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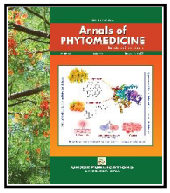

Review Article : Open Access

Terminalia chebula Retz.: An unveiling of a medicinal fruit powerhouse of health-promoting compounds

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Abstract

Terminalia chebula Retz. is a medicinal fruit renowned for its extensive therapeutic potential in traditional and modern medicine. It is rich in many bioactive compounds such as tannins, flavonoids, triterpenoids, glycosides, and phenolic acids, contributing to its diverse pharmacological properties, including antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, and immunomodulatory effects. The fruit is a key ingredient in Ayurveda, particularly in Triphala, and is widely used for managing gastrointestinal disorders, diabetes, respiratory ailments, and skin conditions. This review explores the nutritional and bioactive composition of *T. chebula*, highlighting its pharmacological significance and potential health benefits. Additionally, incorporating *T. chebula* into value-added products, such as herbal teas, dietary supplements, functional foods, cosmetics, and oral care formulations, underscores its growing importance in the nutraceutical and pharmaceutical industries. Despite its well-documented medicinal properties, further clinical studies and advanced formulation strategies are needed to enhance its bioavailability and therapeutic efficacy. This review highlights the nutritional and bioactive compounds of *T. chebula* with their pharmacological significance and therapeutic applications, emphasizing its role as a natural remedy and functional food ingredient for promoting human health as a natural health-promoting power house.

1. Introduction

Terminalia chebula Retz. belongs to the Combretaceae family. It is commonly referred to as harar, haritaki, harada, karkchettu, kadukkaya, and the "king of medicine." The name "haritaki" is derived from its ability to cure various ailments or its association with Lord Shiva (Hara). Haritaki is known by several intriguing synonyms. "Pathya" signifies its role in clearing blockages within the body's pathways and channels. "Abhaya" represents its power to instill courage, while "Amrta" translates to "ambrosia" in Sanskrit. It is also called "Divya," meaning "a divine herb," "Medhya," referring to its properties as a nerve tonic, and "Pranada," meaning "life-saving" (Gupta, 2012). *T. chebula* is commonly found in the sub-Himalayan region, stretching from the Ravi River eastward to western Bengal and Assam, at elevations of up to 1,500 meters (4,900 feet) in the Himalayas. It also thrives in deciduous forests across most of India, except for arid regions. In the northwestern Himalayas, it grows at altitudes ranging from 500 to 1,100 meters in states such as Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, and Uttarakhand. In Himachal Pradesh, *T. chebula* is found at elevations of up to 1,100 meters in districts like Sirmour, Hamirpur, Mandi, Bilaspur, Kangra, and Una. It is also prevalent in mixed dry deciduous forests and commonly occurs in tropical and subtropical zones, particularly in hilly regions (Bag *et al.*, 2013).This medium to large deciduous tree is heavily branched, reaching heights of up to 30 meters with a trunk diameter of 1 to 1.5 meters. Its elliptic leaves measure 10-30 cm in length, featuring a pointed apex and a cordate base, with a distinct venation pattern comprising six to eight pairs of veins. The tree produces short panicles or simple terminal spikes of monoecious flowers that are dull white to yellow, with short stalks and a strong, unpleasant odor. The fruit is ovoid, yellowish-green, measuring 3-6 cm in length and 1.3-1.5 cm in width, each containing a single oval seed (Tariq and Reyaz, 2013). Fruit development occurs between June and December, with ripening taking place from December to March, requiring about two months to mature. Harvesting begins in August and continues until January. The presence of flavonoids is indicated by a yellow coloration, while brown coloration signifies the presence of alkaloids and terpenoids (Bag *et al.*, 2013).

Known as the "King of Medicines," *T. chebula* possesses a wide range of therapeutic properties, making it effective in treating diabetes, dementia, diarrhea, pharyngitis, sore throats, asthma, and dysentery. It is a key component of Triphala, one of the most renowned Ayurvedic remedies, alongside *Terminalia bellerica* (Bihitaki) and *Emblica officinalis* (Amalaki) (Bag *et al.*, 2013). The entire plant has been

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traditionally valued for its medicinal properties, with its fruit offering mild laxative, alterative, tonic, and antispasmodic effects. It has been used to treat bleeding gums, hemorrhoids, dental caries, and oral ulcers. When mixed into a paste with water, it exhibits properties of being an analgesic, anti-inflammatory, detoxifying, and wound-healing. Its decoction serves as a gargle for oral ulcers and sore throats, while its powdered form acts as an astringent dentifrice, helping with gum bleeding, loosegums, and gum ulcers (Singh and Malhotra, 2017). Additional benefits of *T. chebula* include appetite stimulation, gastrointestinal motility enhancement, liver stimulation, and stomachic effects, along with its role as a mild laxative. The fruit powder has been used to manage chronic diarrhea and alleviate nervous irritation and weakness. It is also believed to enhance the function of the five senses. This review aims to compile available scientific data on its biochemical constituents and their potential in combating various human diseases. An optimized extract of *T. chebula* could be highly valuable in pharmaceutical or nutraceutical formulations for disease treatment and prevention. Ideally, such an extract could also serve as an effective dietary supplement.

2. Plant material

2.1 Plant authentication

The plant material (*T. chebula*) authenticatedby Professor and Head, Department of Forest Product, and a Voucher Specimen (No. 14154) was deposited in the Herbarium Department of Forest Product, College of Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh.

3. Nutritional compounds

T. chebula fruits contain carbohydrates, crude protein, crude fat, and a variety of essential minerals, including phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, boron, copper, sodium, chloride, selenium, and silica (Tables 1 and 2).

3.1 Proximate compound

The proximate composition of *T. chebula* highlights its nutritional and medicinal significance. It contains moisture (8-12%), ensuring stability during storage, while crude protein (3-7%) contributes to enzymatic and cellular functions. The crude fat content (1-3%) includes essential fatty acids like palmitic and linoleic acid, beneficial for metabolic health. The ash content (3-6%) signifies the presence of vital minerals such as calcium, magnesium, potassium, iron, and zinc, essential for bone health and immune function. *T. chebula* is particularly rich in crude fiber (20-40%), aiding digestion and gut health. Its carbohydrate content (35-60%) consists of complex polysaccharides and tannins, contributing to its therapeutic properties. Additionally, it is abundant in secondary metabolites like polyphenols, flavonoids, tannins, and triterpenoids, known for their antioxidant, antimicrobial, anti-inflammatory, and hepatoprotective effects. This diverse composition makes *T. chebula* a valuable ingredient in functional foods, nutraceuticals, and herbal medicinal formulations (Barthakur and Arnold, 1991; Jamil *et al.*, 2023; Khalil *et al.*, 2023).

3.2 Minerals

Minerals are vital for maintaining health and longevity, supporting functions such as bone development, nerve transmission, hormone production, and heart regulation. Macro- and microelements contribute to the structure of bones and teeth (*e.g.*, Ca, P, F, Mg, Mn, B), while microelements like Cu, Fe, Mn, Mg, Se, and Zn are essential components of various enzymes. Macroelements (Ca, Mg, P, Na, K) play critical roles in nerve signalling, whereas micro-elements like I, Co, Fe, and Cr are crucial for RBC formation, blood glucose regulation, and antioxidant enzyme activation. Minerals like Ca and K help regulate blood pressure, while others support immune function (Ca, Mg, Cu, Se, Zn) and brain health (Cr, Mn). Iron deficiency can cause anemia, impaired growth in children, pregnancy complications, and reduced adult productivity (Lwin *et al.*, 2020). *T. chebula* fruit contains essential minerals such as Na, K, Mg, Fe, Zn, Cu, Mn, and Co. Heavy metals like Cd and Pb have also been detected. Iron is abundant (815.33 ± 10.33 ppm), vital for physiol-ogical roles in forms like hemoglobin and ferritin (Hussain *et al.*, 2009). Zinc is present at 33.66 ± 0.35 ppm, and copper at 7.05 ± 0.05 ppm. Calcium is found at 0.93 ± 0.05 ppm, while cobalt (5.52 ± 0.22 ppm) is slightly higher than Ca, Mg (0.26 ± 0.02 ppm), and K (4.04 ± 0.05 ppm). Sodium and manganese were reported at 1.56 ± 0.18 ppm and 23.41 ± 1.52 ppm, respectively (Jamil *et al.*, 2023).

3.3 Amino acids

Amino acids, the building blocks of proteins, are classified based on nutritional needs into three categories: essential, semi-essential, and non-essential. Essential amino acids cannot be synthesized by the human body and must be obtained through diet. These include valine, isoleucine, leucine, threonine, phenylalanine, methionine, tryptophan, and lysine. They are crucial for maintaining nitrogen balance, and their deficiency may lead to neurological disorders, impaired mental development, and even death in young animals. Semi-essential amino acids, such as histidine and arginine, are produced in the body but not in sufficient quantities, especially in children, who must obtain them from dietary sources. Non-essential amino acids are synthesized in the body and include alanine, arginine, aspartic acid, asparagine, cysteine, cystine, glutamine, glutamic acid, glycine, proline, histidine, and serine (Gharibzahedi and Jafar, 2017). Barthakur and Arnold (1991) reported the presence of various amino acids in *T. chebula*. Major amino acids identified were aspartic acid (39.6%), glutamic acid (8.6%), arginine (6.7%), proline (6.4%), and lysine (5.0%), which notably enhance the biological value of the fruit's protein. Although, cystine was absent, a small amount of methionine, another sulfur-containing amino acid, was detected. Other quantified amino acids include alanine (61.8 mg/100 g), glycine (71.7 mg/100 g), histidine (47.4 mg/100 g), isoleucine (51.9 mg/100 g), leucine (91.3 mg/100 g), methionine (24.1 mg/100 g), phenylalanine (51.0 mg/100 g), serine (63.9 mg/100 g), threonine (46.8 mg/100 g), tyrosine (62.1 mg/100 g) and valine (50.4 mg/100 g (Salnikow, 2021).

3.4 Vitamins

T. chebula is a rich source of antioxidants, primarily due to its high content of vitamin C and hydrolysable tannins. The unique bonding of vitamin C with tannins helps stabilize the vitamin, protecting it from degradation by heat and light, and preserving its content even during processing. As a water-soluble vitamin not stored in the body, vitamin C must be consumed daily. It plays a crucial role in cellular energy production, sperm formation, collagen synthesis (important for skin, joints, cartilage, and blood vessels), immune function, detoxification, and enhancing nutrient absorption-especially iron. Additionally, it acts as a potent antioxidant, neutralizing oxygen radicals and contributing up to 24% of total peroxyl radical-trapping

activity (Gharibzahedi and Jafar, 2017). *T. chebula* fruit extract contains 46.74 ± 1.10 mg/ml of ascorbic acid per 100 mg. Studies also show that supplementation with *T. chebula* increases heart levels of vitamins C and E in aged rats, indicating its potential in supporting cardiovascular health through phytochemicals like flavonoids and ascorbic acid derivatives (Sarala and Krishnamurthy, 2021).

Table 1: Nutritional components with values of *T. chebula*

Component		Values	References
Moisture		006.08 ± 0.25 (%)	Jamil *et al.* (2023)
		51.66 (%)	Barthakur and Arnold (1991)
		10.55 ± 0.27, 9.66 ± 0.12, 8.64 ± 0.15 (%)	Khalil *et al.* (2023)
		8.65 (%)	Lwin *et al.* (2020)
Ash		004.03 ± 0.13 (%)	Jamil *et al.* (2023)
		4.03 (%)	Barthakur and Arnold (1991)
		003.45 ± 0.13, 3.89 ± 0.11, 4.18 ± 0.13 (%)	Khalil *et al.* (2023)
		2.68 (%)	Lwin *et al.* (2020)
Crude fat		003.40 ± 0.14 (%)	Jamil *et al.* (2023)
		3.40 (%)	Barthakur and Arnold (1991)
		001.88 ± 0.11, 1.54 ± 0.07, 2.25 ± 0.10 (%)	Khalil *et al.* (2023)
		1.45 (%)	Lwin *et al.* (2020)
Crude fiber		018.14 ± 0.63 (%)	Jamil *et al.* (2023)
		18.14 (%)	Barthakur and Arnold (1991)
		005.37 ± 0.31, 5.69 ± 0.17, 6.25 ± 0.61 (%)	Khalil *et al.* (2023)
		19.33 (%)	Lwin *et al.* (2020)
Crude protein		005.36 ± 0.40 (%)	Jamil *et al.* (2023)
		1.20 (%)	Barthakur and Arnold (1991)
		003.84 ± 0.07, 3.24 ± 0.11, 4.53 ± 0.37 (%)	Khalil *et al.* (2023)
		3.78 (%)	Lwin *et al.*(2020)
Nitrogen-free extracts (NFE)		062.20 ± 0.99 (%)	Jamil *et al.* (2023)
		62.20 (%)	Barthakur and Arnold (1991)
		074.91 ± 0.25, 75.98 ± 0.15, 74.15 ± 0.13 (%)	Khalil *et al.* (2023)
		83.43 (%)	Lwin *et al.* 2020
Minerals	Calcium (Ca)	000.93 ± 0.05 (ppm)	Jamil *et al.* (2023)
		081.66 ± 1.12, 89.58 ± 7.60, 95.58 ± 3.81 (mg/kg)	Khalil *et al.* (2023)
	Magnesium (Mg)	000.27 ± 0.01 (ppm)	Jamil *et al.* (2023)
	Potassium (K)	004.01 ± 0.01 (ppm)	Jamil *et al.* (2023)
		101.58 ± 1.50, 105.08 ± 2.50, 113.66 ± 2.26 (mg/kg)	Khalil *et al.* (2023)
	Sodium (Na)	001.29 ± 0.04 (ppm)	Jamil *et al.* (2023)
		001.25 ± 0.90, 1.83 ± 0.38, 2.16 ± 0.38 (mg/kg)	Khalil *et al.* (2023)
	Iron (Fe	815.33 ± 10.33 (ppm)	Jamil *et al.* (2023)
		007.49 ± 1.25, 18.83 ± 2.9, 15.54 ± 0.26 (mg/kg)	Khalil *et al.* (2023)
		446 (ppm)	Barthakur and Arnold (1991)

	Zinc (Zn)	033.66 ± 0.35	Jamil *et al.* (2023)
		000.86 ± 0.06, 0.78 ± 0.04, 0.95 ± 0.04 (mg/kg)	Khalil *et al*. (2023)
		34.4 (ppm)	Barthakur and Arnold (1991)
	Copper (Cu)	007.05 ± 0.05 (ppm)	Jamil *et al.* (2023)
		000.51 ± 0.31, 0.94 ± 0.04, 0.75 ± 0.05 (mg/kg)	Khalil *et al*. (2023)
		24.2 (ppm)	Barthakur and Arnold (1991)
	Manganese (Mn)	033.81 ± 0.41 (ppm)	Jamil *et al.* (2023)
	Lead (Pb)	000.36 ± 0.06, 0.48 ± 0.07, 0.67 ± 0.05 (mg/kg)	Khalil *et al*. (2023)
	Nickel (Ni)	000.79 ± 0.18, 0.91 ± 0.03, 0.96 ± 0.06 (mg/kg)	Khalil *et al*. (2023)
	Cadmium (Cd)	000.14 ± 0.08, 0.08 ± 0.02, 0.15 ± 0.009,(mg/kg)	Khalil *et al*. (2023)
	Cobalt (Co)	6.6 (ppm)	Barthakur and Arnold (1991)

*Analysed three varieties of *T. chebula* (green, black, and kabuli), respectively.

3.5 Dietary fibre

Dietary fiber refers to plant-based components resistant to enzymatic digestion, including cellulose, hemicellulose, pectins, gums, mucilages, and lignin (Hussain *et al*., 2009). It exists in two forms-soluble and insoluble-with the total referred to as total dietary fiber. These indigestible compounds are fermented by gut microflora in the large intestine and offer various health benefits (Kamble *et al*., 2021; Barthakur *et al*., 1991). Dietary fiber also exhibits antioxidant properties due to its association with antioxidant-linked compounds, which are often overlooked by standard analytical methods but contribute significantly to total antioxidant capacity. These components enhance the health-promoting effects attributed to both fiber and antioxidants.

Dietary fiber plays a vital role in preventing constipation, diabetes, cardiovascular diseases, diverticulosis, and obesity. It buffers excess stomach acid, increases fecal bulk, stimulates peristalsis, and promotes beneficial gut microbiota (Atanasiu *et al*., 1998; Maheshand Hazeen, 2007).

T. chebula fruits contain 18.14% crude fiber (Jamil *et al*., 2023). As the fruits are typically dried before full ripening, they retain polysaccharides that may otherwise degrade during ripening (Dhingra *et al*., 2012). Jeong *et al*. (2019) identified amylopectin-type polysaccharides as key antioxidant macromolecules in *T. chebula*. Crude fiber content varies in different plant parts: seeds (16.45%), aerial parts (48.62%), roots (40.67%), and dried fruits (7.10%) (Champ *et al*., 2003).

4. Bioactive compounds

4.1 Tannins

T. chebula is notably rich in hydrolyzable tannins, especially in the fruit pulp and dried pericarp, which contribute to 30-35% of its total composition. These tannins possess both phenolic and carboxylic groups, and include key compounds identified through reverse-phase chromatography such as gallic acid, methyl and ethyl gallate, chebulagic acid, ellagic acid, chebulinic acid, tetra- and penta-O-galloyl-D-glucose (Juang *et al*., 2004). Additional tannins include punicalagin, chebulanin, corilagin, and neochebulinic acid. The leaves also contain polyphenols like punicalin, punicalagin, and terflavins B, C, and D.

Lee *et al*. (2017) identified nine hydrolyzable tannins using spectroscopic analysis, including cinnamoyl- and galloyl-substituted glucose derivatives. Hydrolyzable tannins in *T. chebula*are classified into gallotannins and ellagitannins. Gallotannins are the simpler form, composed of D-glucose esterified with gallic acid to form glucogallin and its multi-galloylated derivatives (Suntar *et al*., 2019). They account for about 40% of the total tannin content and can be hydrolyzed by tannase during fermentation to release gallic acid (Kim *et al*., 2006).

Ellagitannins, in contrast, are formed through oxidative coupling of galloyl groups *via* C-C bonds. A key ellagitannin in *T. chebula*is chebulinic acid (1, 3, 6-tri-O-galloyl-2, 4-chebuloyl-D-glucopyranoside) (Sieniawska and Baj, 2017). Other identified phytochemicals include terchebulin, punicalagin, terflavin A, shikimic acid, tricontanoic acid, palmitic acid, beta-sitosterol, daucosterol, and the triterpene chebupentol (Bhagat *et al*., 2015).

4.2 Triterpenoids

T. chebula also contains a variety of oleanane-type triterpenoids known for their pharmacological activities. Key triterpenoids include arjungenin, arjunic acid, arjunolic acid, terminolic acid, arjunglucosides I and II, arjunetin, bellericoside, and chebuloside II (Zhang *et al*., 2015). These compounds, isolated from methanol extracts of the fruit, exhibit antioxidant potential-particularly arjungenin and its glucoside, which show moderate free radical scavenging activity. Arjunic acid and arjungenin also influence cytochrome P450 enzymes, suggesting possible interactions with drug metabolism (Eshwarappa *et al*., 2016). These findings highlight the therapeutic relevance of triterpenoids in *T. chebula*.

4.3 Flavonoids

Terminalia species are rich in flavonoids such as rutin, myricetin, quercetin, kaempferol, luteolin, orientin, and vitexin. These compounds are typically extracted using polar solvents like aqueous methanol or ethanol due to their high solubility in such media (Eshwarappa *et al*., 2016). Extraction efficiency is influenced by factors such as solvent type, particle size, temperature, solvent-to-solid ratio, extraction time, and the presence of interfering substances (Wang *et al*., 2024).

Advanced extraction methods, including supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), pressurized solvent extraction (PSE), and ionic liquid extraction (ILE), offer advantages over conventional techniques like Soxhlet extraction, such as shorter times, reduced solvent use, and better preservation of bioactive compounds (Moreira *et al*., 2017).

Flavonoid quantification depends on their type and concentration in the sample. Common analytical techniques include spectroscopy, chromatography, capillary electrophoresis, and electrochemical methods, with HPLC and GC being widely used for their accuracy and efficiency (Reddy *et al*., 2020).

4.4 Phenolic acid derivatives

*T. chebula*is rich in phenolic acids that contribute significantly to its therapeutic properties (Tariq and Reyaz, 2013). Key phenolic acids found in *T. chebula* include shikimic acid, which is a precursor in the biosynthesis of aromatic amino acids (Kim *et al*., 2006), and gallic acid, a major constituent known for its antioxidant, anti-inflammatory, and hepatoprotective activities. Other phenolic acids in *T. chebula* include ferulic acid, vanillic acid, p-coumaric acid, caffeic acid, and melilotic acid, all of which possess antioxidant and antimicrobial properties. These phenolic acids enhance the plant's pharmacological activities, including its anti-inflammatory, antioxidant, and antimicrobial effects, highlighting its therapeutic potential in both traditional and modern medicine (Hosamani, 1994).

4.5 Glycosides and other compounds

T. chebula, also known as Haritaki, is a rich source of bioactive compounds, including glycosides and other phytochemicals, which contribute to its extensive therapeutic properties. Notable glycosides identified in *T. chebula* include chebuloside II, arjunglucoside I, and arjunoglucoside II, isolated from the methanol extract of the plant's galls. These compounds are recognized for their significant pharmacological activities (Teodor *et al*., 2020). In addition to glycosides, *T. chebula* is abundant in hydrolyzable tannins like chebulagic acid, chebulinic acid, and corilagin, known for their potent antioxidant and antimicrobial properties. Phenolic compounds such as gallic acid and ellagic acid further enhance the plant's medicinal value, contributing to its antioxidant activity. Flavonoids such as rutin, quercetin, and kaempferol have also been identified, offering anti-inflammatory and cardioprotective effects (Kumari and Jain, 2015). Furthermore, triterpenoids like arjungenin and arjunolic acid contribute to hepatoprotective and antioxidant activities. The diverse array of bioactive compounds in *T. chebula* underscores its importance in traditional medicine and highlights its potential for developing novel therapeutic agents (Farha *et al*., 2020).

Table 2: Nutritional and bioactive compounds of *T. chebula* with health and pharmacological effects

Compound	Category	Health benefits	Pharmacological effects	References
Carbohydrates	Macronutrient	Provides energy, supports metabolism	Boosts digestion, prevents fatigue	Barthakur and Arnold (1991); Jamil *et al.* (2023); Khalil *et al.* (2023)
Proteins	Macronutrient	Muscle building, enzymatic functions	Supports tissue repair and immune function	Barthakur and Arnold (1991); Jamil *et al.* (2023); Khalil *et al.* (2023)
Fats (lipids)	Macronutrient	Supports cell structure, brain function	Maintains cell integrity, anti-inflammatory	Barthakur and Arnold (1991); Jamil *et al.* (2023); Khalil *et al.* (2023)
Dietary fiber	Macronutrient	Aids digestion, regulates blood sugar	Laxative improves gut microbiota	Dhingra *et al.* (2012); Jeong *et al.* (2019)
Vitamin C	Vitamin	Enhances immunity, collagen synthesis	Antioxidant, prevents scurvy	Barthakur and Arnold (1991); Gharibzahedi and Jafar (2017); Sarala and Krishnamurthy (2021)
Vitamin E	Vitamin	Skin health, antioxidant properties	Neuroprotective, prevents oxidative stress	Gharibzahedi and Jafar (2017); Barthakur and Arnold (1991)
Calcium	Mineral	Bone strength, nerve function	Prevents osteoporosis, supports muscle health	Lwin *et al.* (2020)
Iron	Mineral	Red blood cell production prevents anemia	Oxygen transport supports cognitive function	Lwin *et al.* (2020)
Magnesium	Mineral	Muscle relaxation, nerve function	Prevents cramps, supports heart health	Lwin *et al.* (2020); Sarala and Krishnamurthy (2021)
Potassium	Mineral	Regulates blood pressure, heart function	Prevents hypertension, electrolyte balance	Lwin *et al.* (2020); Sarala and Krishnamurthy (2021)
Tannins	Polyphenol	Antimicrobial, gut health	Antidiarrheal, hepatoprotective	Juang *et al.* (2004); Lee *et al.* (2017); Suntar *et al.* (2019)
Flavonoids	Polyphenol	Antioxidant, heart health	Anti-inflammatory, neuroprotective	Eshwarappa *et al.* (2016); Moreira *et al.* (2017)

Gallic acid	Phenolic acid	Detoxification, skin protection	Anticancer, hepatoprotective, antimicrobial	Tariq and Reyaz, (2013); Kim *et al.*(2006); Hosamani (1994)
Ellagic acid	Phenolic acid	Anti-aging, immune booster	Antimutagenic, neuroprotective	Tariq and Reyaz (2013); Kim *et al.* (2006); Hosamani (1994)
Chebulagic acid	Hydrolyzable-tannin	Anti-inflammatory, prevents infections	Antiviral, gastroprotective, antidiabetic	Tariq and Reyaz (2013); Kim *et al.* (2006); Hosamani (1994)
Chebulinic acid	Hydrolyzable-tannin	Antioxidant protects against oxidative stress	Neuroprotective, gastroprotective	Tariq and Reyaz (2013); Kim *et al.* (2006); Hosamani (1994)
Terpenoids	Bioactive compound	Boosts immunity, antiviral	Antimicrobial, anti-inflammatory	Manosroi *et al.* (2013); Zhang *et al.* (2015)
Glycosides	Bioactive compound	Supports detoxification, metabolism regulation	Cardioprotective, anti-inflammatory	Teodor *et al.* (2020); Sanmuga *et al.* (2018)

5. Pharmacological and health effects

Plants of the genus *Terminalia* are widely used in traditional medicine globally, with their bioactive compounds well-established for antimicrobial properties. The dried ripe fruit of *Terminalia* species has been utilized in folk medicine for treating a variety of ailments, including as an antitussive, homeostatic, diuretic, laxative, and cardiotonic (Boakye *et al*., 2014). In recent years, the clinical use of indigenous medicines has grown due to their proven efficacy and minimal toxicity. With increasing antibiotic resistance and the adverse effects of synthetic drugs, researchers are turning to herbal immunomodulators to treat infections (Cock, 2015). Herbal medicines are believed to bolster the body's natural defense mechanisms, and several plants have demonstrated immunomodulatory properties (Lee *et al*., 2005). These herbs are carefully selected and combined to help manage microbial overgrowth in various parts of the body while supporting the immune system's function (Hassan and Curtiss, 1994).

5.1 Anticariogenic effect

T. chebula has shown significant anticariogenic properties, effectively combating dental caries caused by *Streptococcus mutans* and other acid-producing bacteria. Its high tannin content, including chebulinic and chebulagic acids, contributes to antimicrobial action, suppressing bacterial growth and biofilm formation. Additionally, polyphenols and flavonoids neutralize acids produced by cariogenic bacteria, reducing enamel erosion. *T. chebula* mouthwash has proven effective in reducing bacterial load and maintaining oral hygiene, offering a natural alternative to chemical-based mouthwashes (Atal *et al*., 1986; Pallabi *et al*., 1998).

5.2 Gastrointestinal activity

T. chebula supports gastrointestinal health with mild laxative properties, aiding digestion and alleviating constipation. It regulates bowel movements, relieves bloating, and has gastroprotective effects by reducing gastric acid secretion and enhancing mucosal defense. The fruit's antibacterial properties also help combat gastrointestinal infections and diarrhea, while its anti-inflammatory and antioxidant activities promote overall gut wellness (Jagtapand Karkera, 1999; Rekha *et al*., 2014).

5.3 Immunosuppressive effects

T. chebula has demonstrated immunosuppressive effects, making it a potential agent for managing autoimmune diseases and inflammatory disorders. Its bioactive compounds, such as tannins and flavonoids, inhibit lymphocyte proliferation and pro-inflammatory cytokine production, supporting its use in conditions like transplant rejection (Mehra *et al*., 2012; Hamada *et al*., 1997).

5.4 Antidiabetic effects

T. chebula is known for its antidiabetic properties, helping regulate blood glucose levels by enhancing insulin secretion and inhibiting carbohydrate-digesting enzymes. Its antioxidant properties reduce oxidative stress, protecting against diabetes-induced complications like nephropathy. *T. chebula* also improves pancreatic β-cell function and lipid metabolism (Lee *et al*., 2007; Kumar *et al*., 2006; Aung *et al*., 2017).

5.5 Cardiotonic activity

T. chebulas, cardiotonic activity contributes to heart health by improving myocardial function, regulating blood pressure, and enhancing endothelial function. Its lipid-lowering effects help prevent atherosclerosis, while its ability to modulate calcium channels and improve cardiac contractility further support heart health (Gao *et al*., 2008; Ravindra *et al*., 2012).

5.6 Wound healing

T. chebula promotes wound healing by enhancing fibroblast proliferation, collagen synthesis, and angiogenesis. Its antimicrobial, anti-inflammatory, and astringent properties reduce infection, swelling, and pain, speeding up recovery. It is used traditionally for treating cuts, burns, and ulcers (Azeem *et al*., 1992; Suguna *et al*., 2002).

5.7 Hypolipidemic effect

T. chebula demonstrates lipid-lowering properties, reducing cholesterol, LDL, and triglyceride levels while increasing HDL. It modulates lipid metabolism, inhibits lipid peroxidation, and enhances

bile acid excretion, supporting cardiovascular health and reducing atherosclerosis risk (Singh *et al*., 2014; Saravanan *et al*., 2007).

5.8 Antibacterial

*T. chebul*ex hibits antibacterial activity against a wide range of pathogens, including *Staphylococcus aureus*, *Streptococcus mutans*, *Escherichia coli*, and *Pseudomonas aeruginosa*. Its bioactive compounds disrupt bacterial cell walls, inhibit enzyme activity, and reduce bacterial adhesion, making it effective for oral health and wound healing (Eid *et al*., 2011; Kannan *et al*., 2009).

5.9 Antiviral

T. chebula shows antiviral activity against herpes simplex, influenza, HIV, and hepatitis B viruses. Its bioactive compounds block viral attachment, inhibit replication, and enhance immune responses, positioning *T. chebula* as a potential natural remedy for viral infections (Bag *et al*., 2012; Lin *et al*., 2013).

5.10 Antimutagenic

T. chebula demonstrates antimutagenic properties by neutralizing free radicals and preventing genetic mutations. Its ability to enhance DNA repair and modulate detoxification enzymes protects against mutation-related diseases, including cancer (Duncan *et al*., 2020; Singamaneni *et al*., 2020).

5.11 Antioxidant and cytoprotective effects

T. chebula is rich in antioxidants, including polyphenols, flavonoids, and tannins, which reduce oxidative stress and prevent cellular damage. It enhances antioxidant enzyme activity, protecting cells from lipid peroxidation and DNA damage. *T. chebula*'s cytoprotective effects support cellular health and prevent diseases related to oxidative stress (Johnson *et al*., 2010; Naik *et al*., 2012).

5.12 Anticancer activity

T. chebula has demonstrated anticancer potential through its cytotoxic effects on cancer cells, inducing apoptosis and inhibiting cell proliferation. Its antioxidant and free radical-scavenging properties prevent DNA damage and oxidative stress, while its immune-boosting and anti-inflammatory effects support cancer prevention and treatment (Tayal *et al*., 2012; Gao *et al*., 2007).

6. Value-added products

The development of value-added products from *T. chebula's* significantly expanded its applications across multiple industries, including food, pharmaceuticals, nutraceuticals, cosmetics, and personal care. These products leverage the therapeutic, antioxidant, antimicrobial, and digestive benefits of *T. chebula* to cater to diverse consumer needs (Table 3 and Figure 1).

Table 3: Value-added products of *T. chebula* and their benefits

Value-added product	Description	Health benefits	References
T. chebula powder	Finely ground powder for health applications	Rich in antioxidants, supports digestion, anti-inflammatory	Lee *et al.* (2017); Li *et al.* (2025)
Triphala powder	Blend of *T. chebula*, *T. bellerica*, and *E. officinalis*	Enhances digestion, detoxifies, and supports weight loss	Rekha *et al.* (2014); Vani *et al.* (2008); Vignesh *et al.* (2024)
T. chebula murabba	Sweet preserve made from *T. chebula* fruit	Supports gut health, relieves constipation, and is rich	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)
Bakery products (cookies, biscuits, energy bars)	Functional food enriched with *T. chebula*	Provides dietary fiber, supports gut health, and enhances metabolism	Anwar *et al.*(2025); Lee *et al.* (2017); Li *et al.* (2025)
Chyawanprash	Herbal tonic containing *T. chebula*	Boosts immunity, improves respiratory health, antiaging benefits	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)
Haritakyadiguggulu	Ayurvedic formulation with *T. chebula* and Guggulu	Detoxifies, relieves joint pain, supports digestion	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)
T. chebula candy and lozenges	Herbal candies infused with *T. chebula* extract	Soothes sore throat, aids digestion, boosts immunity	Kumar *et al.* (2020); Vani *et al.* (2008); Ullah *et al.* (2020)
T. chebula pickle	Fermented or spiced pickle from *T. chebula*	Improves gut flora, enhances digestion, rich in probiotics	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)
T. chebula jam and crush	Concentrated extract with sweeteners	Boosts digestion, acts as a mild laxative, antioxidant properties	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)
T. chebula herbal tea	Tea made from dried *T. chebula* powder	Detoxifies the body, improves digestion, and enhances immunity	Anwar *et al.* (2025); Lee *et al.* (2017); Li *et al.* (2025)

6.1 *T. chebula* powder

T. chebula powder, made from dried fruits, is a valued ingredient in the pharmaceutical, nutraceutical, and cosmetic sectors. Its bioactive compounds, like tannins, flavonoids, and polyphenols, contribute to its therapeutic properties, including antioxidant, antimicrobial, and digestive benefits. Commonly used in Ayurveda, it aids in gut health, immunity, and metabolic regulation. Additionally, it finds use in cosmetic formulations for skin rejuvenation and oral care products due to its natural antimicrobial action. The increasing demand for organic herbal products has boosted their popularity globally (Lee *et al*., 2017; Nigam *et al*., 2020).

6.2 Triphala

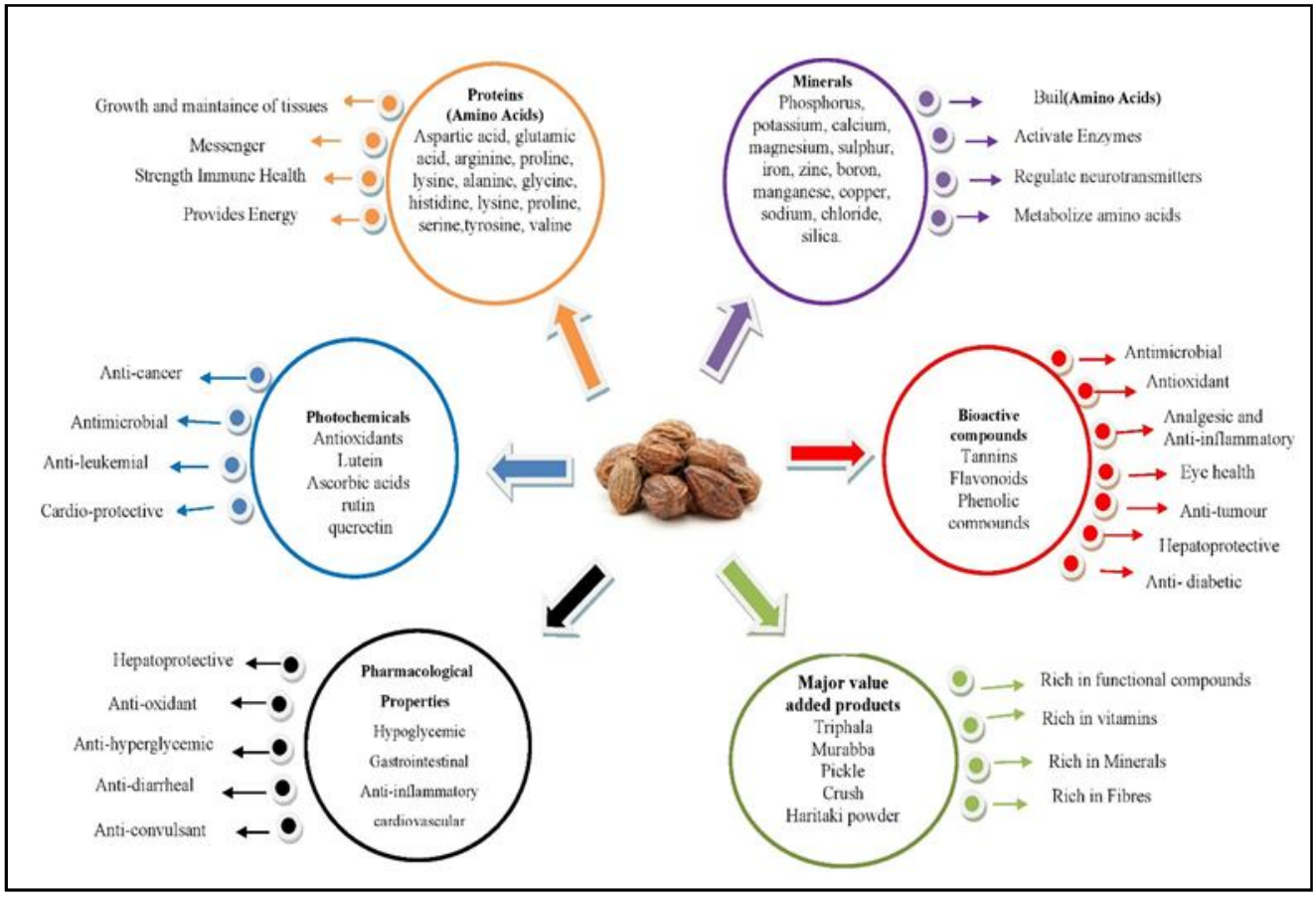
Triphala, an Ayurvedic blend of *T. chebula*, *Terminalia bellerica*, and *Emblica officinalis*, is known for its potent antioxidant, anti-inflammatory, and digestive-enhancing properties. Rich in bioactive compounds, Triphala is used in dietary supplements, herbal teas, and functional foods. Its growing demand stems from its digestive benefits and efficacy in enhancing general well-being. Moreover, it is incorporated into cosmetics for skin rejuvenation and oral care. Advances in processing techniques have improved the stability and bioavailability of Triphala-based products (Vani *et al*., 2008; Vignesh *et al*., 2024).

6.3 *T. chebula*murabba

T. chebula Murabba, made by soaking *T. chebula* fruits in sugar syrup or honey, enhances the bioavailability of the fruit's bioactive compounds, offering digestive regulation, antioxidant activity, and immune support. It is used for gastrointestinal disorders and is valued for its rejuvenating effects. With growing demand for herbal foods, innovations like honey and jaggery additions have enhanced their nutritional profile, making them a popular functional food (Lee *et al*., 2017; Li *et al*., 2025).

6.4 Bakery application

T. chebula is emerging as a functional ingredient in the bakery industry, enhancing nutritional value and offering digestive and antimicrobial benefits. It acts as a natural preservative, extends shelf life, and provides antioxidant benefits in bakery items like bread, cookies, and cakes. Its bitter taste can be balanced with sweeteners such as honey or jaggery. The demand for functional, health-promoting baked goods has led to the use of *T. chebula* in innovative recipes (Anwar *et al*., 2025; Li *et al*., 2025).



Figutr 1: Presence of various active compounds and properties in *T. chebula* and their food applications.

6.5 Chyawanprash

Chyawanprash, an Ayurvedic formulation containing *T. chebula*, Emblica officinalis, and *Terminalia bellerica*, is known for its immunity-boosting and rejuvenating properties. It is rich in antioxidants and nutrients, supporting immunity, digestion, and respiratory health. The growing trend for preventive healthcare has enhanced Chyawanprash's market appeal, with versions like sugar-free and organic available to meet consumer preferences (Anwar *et al*., 2025; Li *et al*., 2025).

6.6 Haritakyadiguggulu

Haritakyadi Guggulu, combining *T. chebula* with *Commiphora wightii* (Guggulu), is used for anti-inflammatory, detoxifying, and rejuvenating purposes. Commonly used for joint disorders, obesity, and digestive issues, this formulation is gaining recognition in the nutraceutical industry. It combines the digestive benefits of Haritaki with Guggulu's lipid-lowering effects to address metabolic and inflammatory health issues (Li *et al*., 2025; Lee *et al*., 2017).

6.7 *T. chebula* candy and lozenges

T. chebula-based candies and lozenges offer a palatable, convenient way to consume *T. chebula* for throat health, digestion, and immunity. These products combine *T. chebula* extract with sweeteners and essential oils, providing antioxidant and antimicrobial benefits. They are gaining popularity as natural alternatives to synthetic lozenges, supporting general wellness and digestive health (Ullah *et al*., 2020; Kumar *et al*., 2020).

6.8 *T. chebula* pickle

T. chebula pickle, made from *T. chebula*, combines its therapeutic benefits with the flavors of traditional pickling. The fermentation process, along with spices, mustard oil, salt, and vinegar, preserves the fruit while enhancing its medicinal properties. *T. chebula* pickle offers digestive support, antioxidant, and immunomodulatory benefits, aiding in gut health, liver function, and overall wellness. Its probiotic potential, derived from fermentation, further boosts its health benefits, including aiding digestion, reducing bloating, and alleviating constipation. This product caters to the rising demand for functional and herbal foods, blending traditional medicine with modern culinary practices (Anwar *et al*., 2025; Li *et al*., 2025).

6.9 *T. chebula* jam and crush

T. chebula jam and crush are innovative products that combine the health benefits of *T. chebula* with modern food processing techniques. *T. chebula* crush is made by blending fruit pulp with natural sweeteners, creating a concentrated syrup used as a refreshing drink or tonic. *T. chebula* jam, cooked with natural sweeteners and spices, offers both a delicious taste and medicinal value. These products retain the bioactive compounds of *T. chebula*, which contribute to digestive health, immunity, and metabolism. With the growing demand for functional foods, *T. chebula* jam and crush provide an alternative to conventional fruit spreads and syrups, offering a unique combination of taste and wellness (Lee *et al*., 2017; Li *et al*., 2025).

6.10 Herbal tea

T. chebula herbal tea is a functional beverage made from *T. chebula* and other medicinal herbs, offering a variety of health benefits. Rich in antioxidants, polyphenols, tannins, and flavonoids, this tea supports digestion, detoxification, immune modulation, and inflammation reduction. Often blended with ingredients like ginger, tulsi, cinnamon, and licorice, *T. chebula* herbal tea is a popular natural remedy for digestive issues, sore throats, and respiratory conditions. With increasing consumer interest in caffeine-free wellness beverages, *T. chebula* herbal tea caters to those seeking organic, Ayurvedic formulations for daily health maintenance (Anwar *et al*., 2025; Lee *et al*., 2017; Li *et al*., 2025).

7. Conclusion

T. chebula stands out as a medicinal powerhouse rich in bioactive compounds with a broad spectrum of health benefits. Its composition, including tannins, flavonoids, triterpenoids, glycosides, and phenolic acids, contributes to its diverse pharmacological properties, such as antimicrobial, antioxidant, anti-inflammatory, immunomodulatory, and gastroprotective effects. The fruit is widely used in traditional medicine and modern formulations, including dietary supplements, herbal teas, oral care products, and cosmeceuticals. Additionally, its potential as an α-glucosidase inhibitor makes it promising for managing diabetes and metabolic disorders. Despite extensive research highlighting its therapeutic applications, further clinical studies are required to validate its efficacy in humans and establish standardized dosages for different health conditions. Advanced extraction techniques, formulation development, and biotechnology approaches can enhance its bioavailability and efficacy. Additionally, integrating *T. chebula* into functional foods, nutraceuticals, and value-added products like candies, lozenges, herbal teas, and bakery goods can promote its consumption for preventive healthcare. Future research should focus on in-depth toxicological assessments, clinical trials, and mechanistic studies to explore new pharmacological potentials of *T. chebula*. Encouraging sustainable cultivation and processing practices will ensure its availability while maintaining its medicinal potency. By incorporating this medicinal fruit into daily dietary and therapeutic regimens, *T. chebula* can significantly contribute to holistic health and well-being.

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Conflict of interest

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

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