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Unraveling the Diversity and Ethno pharmacological Significance of *Garcinia* Species in North-East India: Current Applications and Future Prospects

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Abstract

Garcinia is a genus of plants widely distributed in the tropical regions of Asia and Africa, with a rich diversity found in North-East India. This review explores *Garcinia* species, focusing on both the fruit and the whole plant, particularly emphasizing their ethnopharmacological applications. Notably, species like *G. pedunculata, G. paniculata,* and *G. cowa* are integral to traditional Assamese medicine and cuisine. *Garcinia* fruits contain bioactive compounds such as hydroxycitric acid, xanthones, garcinol, and isogarcinol, which exhibit anti-inflammatory, antioxidant, anti-obesity, and anti-aging properties. The review also discusses various extraction methods including ultrasonic-microwave assisted extraction and supercritical fluid extraction, highlighting their potential to isolate therapeutic compounds. Modern processing techniques such as freeze drying and microencapsulation improve shelf-life and nutritional retention. Despite promising preclinical evidence, clinical validation remains limited. This review underscores the need for further pharmacological studies, standardization of extraction protocols, and value-added product development to harness the full potential of *Garcinia*.

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Abbreviation

DPPH	2,2-diphenyl-1-picrylhydrazyl
ROS	reactive oxygen species
RNS	reactive nitrogen species
HCA	hydroxycitric acid
UMAE	ultrasonic-microwave assisted extraction
SCCO2	supercritical carbon dioxide

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Introduction

North-East India is a region known for its rich biodiversity, and it is home to a wide variety of fruit. While some fruits are globally recognized, there is a treasure trove of minor fruit found in this region that are often overlooked. These minor fruits hold immense cultural, ecological and economic significance for the local communities. The minor fruit of North-East India represent the regions diverse flora and provide a glimpse into the traditional cuisines, cultural practices and rich biodiversity of the area. These fruit not only offer unique flavors but also possess nutritional and medicinal value. *Spondias dulcis, Aegle marmelos, Limonia acidissima, Emblica officinalis* and *Garcinia* are few examples of minor fruit from North-East India, is a lesser-known minor fruit of North-East India and is a genus of flowering plants in the family *Clusiaceae*. plants are known for their fruit-bearing trees or srubs. These plants are native to tropical regions of Asia. The species of the *Clusiaceae* family comprises more than 300 medicinal plants.[1] In India, 35 different species of have been identified, 17 of these are endemic species, 7 of these are indigenous to the Western Ghats, 6 are found in the Andaman and Nicobar Island and *G. pedunculata Roxb, G. cowa Roxb, G. lanceaefolia Roxb* and *G. xanthochymus Hook.* (yellow mangosteen) are four common species found in northeastern region of India, particularly in Brahmaputra valley of Assam.[2,3] Other species includes white kokum (*G. morella*), Malabar tamarind (*G. cambogia*), Kokum (*G. indica*), purple mangosteen (*G. mangostana*), asam gelugur (*G. atroviridis*) and bitter kola (*G. kola*). The commercial important species of this genus are *G. mangosteena, G. india, G. gummigutta, G. xanthochymus, G. morella*. Other few species included *G. fusca, G. hopii, G. planchonii, G. nigrolineata* and *G. gaudichaudii*.[4,5] These fruits containing have a great nutritional and commercial value both as food and for health. Peel and seed, two of its byproducts, are a significant source of bioactive compounds. Several tumour cell lines exhibit action towards compounds that have been identified from this genus. These plants are mostly grown as semi-wild condition in the backyard garden. The fruit is locally called as "thekera" in Assam, rich in antioxidants and is known for its medicinal properties among various indigenous communities of Assam.[6] During the peak season of year, fresh, ripe fruits are often offered in the local market. The lack of knowledge among the rural people in the native region has resulted in the absence of value-added goods of from the market, apart from fresh fruits. When the fruits develop their magnificent red colour in May, they are picked. In general, fruit is collected by shaking off and hand-picking it from the ground or by hitting the branches with bamboo sticks. Because there is no common harvesting equipment, fully ripe fruits might be mechanically damaged during harvesting. The fruits have a 3–5-day shelf life at room temperature.

The fruit rinds that have been sun-dried are used to make "sharbat" a refreshing drink, a cooling agent that relieves heatstroke and satisfy thirst. fruits are used in Ayurvedic medicine to treat urinary issues, infections, piles, and enhance digestion.[7] The gummy exudates of are employed as emetics and cathartics in traditional medicine. *G. dulcis* is a laxative and expectorant in traditional medicine. Young twigs of *G. lanceifolia, G. pedunculata,* and *G. xanthochymus* are used by ethnic groups in Assam, India, for tooth cleaning and pain alleviation.[8] Conversely, some indigenous populations employ the young leaves of *Garcinia* in their food. *Garcinia* spices have been shown in several research studies to have both pharmacological and nutraceutical advantages. Numerous pharmacological activities, such as antioxidant, cardioprotective, neuroprotective, anticancer and antidiabetic, have been linked to *Garcinia* spices with abundant amounts of xanthones, benzophenones, phloroglucinols, and bioflavonoid.[7,9-11] Currently, the market offers a variety of health-promoting dietary supplements that include *G. cambogia or G. mangostana*.[12] Many pharmaceutical products, including pills, lotions, creams, gels and syrups, have been produced recently that include extracts from *Garcinia*.

The proximate composition of *Garcinia* species reveals variations in the moisture content, ash content, protein content, lipid content and carbohydrate content among the different species. Moisture content ranges from approximately 80 % to 90 %, indicating a relatively high-water content in fresh *Garcinia* fruit.[13,14] The ash content, representing the inorganic residue after combustion, generally ranges from 0.23 % to 3.23 %, suggesting the presence of minerals and trace elements.[15] The protein content of *Garcinia* fruit varies from 0.93 % to 4.93 %, indicating relatively low protein content compared to other food sources.[8,16] The fat content of the fruit varies significantly, ranging from 0.12 % to 5 % . Carbohydrates constitute a major portion of the proximate composition of *Garcinia* fruit, typically ranging from 3.75 % to 15.12 %.[14,17] These carbohydrates include dietary fiber, sugars and starches. Fruit of *Garcinia* also exhibited fair amount of minerals such as potassium (52.3 mg / 100 g), sodium (1.35 mg / 100 g), calcium (12.54 mg / 100 g), iron (9.0 mg / 100 g), magnesium (30.23 mg / 100 g), and phosphorus (3.64 mg / kg). Major organic acids present in fruit of this species also estimated and found presence of oxalic acid (1.70 %), malic acid (10.02 %), acetic acid (0.14 %), citric acid (1.45 %), and tartaric acid (0.23 %).[18] Further, determination of vitamin composition revealed that fruits contain vitamin C (30.23 mg/ 100 g), vitamin B1 (52.0 µg / 100 g), vitamin B2 (283.0 µg / 100 g), vitamin B3 (45.0 µg / 100 g) and vitamin B12 (8.03 µg / 100 g). The proximate composition of *Garcinia* fruit varies among different species and these variations offer opportunities for diverse applications in the food, pharmaceutical and nutraceutical industries. In the food processing industry, selections of raw material, fruits and vegetables on product development, quality assurance, and regulations are made using this scientifically grounded proximate composition of the particular fruit and vegetable.

Study Objectives

The primary objective of this review is to provide a comprehensive synthesis of existing knowledge on the diversity, ethno pharmacological applications, and future potential of *Garcinia* species native to North-East India. Specifically, the review seeks to explore the nutritional and medicinal significance of various *Garcinia* fruits, emphasizing their traditional uses and emerging therapeutic roles. It also aims to critically examine recent advances in the extraction and characterization of bioactive compounds, such as hydroxycitric acid, xanthones, and garcinol, that contribute to their pharmacological effects. Furthermore, the review discusses modern processing techniques and highlights the need for standardization, clinical validation, and sustainable value-added product development. By consolidating scattered ethnobotanical and scientific data, this work aims to identify gaps in current knowledge and propose directions for future research and commercial utilization.

Materials and Methods

As this is a review article, the methodology involves a comprehensive literature survey across major scientific databases including PubMed, Scopus, Google Scholar, and ethnobotanical repositories. Keywords such as "*Garcinia*," "North-East India," "bioactive compounds," "ethnopharmacology," and "hydroxycitric acid" were used. Studies published between 2000 and 2024 were prioritized. Inclusion criteria focused on peer-reviewed articles in English that discussed the pharmacological properties, nutritional value, and processing techniques of *Garcinia* species. Relevant data from in vitro, in vivo, and limited clinical studies were extracted, compared, and synthesized thematically

Ethno-Pharmacological Importance of *Garcinia*

The ethno-pharmacological importance of *Garcinia* as a whole plant includes leaves, fruit and bark from its profound role in traditional medicine across diverse cultures. Various species among *Garcinia* have been integral to indigenous healing practices for centuries. The rich history rooted in ayurveda and traditional medicine.[1,3,7]

An ethno-botanical investigation on *G. pedunculata Roxb., G. paniculata Roxb., G. cowa Roxb., G. lanceaefolia Roxb.* and *G. xanthochymus Hook.* unveiled a rich tapestry of traditional knowledge and practices associated with these *Garcinia* species in India.[19] Table 1 summarized ethno-pharmacological importance of different *Garcinia* Species in North-East India. The leaves, bark and fruits of *Garcinia* species, characterized by their sour, astringent, thermogenic, constipating and digestive properties, find application in herbal preparations within the realm of treating inflammatory conditions, rheumatic pains and bowel complaints.[9] Fruit of *G. pedunculata* Roxb., exhibited efficacy in treating dysentery and jaundice, while the raw fruit were employed as vegetable and used to make pickle, eaten raw and traditionally used by people of Assam to make curry with fish.[20,21] Literature survey have revealed that *G. pedunculata* Roxb., is a good source of antioxidant and HCA.[22] *G.paniculata* Roxb. fruits are highly flavoured, delicious and eaten raw. Leaves are reported to have medicinal value and traditionally used to cure round-worm.[23] The whole *G.cowa* Roxb. plant is widely used in traditional folk medicine. The fruits are sun dried and preserve for off-season to treat dynsentery. While, leaves are eaten raw and used to increase blood circulation. Also, various parts of the plant are used as blood thinner and to treat stomachache. Fruits of *G. lanceaefolia* processed for preparation of jam-jelly, pickles and squash and sometimes consumed as vegetables. The dried sliced pericarps are used as medicine against stomachache and have antidiabetic property.[24] Various parts of the plant are used to treat headache, diarrhea and dysentery. Juice and oil extracted from *G. morella* Desr. are used to cooling for fever. *G. xanthochymus* reported to cure tumors, diarrhea and also useful in piles and dysentery.[25] The fruits of *Garcinia* spp. are recognized for its cardiotonic and anthelmintic properties in the therapeutic range. The rind, made into a juice, has several uses, including treating ulcers, ear infections, wounds, dysentery and dermatitis. It also helps with haemorrhoid, facilitates digestion and reduces excessive sweating. The ethno-botanical exploration provides a comprehensive understanding of the cultural, culinary uses and traditional medicinal uses associated with *Garcinia* species offering valuable insights for conservation efforts and sustainable resource management.

Table 1: Uses, traditional knowledge and medical practices of *Garcinia* Species

Fruit name	Consumed as food	Traditional knowledge and medical practices
G. pedunculata Roxb.	Pickle and curry preparation	Used to cure dysentery and jaundice natural anti-obesity agent[23,26]
G. paniculata Roxb.	Eaten raw	Remedy for round- worm[26]
G. cowa Roxb.	Dried slices (specially sun dried)	Remedy for dysentery, blood circulation, blood thinner and used to treat stomachache[26]
G. lanceaefolia	In the form of jam-jelly, pickles, squash and curry preparation	Used in the treatment of diarrhea and dysentery[26]
G. Morella Desr.	Dried slices	Dried pulp of the fruit is used as an antiscorbutic, cardiotonic and anthelmintic. juice & oil of fruits are used to cooling for fever [26]
G. xanthochymus	jam, jelly, chutney	Used to cure tumors, diarrhea. Also useful in piles and dysentery [25,26]

Potential Health Benefits Associated with *Garcinia* Fruit

Researchers have been studied on *Garcinia* fruit for their bioactive compounds, which may have potential health benefits. Some of the bioactive compounds that have been identified in *Garcinia* fruit include Xanthones, flavonoids, garcinol and polyphenol.[27,28] Also, the fruit contain a compound called HCA,[22,29] which suppress appetite and inhibit the enzyme responsible for converting excess carbohydrates into fat.

Potential Health Benefits

Garcinia fruit offer a range of potential health benefits, including weight management support, antioxidant properties, digestive health promotion, anti-inflammatory effects, blood sugar control and potential anticancer properties.[20,21] Certain *Garcinia* fruit have been traditionally used for promoting digestive health and used in the treatment of dysentery, diarrhea and fever. *Garcinia* fruit are rich in antioxidants such as vitamin C, flavonoids and xanthones. These compounds help combat oxidative stress and reduce damage caused by harmful free radicals in the body. Antioxidants are associated with a reduced risk of chronic diseases, including cardiovascular diseases, cancer and neurodegenerative disorders. Several *Garcinia* fruit, including *G. cambogia* and *G. mangostana*, exhibits anti-inflammatory properties.[30] The presence of bioactive compounds like xanthones in this fruit contributes to their anti-inflammatory effects. These properties may help reduce inflammation in the body and alleviate symptoms associated with inflammatory conditions, such as arthritis and inflammatory bowel disease. Some studies suggest that *Garcinia* fruit, particularly *G. cambogia*, may help regulate blood sugar levels. The HCA present in *Garcinia* species might enhance glucose metabolism and improve insulin sensitivity.[22,29] However, more research is needed to establish the effectiveness of *Garcinia* fruit in managing diabetes. Certain compounds found in *Garcinia* fruit, such as xanthones, have shown potential anticancer activities in preclinical studies. These compounds have demonstrated inhibitory effects on the growth and proliferation of cancer cells. However, further research including clinical trials, is required to determine their effectiveness in cancer prevention and treatment.

Free Radical Scavenging Activity

Damage to proteins, lipids, DNA, and other macromolecules is caused by free radicals, which are comprised of ROS and RNS produced in excess.[31] In order to stop the production of ROS and RNS and to counteract their harmful effects, antioxidants are thus necessary. According to studies, scavenging free radicals is also accomplished by commercially available concentrated syrup, cold aqueous extract, and hot (cooked) aqueous extract of *Garcinia*.[32] *G. atroviridis* dried sample was subjected to the DPPH experiment to determine its antioxidant activity.[33] Low antioxidant activity has been observed by the plant. The highest percentage of antioxidant activity was found by *Garcinia* leaves in ethyl acetate extract (59.18 %), *Garcinia* leaves in methanol extract (57.97 %), and followed by *Garcinia* leaves in hexane extract (55.67%). While not correlated with the total flavonoid and tannin content, the overall phenolic content had shown a significant correlation with the antioxidant activity. The IC_{50} value for *Garcinia* species varies depending on the specific species, extract, and assay used. According to a study published, among three *Garcinia* fruits, (*G. pedunculata, G. xanthochymus* and *G.morella*) the methanol extract of G.pedunculata showed highest antioxidant potential with IC_{50} value 47.03 ± 13.48 µg / ml indicating effective antioxidant capacity. The IC_{50} value of standard (L-Ascorbic acid) was found 4.98 ± 0.24 µg / ml while the other two *Garcinia* species have low antioxidant potential.[8,34]

Anti-Fungal And Anti-Bacterial Effects

An urgent need for novel and effective natural remedies is highlighted by the rise in invasive fungal infections, as well as problems with limited effectiveness, drug related side effects, non-optimal pharmacokinetics and some fungal strains developing resistance to specific treatments. The fruit of *Garcinia* showed antimicrobial and antibacterial activity.[35] It is a naturally occurring medication that lacks toxicity and exhibits inhibitory bioactivity against a wide range of microorganisms. The aqueous, ethyl acetate and methanolic extracts of *G. cambogia* demonstrated broad range antibacterial activity and the extracts were effective against both gram negative and gram-positive bacteria.[36]

Anti-Diabetic Activity

A condition as ancient as humanity, diabetes is characterized by prolonged hyperglycemia. According to recent statistics, it affects around 5% of the world's population and is the most common endocrine condition. Secondary consequences from chronic hyperglycemia are more hazardous than hyperglycemia itself and require ongoing medical attention and care. It has been demonstrated that giving *streptozotocin*-induced type 2 diabetic rats an oral dose of *Garcinia* rind aqueous extract (100 mg / kg and 200 mg / kg) for four weeks effectively reduces fasting and postprandial blood glucose levels.[37] Also, HCA is a major compound that was reported in different genus of *Garcinia*, has been proposed to have the potential to treat diabetes since it has been showed to significantly slow the absorption of intestinal glucose.[38]

Anti-Obesity Activity

A significant issue in both developed and developing country is obesity, which carries a number of health risks including high blood pressure, diabetes mellitus and heart disease. As per WHO estimate, out of nearly a billion overweight adults worldwide, at least 300 million are clinically obese. The primary factor contributing to obesity is diet. HCA the key ingredient that helps with weight reduction by preventing the formation of fat and reducing hunger is abundant in the *Garcinia* fruit.[39] An enzyme that aids in the synthesis of body fat for storage in adipose tissue is inhibited by citrine, an extract found in *Garcinia* that is between 50-60 % HCA.[40,41] By initiating the process of thermogenesis, HCA enhances the body's production of heat, reduces hunger, lowers the production of cholesterol and fatty acids, inhibits lipogenesis, increases the generation of energy, and boosts energy . High levels of HCA, an important ingredient in *G. cambogia*, have been linked to enhanced brain serotonin release and hepatic glycogen production, both of which have been shown to have an appetite-suppressive impact that subsequently results in decreased body weight. An increasingly common constituent in many weight-loss products is *G. cambogia* extract.

Anti-Aging Activity

Skin sinking and the appearance of wrinkles are two noticeable effects of ageing, which is a normal process. Sagging develops gradually as a result of the skin's decreased elasticity with age, which is caused by the enzyme elastase. The primary aspect of cellular ageing is increased production of ROS.[41] Radicals are very reactive and have the ability to interact violently with biological macromolecules because of the nature of reactive oxygen species. When skin fibroblasts are directly exposed to radicals, the caspases pathway is activated, which might result in apoptosis. Radical compounds not only impact the skin's cellular components, but they also play a significant role in the production of proteins linked to the extracellular matrix's disintegration. Hyaluronic acid levels also drop concurrently, which causes the skin to become dry and wrinkled. The process of ageing and wrinkles is accelerated by sun exposure and harmful chemical exposure; however, the application of antioxidant-rich cosmetics is believed to slow down this process. Studies have shown that the methanolic extract of *Garcinia* rind, both in its whole and in its ethyl acetate and water fractions, has anti-hyaluronidase and anti-elastase properties *in vitro.*[42] The aqueous fraction was shown to be effective against both elastase and hyaluronidase (90 µg / ml), but the ethyl acetate fraction demonstrated considerable hyaluronidase inhibition at a low dose (25 µg / ml). Additionally, it has been found that *Garcinia* pigments absorb UV rays, which suggests that they may be beneficial for skin care.[43]

Anti-Inflammatory Activity

Pathogen clearance often falls under the purview of the immune system. The innate immune system offers a defence mechanism that may respond immediately to eradicate harmful germs in order to preserve immunological homeostasis. Numerous inflammatory cytokines must be produced in order to achieve this goal. Toll-like receptor 4 (TLR4) is used by immune cells, such as macrophages, to identify lipopolysaccharide (LPS) from Gram-negative bacteria's cell membrane.[44] When LPS binds to TLR4 on macrophage cell surfaces, it initiates the NF-κB signalling pathway, a traditional inflammatory cascade. Pro-inflammatory cytokines, such as tumour necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and IL-6, and pro-inflammatory mediators, such as inducible nitric oxide synthase (iNOS) and *cyclooxygenase*-2 (COX-2), which are involved in the production of nitric oxide (NO) and prostaglandin E2 (PGE2), are produced when the NF-κB signalling pathway is activated . Even while an acceptable level of inflammation aids in the removal of infections, a severe reaction, such as the overproduction of inflammatory cytokines, can harm the host's essential organ tissues and may even result in death. Treating inflammatory diseases may therefore be made possible by regulating the over expression of pro-inflammatory cytokines and the associated mediators. Studies on inflammatory therapies have shown that a number of plant extracts contain anti-inflammatory properties with less adverse effects than manufactured anti-inflammatory drugs. Garcinol is one of the several advantageous phytoconstituents found in *Garcinia*, making it a significant medicinal plant. Using LPS-activated THP-1 and Raw 264.7 macrophages, the anti-inflammatory properties of garcinol extracted from *G. dulcis* fruit were examined.[45] The outcomes showed that cell viability was unaffected by the low concentration of garcinol. Moreover, pro-inflammatory mediators like COX-2 and iNOS were not expressed at the mRNA or protein levels when garcinol and LPS were co-incubated. Pro-inflammatory cytokines including TNF-α, IL-8, IL-6, and IL-1β were also not produced. Furthermore, garcinol reduced the release of NO, PGE2, IL-1β, IL-6, and TNF-α. Also, a modification in the NF-κB signalling pathway was implicated in the anti-inflammatory effects. Reduced translocation of pNF-κB from the cytosol into the nucleus was the result of down regulating pIKKα/β, pIκBα, and pNF-κB, which in turn reduced the generation of pro-inflammatory chemicals. As a result, the garcinol that was extracted from *G. dulcis* shows promise as an anti-inflammatory drug for the treatment of diseases linked to inflammation.

However, *Garcinia* species are widely used as weight loss supplement, exhibits both beneficial and adverse effects. Consumption of the fruit reduce fat accumulation and aid in weight loss, where as there are significant risks include gastrointestinal problems, liver damage, and serotonin toxicity. As herbal supplements these fruits are gaining popularity, as the same time it is essential to state about potential risks associated with *Garcinia* species and other botanicals, particularly when used concurrently with prescription medications.

Table 2: Extraction method used to extract different compound

Extraction technology	Extracted constituents	Extraction yields
Ultrasonic-Microwave Assisted Extraction (UMAE) [46,47]	Phenolic and Xanthones particularly: α-mangostin flavonoids	-
Microwave Assisted Extraction[48]	HCA	82-84%
Supercritical fluid extraction[49,50]	Phenolic and α-mangostin	-
Solvent extraction[22,51]	Anthocyanin, Polyphenols, garcinol, isogarcinol and hydroxycitric acid	0.91-10.63%

Extraction Method and Different Extracted Compounds From *Garcinia* Species

Various extraction technologies are employed to isolate compounds from plants. Table 2 provides an overview of selected extrcation method used for extraction of different compounds from different *Garcinia* species.

Extraction Methods

Ultrasonic-Microwave Assisted Extraction (UMAE)

The extraction technique known as Ultrasonic-Microwave Assisted Extraction (UMAE) is a sophisticated method that enhances the extraction efficiency of bioactive chemicals from plant materials by using both ultrasonic vibrations and microwave radiation.[46] Compounds are released more easily when cavitation bubbles produced by ultrasonic waves in the extraction solution collapse and break down plant cell walls. As a result, combining microwave and ultrasonic technology could decrease or prevent extract degradation, provide larger yields, extract active chemicals that are thermally labile. Also accelerate the extraction process, and enhance the extraction of bioactive compounds.[47] On the other hand, the solvent and plant material are heated quickly by microwave radiation, which speeds up the mass transfer rate of the target chemicals into the solvent. By combining these technologies, UMAE becomes a potent technique for getting high-quality extracts for a range of uses in food, cosmetics, and medicines . These technologies also increase the extraction yield, speed, and efficiency. Polysaccharides from a variety of natural sources have been successfully extracted using this sophisticated complementary approach.

Supercritical Fluid Extraction

SFE is a widely used green extraction technique that is used in both commercial and laboratory settings to recover important non-polar or mid-polar chemicals such lipids, carotenoids and essential oils . By raising the temperature and pressure over their critical points, solvents are used in their supercritical states, which form the basis of this approach.[48] Many solvents are used to extract bioactive compounds from plant-based sources but carbon dioxide is recommended as for Supercritical fluid extraction as it is non-toxic, safe, environmentally friendly, non- flammable, non-explosive, readily available, and cheap.[49] Pressure and temperature during the extraction process have an impact on the solubility of different chemical and selectivity in the supercritical fluid. Because of its comparatively low critical temperature (31.1 ºC) and pressure (73.8 bar), carbon dioxide is a great solvent for the extraction of bioactive chemicals that are heat-sensitive. Combining hydrothermal treatment with (SCCO2) extraction is a novel approach for the effective and sustainable extraction of bioactive chemicals. Target chemicals can be more effectively dissolved and broken down under hydrothermal conditions (using water at high temperatures and pressures), while with low viscosity and high diffusivity SCCO2 allow it to permeate plant matrix with effectiveness . This combination makes it possible to extract a number of bioactive compounds, which makes it an effective and sustainably acceptable approach for use in food and pharmaceutical industry.[50]

Solvent Extraction

A widely used method for extracting compounds according to how soluble they are in two immiscible liquids—usually an organic solvent and water—is solvent extraction technology. Solvents like acetone, methanol, ethanol, n-hexane, petroleum ether and water are most commonly used solvents. This method takes use of the different solubility of substances by moving a solute from one solvent to another. It is frequently used to separate and purify certain components in sectors including chemical engineering, food processing, and medicines. Solvent extraction has several benefits, such as superior efficiency, selectivity, and versatility in handling intricate combinations. But it frequently necessitates giving the solvent selection and environmental impact some thought. Aqueous Two-Phase Systems: A process known as Aqueous Two-Phase Systems extraction technology divides biomolecules, including proteins, nucleic acids, and other bioactive substances, into two immiscible aqueous phases.[51] This technique takes use of the targeted molecules varying solubility in the two phases. Target molecules are usually made up of salts or other polymers and water-soluble polymers like polyethylene glycol. Co-solvents such as ethanol (5–10% v/v) are sometimes added to enhance solubility. Specific examples include the extraction of α-mangostin and xanthones from *G. mangostana* pericarp using 250 bar CO_2 at 40°C for 90 minutes.[52]

Bioactive Compounds Extracted From *Garcinia*

Xanthones

The pericarp of *G. mangosteen*, is made up of a number of polyphenolic acids, such as xanthones and tannins, which provide astringency to prevent animal predation, fungal, bacterial, viral, and insect infestation while the fruit is still immature. The compound Xanthones found in *Garcinia* fruit, have shown antioxidant, anti-inflammatory and anticancer properties in various studies. Currently, there are around 200 xanthones known to occur in nature, with the *G. mangosteen* containing over 50 of them. The conjugated ring structure of the xanthones is composed of six carbons and has many double carbon bonds. Some examples of xanthones found in *Garcinia* fruit, particularly in *G. mangosteen* are alpha-mangostin, beta-mangostin and garcinone. A study on xanthones extract from the pericarp of *G. mangosteen* shows anti-cancer effect, Garcinone D a natural xanthone from mangosteen, promotes the proliferation of C17.2 neural stem cell. Garcinone D increases the protein levels of phosphorylated signal transducer and activator of transcription 3 (p-STAT3), Cyclin D1 and nuclear factor erythroid 2-related factor (Nrf2), heme oxygenase-1 (HO-1) in concentration- and time- dependent manners.[53]

Flavonoids

Flavonoids contribute to the color of the fruit and have been associated with various health benefits. These plant-based compound is known for their antioxidant and anti-inflammatory effects. The biflavonones are the most dominant components in most *Garcinia* species. Aqueous extracts of the stem bark of *G. huillensis* are used in traditional medicine against venereal diseases, sores, bronchitis, pneumonia, angina, measles and dermatitis. When rats were provided with normal and cholesterol-containing diets, the administration of *G. cambogia* flavonoids at a dosage of 1 mg / 100 g body weight significantly reduced their lipid levels. β-methyl β-hydroxy glutaryl coenzyme A reductase demonstrated significant decrease in rats with normal cholesterol levels.[54] Significant reductions were seen in the activities of isocitrate dehydrogenase and glucose-6-phosphate dehydrogenase. Animals fed flavonoid were shown to have highly increased activity of the enzyme's lipoprotein lipase and plasma lecithin cholesterol acyl transferase. Significant elevations in faecal neutral sterols and hepatic and faecal bile acids suggested a faster rate of cholesterol breakdown. Therefore, a decreased rate of lipogenesis and an increased rate of degradation may be the cause of these flavonoids hypolipidemic action.

Garcinol

Polyisoprenylated benzophenone, or garcinol, is derived from the fruit peel and leaves of *G. indica*.[55] It was utilized in conventional medicine for its anti-inflammatory and antioxidant qualities. Anti-proliferative effects of garcinol were observed azoxymethane induced colon tumors of male mice models at 500ppm oral dosage. The oral administration of garcinol-enriched fraction at 25, 50 and 100 mg / kg exhibited atherosclerosis risk factor and altered the associated oxidative stress and inflammation. And significant reductions in body weight were reported for male mice fed with 25, 50 and 100 mg / kg of garcinol-enriched fraction.[56] Peptic ulcers is a complex disease affects a significant portion of the global population. Research studies have indicated that oral administration of garcinol at dose ranging from 40 to 200 mg / kg reduced gastric ulceration induced by indomethacin in rats.

The most optimal protective effects were observed at a dose of 200 mg / kg, which even outerformed the positive control. In vitro studies have shown that garcinol exhibited efficacy against H. pylori, a causative agent of gastric ulcers and cancer. These findings collectively indicate the potential of garcinol for preventing gastric ulcer development.[57]

Isogarcinol

G. mangostana fruit rind is a natural source of isogarcinol, a polyphenolic substance obtained from the *Garcinia* species. It is well-known for having a number of biological effects, including as anti-inflammatory, anti-cancer, and antioxidant activities.[58] The ability of isogarcinol to suppress the development of cancer cells, protect against cellular oxidative damage, and alter immunological responses has all been investigated. It is being researched for use in pharmaceutical and nutraceutical applications because of these therapeutic qualities.

Hydroxycitric Acid (HCA)

HCA is the most well-known compound found in *Garcinia* fruit, particularly in the rind of *G. cambogia*.[59] HCA has been studied for its potential effects on weight loss and appetite suppression. In a clinical study, 100 obesity individuals (20 - 45 years old) took 600 mg *Garcinia* caplets (250 mg extract, 350 mg powder) twice daily for 3 months. Extract had 60-66 % HCA via water extraction after removing hydrophobic compounds.[60] Participants with weight reduction showed an average fat and fat-free mass decline of 57.8 g and 5.6 g per day, while those with weight gain had 28.9 g fat increase and 52.2 g fat-free mass increase per day.

Processing and Product Derived from *Garcinia*

Garcinia is categorized as minor fruits which play a vital role in the livelihoods of local communities of North-East, India and contribute to the region's agro-economy. However, these fruits are often underutilized due to limited processing techniques and value addition. An overview of the techniques used and highlighted the significance in the processing of the minor underutilized fruits in North-East India. Many researchers explore various processing methods employed to enhance the shelf life, marketability and overall value of these fruits. The techniques discussed include traditional methods such as sun drying and fermentation as well as modern approaches like freeze-drying and extraction.[24] These methods aim to reduce post-harvest losses, preserve the unique flavours and aromas of the fruits and ensure their availability beyond their limited seasonal periods. The processing of minor fruits in North-East India is a multifaceted endeavour that blends traditional knowledge with modern technologies. Enhancing the processing techniques for these fruits can lead to increased income for local communities, preservation of biodiversity and greater access to nutritious and culturally significant food products. *Garcinia* have various uses and can be processed into different products.

Garcinia fruit can be processed using various methods to develop a range of products. Processing of the fruit enhance the shelf life, improve the flavors and increase the versatility of *Garcinia* fruit. One of the oldest and most important ways to preserve agricultural products for food security, preservation, safety, ease of handling, and economical transportation is drying. Different sun dryers have been created throughout the years, and studies have been conducted using this equipment to dry a wide range of agricultural goods. It involves removing the moisture content from the fruit, thereby extending their shelf life. Dried *Garcinia* fruit can be used in various forms, such as whole dried fruit, sliced or powdered form.[61] This dried fruit can be used in cooking, baking and as flavorings in teas, sauces and snacks. Studies on drying of *G. pedunculata* using convection corrugated solar dryer and conventional open sun drying reported that after drying for 28 h the moisture content decreases from 88 % (wb) to 7.22 % (wb) and 7.10% (wb) in first batch and second batch respectively. Another processing method is extraction, used to obtain the bioactive compounds and flavors from *Garcinia* fruit.[62] The most common extraction method is the use of solvents, such as water or ethanol, to extract the desired components. The extract obtained can be further processed to produce various products, including liquid extracts, concentrates or powdered forms. The fruit, heartwood, pericarp and leaf of *G.mangostana* are known to contain xanthones, which are known to have a range of pharmacologic effect, such as anti-inflammatory, anti-tumor, antifungal, anti-bacterial, anti-allergic and anti-viral properties. In various phases of carcinogenesis (initiation, promotion, and progression), xanthones have been shown to have potential chemopreventive and chemotherapeutic properties. They are also known to regulate apoptosis, inflammation, metastasis, and cell division and growth. By altering several targets and signalling transduction pathways, xanthones have been shown to limit the growth of a variety of human tumour cell types in both *vitro* and *in vivo* experiments. Furthermore, these extracts techniques are often used in the formulation of dietary supplements, functional foods and beverages.

Fermentation is a traditional method used to process *Garcinia* fruit in certain culture. The fruit are fermented by naturally occurring microorganisms, which can enhance their flavors, improve digestibility and increase their nutritional value. Fermented *Garcinia* fruit can be used in the production of condiments, pickles and traditional fermented beverages.[63] *Garcinia* fruit, such as *G. xanthochymus*, are often processed through juicing or pulp extraction methods. *Saccharomyces cerevisiae* was used to ferment the ameliorated must of *G. xanthochymus* to create *Garcinia* wine.[64] The effects of *Garcinia* must fermentation on changes in organic acids (reduction of oxalic acid), free sugars, antioxidant activities, and biochemical parameters (brix, pH, aldehydes, esters, and alcohols) were examined. The calorific value of the prepared wine was increased by a larger amount of residual sugar. The resulting wine had an aldehyde level of 0.034 % and an esters content of 0.26 %. Aspartic acid and glutamic acid were synthesised, but antinutritional factors including citric acid and oxalic acid were reduced. With a 6.1 % alcohol concentration, the *Garcinia* beverage passed sensory study with overall acceptability for both overall quality and desirable attributes.64 Traditionally, fruit are crushed or pressed to extract the juice or pulp, which can be used in the production of beverages, jams, jellies and fruit-based desserts. These products retain the natural flavors and nutritional properties of the fruit.

Freezing is preservation method that helps retain the freshness and nutritional value of *Garcinia* fruit. The fruit are washed, peeled and then frozen to preserve their flavor and texture. Frozen *Garcinia* fruit can be used in smoothies, desserts.[65,66] Freezing drying, is a technique that involves freezing the fruit and then remove the moisture through sublimation. This method helps retain the shape, flavor and nutritional content of the fruit and is commonly used in the production of freeze-dried *Garcinia* fruit snacks or powder. A key technique in microencapsulation is freeze drying technology, which offers a valuable and efficient way to preserve and protect sensitive materials. This procedure entails freezing the substance, followed by sublimation under vacuum to eliminate moisture. Freeze drying presents several benefits in the context of microencapsulation, including the retention of bioactive components, regulated release upon rehydration, reduced oxidation and degradation, and the generation of stable powders with enhanced solubility. Because of its adaptability, it may be used to encapsulate a variety of substances, including as probiotics, flavours, medications, and dietary supplements. Pharmaceutical, culinary, and food processing sectors support freeze drying as a preferred process because of the ease handling and storage of the resultant stable and dry powders. The rinds of *G. cowa* fruits are a rich source of (HCA), which has been linked to a number of health advantages. However, HCA is sensitive to heat and hygroscopic in nature. Therefore, by freeze drying at 30% concentration, *G. cowa* fruit extract was microencapsulated using three different wall materials: whey protein isolate (WPI), maltodextrin (MD), and a mixture of whey protein isolate and maltodextrin (WPI + MD in 1 : 1 ratio).[67] The effects of the microencapsulated powders on the concentration of free HCA and bread quality were assessed. In addition to having a greater free HCA content, bread with WPI encapsulation had a larger volume, softer crumb texture, appealing colour, and other sensory characteristics. This shown that, in comparison to the other two wall materials, WPI had superior encapsulation efficiency during bread baking. Additionally, *Garcinia* fruit have gained attention for their potential health benefits. These processed products provide consumers with a convenient and versatile way to incorporate *Garcinia* fruit into their diets while enjoying their unique attributes.

Discussion

The *Garcinia* genus, notably diverse in North-East India, offers a unique convergence of ethnomedicinal value, nutritional richness, and phytochemical complexity. This review highlights multiple species, particularly *G. pedunculata, G. paniculata, G. cowa,* and *G. xanthochymus*, which are deeply embedded in traditional healing practices and local dietary systems. While ethnopharmacological records indicate widespread use of these fruits for ailments such as dysentery, fever, gastrointestinal discomfort, and inflammation, scientific validation remains at a nascent stage. Bioactive compounds such as HCA, xanthones, garcinol, and flavonoids contribute to the pharmacological potential of *Garcinia*, offering antioxidant, anti-inflammatory, anti-obesity, and antimicrobial activities. Traditional processing techniques—such as drying, fermentation, and sun-drying—play a pivotal role in extending the usability of *Garcinia* fruits. With increasing interest in nutraceutical applications, modern methods such as freeze drying, microencapsulation, and UMAE have emerged as effective tools for preserving bioactivity and enhancing product stability. These technologies not only retain key phytochemicals but also facilitate the development of value-added products such as syrups, powders, and bakery ingredients. Yet, integration of such innovations into local agro-economies remains limited due to lack of infrastructure and knowledge dissemination among indigenous communities. The nutritional profile of *Garcinia* fruits, rich in moisture, organic acids, vitamins, and essential minerals, supports their inclusion in health-promoting diets. However, variability in compositional data across species and regions calls for a more rigorous analysis to guide product development and regulatory compliance. Proximate analysis across multiple species revealed a favorable profile for functional foods, yet few attempts have been made to translate these attributes into scalable commercial products.

Furthermore, conservation and sustainable harvesting practices remain critical in maintaining the biodiversity of *Garcinia* species in North-East India. The semi-wild nature of cultivation and lack of formal agronomic practices limit both yield and quality. Developing region-specific cultivation protocols, post-harvest technologies, and market linkages can enhance the socio-economic impact of *Garcinia* farming. Ethnobotanical knowledge should be integrated into such strategies to ensure cultural continuity and resource stewardship.

Conclusion

This review highlights the nutritional, ethno pharmacological, and industrial value of *Garcinia* species from North-East India. With significant health benefits and traditional applications, *Garcinia* has immense potential in functional food and nutraceutical sectors. Future work should focus on clinical validation, sustainable harvesting, and standardization of extraction techniques.

In order to facilitate domestication of the species in regions of its natural distribution documentation of existing data on traditional knowledge and ethnobotanical component is advocated. Uses of *Garcinia* with possible health advantages suggest that the food business has a bright future for this supplement. There is a good chance that more functional foods and beverages will contain *Garcinia* extracts as research into the weight-management, anti-inflammatory, and antioxidant qualities of these substances continues. Thus, comprehensive research on the pharmacological characteristics and nutritional composition needed to fully understand its potential for health promotion. As consumer preferences shift towards natural and plant-based ingredients, *Garcinia* as a natural additive may grow, offering both flavor enhancement and potential health benefits. In order to attain higher quality and more productive output, effective multiplication protocols and site-specific agricultural techniques should be developed. Reduce post-harvest losses and encourage effective use of harvested goods by concentrating on secondary agriculture and creating value-added and processed products. Furthermore, creating novel food formulations like drinks or snacks with *Garcinia* might attract to consumers who are health-conscious.

Garcinia fruit are a valuable botanical resource with diverse applications and potential health benefits. The culmination of research and traditional knowledge surrounding this fruit highlighted their diverse applications and promising health benefits. Their low-calorie nature makes them an attractive option for individuals aiming to manage their weight or improve their overall health. Their nutritional composition, medicinal properties, and industrial potential demands continued scientific investigation. Further scientific exploration and evidence-based research are necessary to fully understand their properties, establish their role in human health, and maximize their utilization in different domains.

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- **Ajita Tiwari:** Conceptualization, supervision, writing – review and editing.
- **Jatin Kalita:** Resources, visualization, and manuscript editing.

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