

Nutraceutical supplements from subtropical fruits

Nutraceuticals, derived from food sources with health-promoting properties, are increasingly recognized as essential components of preventive healthcare and functional foods. The growing prevalence of chronic diseases and rising consumer demand for natural remedies have accelerated the global expansion of the nutraceutical market. Subtropical fruits such as mango, jamun, guava, bael, aonla, and wood apple serve as valuable sources of bioactive compounds, including polyphenols, flavonoids, carotenoids, and glycosides, with well-documented therapeutic benefits. Advanced processing technologies like infrared drying and nano-encapsulation further enhance the bioavailability, stability, and shelf life of fruit-derived products. Nutraceutical-enriched food supplements developed from subtropical fruits at ICAR-CISH Lucknow are briefly highlighted in this article, emphasizing their role in nutrition and health.

Keywords: Bioactive compounds, Functional foods, Nano-encapsulation, Nutraceutical supplements, Subtropical fruits

NUTRACEUTICALS, a term derived from nutrition and pharmaceuticals, represent food-derived products that provide health benefits beyond basic nutrition. With increasing consumer demand for natural remedies and preventive healthcare, nutraceutical supplements have gained significant attention in functional food industries and clinical nutrition. These food supplements have recently gained popularity due to their safety profile, therapeutic effects, and added nutritional benefits. Presently, the nutraceuticals industry is growing exponentially, driven by the rising incidence of chronic diseases such as diabetes and obesity. The global nutraceuticals market, valued at USD 483.49 billion in 2024, is projected to reach USD 969.11 billion by 2035, representing a CAGR of 6.4% during the forecast period. According to statistics, 15% of our population is undernourished. Various initiatives such as the Integrated Child Development Services (ICDS) program, National Health Mission (NHM), and the mid-day meal scheme are helping ensure nourishment reaches all. Nutraceutical supplements, available in various forms such as capsules, powders, extracts, and functional beverages, are increasingly recognized as important tools for promoting health, preventing chronic diseases, and complementing therapeutic regimens.

Nutraceuticals from important subtropical fruit

A diet containing high levels of fruits and vegetables has been associated with a lower risk of chronic diseases because, in addition to their high vitamin and mineral content, these foods also contain compounds with health-protective effects, particularly antioxidant and anti-

Various forms of available nutraceutical supplements

Forms	Nutraceutical supplements
Product type	Vitamins and minerals Herbal and botanical extracts Proteins and amino acids Omega and essential fatty acids Probiotics and prebiotics Functional and superfood blends
Form	Capsules and soft gels Tablets Powders Gummies and chewable Liquids and syrups
End-use	Dietary supplements Functional foods and beverages Pharmaceuticals and therapeutic use Infant and child nutrition Sports nutrition Geriatric nutrition Personal care and beauty
Type of application area	Allergy and intolerance Bone and joint health Cancer prevention Children's health Diabetes Digestive/gut health Energy and endurance Immune system

inflammatory compounds. Subtropical fruits represent a valuable resource for the nutraceutical industry, offering a wide spectrum of bioactive compounds with proven health benefits. With growing consumer interest in natural and

Nutraceutical supplements from important subtropical fruit

Fruit crops	Plant parts	Key bioactive components	Health benefit/function
Mango	Pulp, peel, leaves, kernals	Mangiferin Leupol Polyphenols Carotenoids	Anticancer Antioxidant, Anti-inflammatory Skin health Immunity booster
Guava	Pulp, leaves	Lycopene Quercetin Vitamin C Fiber Pectine	Immune boosting Anti-diabetic Gut health
Jamun	Pulp, seed, leaves	Anthocyanins Jamboline, Ellagic acid	Anti-diabetic Antioxidant Blood purifier
Bael	Pulp, leaves	Marmelosin, Mucilage Tannins Pectin	Digestive health Anti-diarrheal Gut soothing Skin health
Aonla	Pulp	Vitamin C Polyphenols Ellagic acid Gallic acid	Immunity Anti-aging Liver health Skin and hair care
Karonda	Pulp	Iron Anthocyanins Flavonoids	Anemia prevention Antioxidant Heart health

preventive healthcare solutions, nutraceutical supplements derived from these fruits have the potential to play a vital role in health management. These fruits are not only valued for their sensory attributes but are also packed with vitamins, minerals, antioxidants, and phytochemicals such as polyphenols, flavonoids, carotenoids, and glycosides. Future trends also emphasize the valorization of fruit by-products (peels, seeds, and leaves), which are often richer in bioactive compounds than the edible pulp. Their bioactive properties make them excellent candidates for nutraceutical formulations.

Product formulation and functionality

Bioactive compounds from fruits can be applied in the creation of nutraceuticals, functional foods, nutritional supplements, and pharmaceutical formulations. They aid in enhancing human health and addressing several medical issues. While these fruits offer immense potential as nutraceutical sources, challenges such as variability in phytochemical content, poor stability during processing, and limited bioavailability must be addressed when converting them into various products. Advanced technologies such as nano-encapsulation, spray drying, and microencapsulation are being explored to improve the shelf life and bioavailability of fruit-derived nutraceuticals. Fruit-based nutraceutical supplements should be consumer-friendly, palatable, convenient to use, and have defined health benefits. They are easily transportable in compact forms like powders, capsules, or sachets with longer shelf life. Processing techniques

Product formulation from subtropical fruits and functionality

Functionality	Products
Anti-diabetic supplements	Jamun seed powder capsules/tablets Jamun juice fortified with Karela/Aonla juice Guava leaf tea or capsules Bael fruit tablets
Immunity boosters	Aonla vitamin C capsules or effervescent tablets Guava - Aonla blend powder Mangiferin-rich energy bars
Digestive and gut health	Bael fruit gut health powder Guava high-fiber granules Aonla - bael herbal tonic Wood apple pulp powder
Anti-oxidant / anti-aging	Jamun anthocyanin-rich extract capsules Mango peel - aonla polyphenol drink Guava pulp extracts Karonda antioxidant gummies
Skin and hair health	Aonla - biotin hair growth capsules Mango seed oil-based skin cream Guava leaf extract face mask or serum
Women's health / iron deficiency	Karonda iron syrup or chewables Amla-karonda fortified bars
Heart health	Jamun-Aonla Juice Guava leaf extract Mango fruit extract powder
Anti-cancerous	Mangiferin-enriched powders Guava leaf extract tablets Karonda antioxidant gummies Karonda-hibiscus herbal tea

employed should ensure better nutrient retention by protecting sensitive bioactive compounds from heat, oxidation, and degradation.

Nutraceutical-enriched products developed at Institute from subtropical fruits

Mangiferin-enriched value-added products

Fresh mango leaves were carefully harvested as a sustainable source of bioactive compounds. Using an optimized alcoholic solvent extraction process, mangiferin—a xanthonoid known for its strong antioxidant, anti-inflammatory, and immunomodulatory properties—was isolated in high purity. This concentrated extract was subsequently incorporated into bael squash and guava squash formulations to enhance their functional value. The infusion not only elevates the nutritional content of these fruit beverages but also offers potential health-promoting



benefits such as improved metabolic balance, better oxidative stress management, and enhanced immune support. By combining traditional fruit-based products with scientifically validated phytochemicals, this approach creates a novel functional drink with both superior taste and therapeutic potential.

Anti-diabetic jamun seed powder

Jamun seed powder contains diverse bioactive compounds, which help regulate blood sugar levels and support pancreatic health. The powder was prepared using infrared drying of the seed. *Jamun* seed powder-based food supplement was developed with enhanced nutraceutical properties, especially as anti-diabetic, anti-inflammatory, and anti-microbial. A total of 61 bioactive compounds were identified in *jamun* seed powder, categorized under 18 different chemical groups, reflecting a highly diverse phytochemical composition. These include phenolics, flavonoids, tannins, alkaloids, terpenoids, glycosides, saponins, amino acids, organic acids, sugars and sugar alcohols, fatty acids/lipids, vitamins, steroids, coumarins, hydroxybenzoic, and hydroxycinnamic acid derivatives. The wide range of chemical classes supports the therapeutic values of the jamun seed-based product as anti-diabetic, anti-inflammatory, and anti-microbial.



Detoxifying jamun-aonla juice

Jamun-Aonla juice is a powerful health drink combining the medicinal benefits of *Jamun* and *Aonla*. Rich in antioxidants, vitamin C, iron, and polyphenols, this juice supports blood sugar regulation, boosts immunity, and improves digestion. Juice was prepared from fresh ripe jamun fruits and aonla mixed in a 60:40 ratio. A small amount of black salt was added to enhance the taste. Consuming this juice regularly may help manage diabetes, detoxify the body, enhance skin health, and improve liver



function. Its astringent and cooling properties make it an excellent natural remedy for summer ailments. For best results, the juice should be consumed fresh on an empty stomach or before meals.

Guava pulp extracts powder

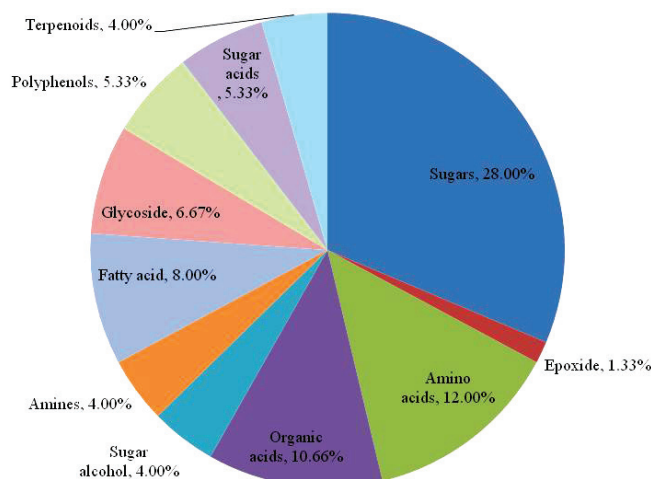
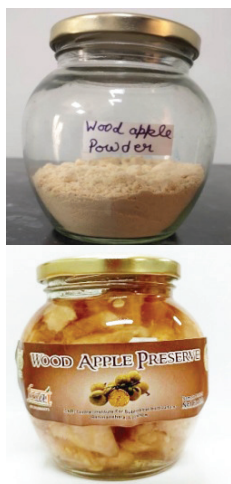
Fruits are peeled, deseeded, and the pulp extracted. This pulp is subjected to pasteurization to reduce microbial load and preserve nutritional quality. The pulp is dried using a cabinet dryer at 50°C for 16 hours. After drying, the residues are cooled and ground into fine powder. The resulting guava pulp powder is sieved, packed in moisture-proof containers, and stored in cool, dry conditions to maintain its quality. Antioxidants in guava powder combat oxidative stress, potentially reducing the risk of chronic diseases such as heart disease and cancer. Its dietary fiber promotes digestive health, supports regular bowel movements, and may aid in managing blood sugar levels.

Wood apple pulp powder

Wood apple (*Feronia limonia* (L.) Swingle) is an underutilized fruit with unique consumption-linked properties at different maturity stages. The fruit pulp was dehydrated through infrared drying methods to preserve its bioactive compounds. Once completely dried, the pulp is ground into fine powder and stored in airtight containers. It is used as a functional ingredient in herbal supplements, smoothies, health drinks, and Ayurvedic formulations. With a long shelf life and high nutritional value, dried wood apple pulp powder serves as a convenient and versatile superfood for culinary and medicinal applications. A total of 75 compounds were detected under 12 distinct broad chemical groups in infrared-dried wood apple pulp powder. These diverse biochemical profiles contribute to its antioxidant, anti-fungal, anti-inflammatory, hypoglycemic, hypolipidemic, hepatoprotective, and cardiovascular properties.

Phenolic profiling of seven varieties of guava powder (µg/g)

Variety	Gallic acid	Chlorogenic acid	Catechin	Epicatechin	Caffeic acid	Ellagic acid
Allahabad Safeda	2181.08	40.09	224.06	30.91	ND	174.90
L-49	2126.18	76.56	1099.15	96.29	86.71	163.73
Lalit	517.58	432.21	768.87	190.71	82.58	98.59
Shweta	1919.19	97.79	138.76	38.62	15.38	107.55



Relative proportion of different metabolites in wood apple pulp powder

and *aonla*, minimizing nutrient loss compared to conventional drying. This synergistic blend offers prebiotic potential, supports gut microbiota balance, and aids in relieving constipation, acidity, and indigestion. Rich in antioxidants and immune-boosting phytochemicals, it also helps reduce oxidative stress and inflammation. The convenient powder form ensures longer shelf life, easy incorporation into diets, and functional health benefits for overall gastrointestinal well-being.

Bael-Aonla based gut health powder

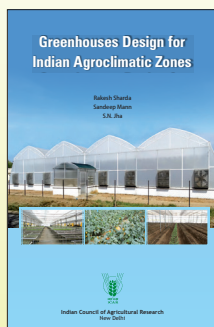
Bael-Aonla based gut health powder developed using infrared drying is a novel nutraceutical formulation aimed at promoting digestive wellness. The process involves gentle infrared drying that preserves bioactive compounds, especially marmelosin and psoralins, polyphenols, vitamin C, and dietary fibers from bael



CONCLUSION
The development of nutraceutical products from subtropical fruits highlights their immense potential in preventive healthcare and functional nutrition. Value-added products like mangiferin-enriched beverages, *jamun* seed powder, guava pulp powder, wood apple pulp powder, and *bael-aonla* gut health formulations demonstrate the scope of integrating fruits with modern processing technologies. These value-added products retain bioactive compounds with antioxidant, anti-inflammatory, hypoglycemic, and gut-modulating properties, offering both therapeutic and nutritional benefits. Despite challenges of variability, stability, and bioavailability, fruit-based nutraceuticals hold strong potential as consumer-friendly, sustainable, and health-promoting supplements for future dietary interventions.

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