraperitoneally. At the same time stem extract of *A. carambola* stated the bactericidal activity against *Streptococcus aureus* (Sripanidkulchai *et al*., 2002).

4.2.3. *Hypoglycemic effect*

A. carambola has demonstrated the potential to lower blood sugar levels. This effect was attributed to specific types of dietary fiber found in the fruit, including those that are not soluble in alcohol or water. These fiber-rich fractions were isolated from the leftover pulp of *A. carambola* (Chau *et al*., 2004).

In a different study, it was found that the ripe fruit pulp of *A. carambola* had a hypoglycemic effect in healthy male Sprague Dawley rats. This effect was observed after an 8-week treatment period, specifically in comparison to the control group of normal rats (Dasgupta *et al*., 2013). This suggests that regular consumption of ripe star fruit may help regulate blood sugar levels.

4.2.4. *Antimicrobial activity*

In a study using the disc diffusion method, researchers investigated the antimicrobial properties of the *A. carambola* plant. They found that various extracts from the bark of *A. carambola* including petroleum ether, carbon tetrachloride, chloroform, aqueous soluble fractions, and methanolic extract were effective in inhibiting the growth of both gram-positive and gram-negative bacteria as well as fungi. The potency of these extracts varied depending on their concentration, with the lowest concentration (0.78125 μg/ml) showing the highest effectiveness and the highest concentration (400 μg/ml) exhibiting the lowest. Notably, the carbon tetrachloride soluble fraction of the methanolic extract demonstrated the most promising antimicrobial activity. This suggests that *A. carambola* extracts, particularly from the methanolic fraction, have potential as natural antimicrobial agents against a range of microorganisms (Mia *et al*., 2007).

4.2.5. *Antioxidant activity*

In a study assessing antioxidant capabilities through various tests like ferric reducing antioxidant power (FRAP), 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (DPPH), vitamin C content, total phenolic content, and total flavonoid content, *A. carambola* ranked as the third most potent antioxidant among 20 commonly available fruits in Sri Lanka (Silva & Sirasa, 2018). Furthermore, when the methanol extract of *A. carambola* leaves (MEACL) was tested at concentrations ranging from 50 to 375 μg/mL, it displayed a dose-dependent moderate antioxidant effect in both DPPH and ABTS+ assays. The IC50 values, which indicate the concentration required to achieve a 50% reduction in activity, were measured at 62.0 μg/mL for DPPH and 6.0 μg/mL for ABTS+. This signifies that the leaf extract of *A. carambola* holds promising antioxidant properties (Siddika *et al*., 2020).

4.2.6. *Hepatoprotective activity*

Azeem *et al*. (2010), in their study, investigated the impact of *A. carambola* fruit extract on liver damage induced by carbon tetrachloride. The results showed a significant decrease in serum levels of enzymes ALT, AST, and ALP, indicating improved liver function. Additionally, the levels of liver-reduced glutathione significantly increased 24 hours after administering carbon tetrachloride, indicating enhanced antioxidant activity.

In another research conducted by Huang *et al*. (2019), mice with acute liver injury were treated with *A. carambola* root extract for seven days. The study found that the treatment led to lower levels of enzymes associated with liver damage (AST and ALT), reduced levels of inflammatory markers (IL-1 and IL-6), and decreased levels of malondialdehyde (MDA) in the liver. Conversely, levels of antioxidants like superoxide dismutase (SOD), Glutathione (GSH), and plasma glutathione peroxidase (GSH-Px) were elevated. At the molecular level, proteins involved in inflammation and cell death were downregulated, suggesting a protective effect.

In their study Pang *et al*. (2017) investigated the impact of *A. carambola* free phenolic extract (ACF) on hepatic steatosis in mice deficient in the leptin receptor (db/db mice). After eight weeks of ACF administration, the content of liver triglycerides (TG) significantly decreased compared to the control group. The treatment worked in part by reducing the activity of key enzymes involved in lipogenesis (SREBP-1c, SCD1, and FAS) and increasing the activation of AMP-activated protein kinase α. Additionally, certain microRNAs, specifically mircoRNA-34a and mircoRNA-33, played a crucial role in modifying this signaling pathway. This indicates a potential therapeutic effect of ACF on liver steatosis.

4.2.7. *Neuroprotective activity*

In a study by Lu *et al*. (2019), they investigated the effects of a compound called DMDD (2-dodecyl-6-methoxycyclohexa-2,5-diene-1,4-dione) on memory and brain cell loss in mice with Alzheimer's disease (AD), specifically those with a genetic predisposition (APP/PS1 transgenic mice).

During the study, the mice were administered at varying doses of DMDD for a period of 21 days. The results showed that DMDD had a neuroprotective effect, meaning it helped protect the brain. It led to a reduction in cell death (apoptosis) in the hippocampal tissues of the APP/PS1 mice. This resulted in improved memory and spatial learning abilities, and also prevented the loss of neurons. This suggests that DMDD may have potential as a treatment for memory problems and brain cell loss in Alzheimer's disease.

4.2.8. *Antiulcer activity*

In their study Goncalves *et al*. (2006) investigated the potential gastroprotective effects of an alcoholic aqueous extract derived from the leaves of *A. carambola* in rats. They tested this extract in various ulcer models. When it came to an acidified-ethanol-induced model, they observed a notable anti-ulcer activity. However, in models involving indomethacin and acute-stress ulcer formation in mice, the extract did not demonstrate any protective benefits. This led the researchers to conclude that star fruit possesses a relatively lower level of antiulcer activity.

5. TOXICITY PROFILE OF STAR FRUIT

5.1. *A. carambola* Really Toxic or Fable

There's ongoing debate regarding the toxicity of star fruit, with conflicting findings. High intake, especially when the fruit contains elevated levels of oxalic acid, has been linked to nephrotoxicity. In cases of excessive consumption or concentrated fruit juice intake, nephropathic patients have exhibited symptoms like abdominal pain, vomiting, nausea, and kidney blockage (Neto *et al*., 2003; Chen *et al*., 2005). Studies suggest that individuals experiencing symptoms due to oxalate deposition can recover within about four weeks with standard treatment. However, in severe cases, obstruction caused by oxalate crystals may lead to renal failure. This isn't the sole reason; programmed cell death of renal epithelial cells, as depicted in Figure 3, might also contribute to this condition. Moreover, separate research has highlighted additional neurotoxic symptoms associated with star fruit toxicity. These symptoms include back pain, mental confusion, intractable hiccups, epileptic seizures, vomiting, and insomnia, which have proven lethal for some patients (Martin *et al*., 1993; Tsai *et al*., 2005).

Until the 1980s, neurotoxic symptoms were attributed to oxalic acid present in fruit juice, as indicated by Chen *et al*. in 2001. Research showed that injecting mice with a peritoneal dose of 8 g/kg resulted in tremors (Muir & Lam, 1980). However, recent studies have shed new light on the neurotoxic effects observed in the central nervous system, such as confusion, hiccups, convulsions, and even fatalities. These effects are linked to the inhibition of the GABAergic system and a substance called caramboxin. Patients with fatal renal conditions exhibited severe symptoms in a dose-dependent manner, particularly those who consumed over 2 liters of juice or around eight carambola fruits. Intriguingly, a study challenged the notion of attributing toxicity solely to the carambola fruit. It revealed that avoiding this fruit for individuals with kidney disease eliminates the triggering of detrimental effects, as both oxalic acid and caramboxin are eliminated, as depicted in Figure 4 (Garcia-Cairasco *et al*., 2013).

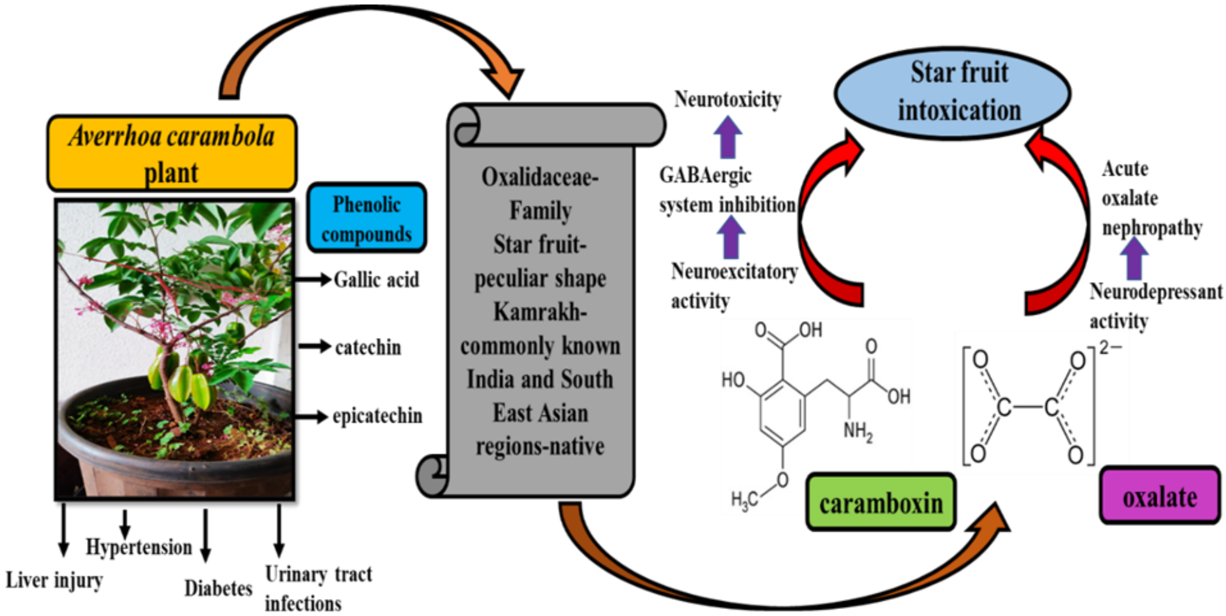

Figure 4. Schematic representation of toxicity, benefits, and description about *A. carambola.*

6. CONCLUSION

The current analysis provided an overview of Averrohoa carambola's traditional usage, therapeutic benefits, phytochemical, pharmacological, and intoxication profile. These days, the culinary and pharmaceutical industries are very interested in star fruit. *A. carambola* is a top pick for the pharmaceutical and health industries because of its superior nutritional, medicinal, and pharmacological qualities. The *A. carambola* plant is widely spread worldwide and possesses a variety of pharmacological properties, including anti-inflammatory, hepatoprotective, hypoglycemic, analgesic, antioxidant, and antibacterial properties. Star fruit contains several phytoconstituents with specific pharmacological activity i.e., gallotannin, catechin, epicatechin, flavonoids, saponins, alkaloids. There have been few investigations on the toxicity of consuming large amounts of star fruit juice, and the substances caramboxin and oxalates have been linked to nephrotoxicity and neurotoxicity. Further study is needed to close this knowledge gap and determine the precise mechanism underlying star fruit intoxication. Until there are a number of studies on starfruit that address the phytoconstituent and its bioactive components, additional work and studies need to be concentrated.Certainly, this plant has many opportunities with countless beneficial effects, but we must not forget the challenges. This review offers a balanced assessment, setting it apart from other studies.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the authors.

Authorship Contribution Statement

Suchita Gupta: as the first author, contributed to the literature review and manuscript preparation. **Reena Gupta**: as the corresponding author, provided invaluable guidance, oversight, and expertise throughout the entire process of writing and finalizing this review paper.

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