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Nutritional composition and pharmacological behaviour of water chestnut: A review

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Abstract

Water chestnut is an overlooked aquatic plant by many researchers for its seasonal availability. It originated in Europe and Asia. China is the world's biggest producer of water chestnuts. In India, around 11.6 million acres of land are under cultivation. It is high in vitamins and minerals and has numerous health benefits such as antibacterial characteristics, anti-ulcer properties, neuroprotective capabilities, and immunomodulation activities. Water chestnut has a high antioxidant concentration, with flavonoids, flavones, and total phenol content. This is used in Ayurveda formulations as a nutrient, appetiser, astringent, diuretic, aphrodisiac, cooling, anti-diarrheal, and tonic. It is also employed in the treatment of lumbago, sore throats, bilious disorders, bronchitis, fatigue, and inflammation. There are numerous fortified goods on the market. Water chestnuts are rich in calcium and iron and fortification with other gluten-free flour helps in providing a suitable diet for celiac disease patients.

Keywords: *Trapa natans*, phenolic compounds, anti-microbial, anti-inflammatory, hepatoprotective, fortified products

Introduction

Aquatic plants have been known to have healing properties since antiquity. As the world's population grows, insufficient drug supply, high treatment costs, side effects and drug resistance have resulted in a greater emphasis on using plants to treat human diseases. Water chestnut is a floating aquatic annual nut crop that grows in swamps and shallow lakes of tropical and sub-tropical areas (Garg *et al.*, 2020; Bhatiwal *et al.*, 2012) [22, 9]. It is a knobby edible nut with reddish-black and pure green skin, white, crisp pulp, and a reddish centre (*Trapa Bispinosa Roxb*). The water chestnut kernel (*Trapa natans*) is roofed with a thick jet-black outer pericarp-shaped sort of horn protruding from the head part of a buffalo (Neha *et al.*, 2020). It is an easy-growing water plant that performs best in soft nutrient-rich water of lakes and shallow ponds. Water chestnut is available abundantly after the rainy season to mid-winter (Alfasane *et al.*, 2011) [6]. It can flourish in pH 6 to 7.5 (Manoj *et al.*, 2012) [45].

History

It originated in Europe and Asia, where it is known by many names, including devil's pod, buffalo nut, and water caltrop (Jana, 2021) [30]. The water chestnut has been grown and used as a food source since Neolithic times in Europe. Water caltrop was an important food for worship as prayer offerings during the Chinese Zhou Dynasty. According to Zhou (2nd century BC) "rites, a worshipper should carry a bamboo basket containing dried water caltrops" (Adkar *et al.*, 2014; Poudel, 2021) [1, 52]. The species *Trapa bispinosa Roxb.* is native to India and commonly referred to as "Paniphall" and it thrives in the freshwater lakes of Kashmir, Orissa, Assam and some other parts of India (Karmakar *et al.*, 2011; Prashanth, 2016) [35, 54]. *T. bispinosa (Roxb.)* is consumed as a food source for humans and animals in India, China and South East Asia (Singh *et al.*, 2017) [64]. It is grown in India mainly for human consumption either in sort of vegetable, dried to prepare flour to make flattened bread called chapatti or within the shape of sweet dishes of many kinds according to individual's taste (Jana, 2016) [31]. The sweet, tender, and delicious taste, of cooked water chestnut, is one of the favourite starchy desserts in Asian countries. When the fruit is dried, it is crushed into flour known as singhara ka atta, which is utilised in numerous religious rites and can be eaten as a Phalahar diet during the Hindu fasting days, a traditional festival known as "Navratri" (Chandana *et al.*, 2013) [14]. Different species like *T. Bispinosa*, *T. Natans*, *T. Quadrispinosaor* and *T. bicornis* are mainly cultivated in various states of India like Bihar, West Bengal, M.P. and some parts of Uttaranchal, UP and Orissa (Jana *et al.*, 2019) [32].

Plant description

Water chestnut is a floating aquatic plant with two styles of leaves. One is divided like a feather and submerged that grows along the length of the stem. The other one is undivided floating leaves that grow in a rosette near the water's surface (Jana, 2016) [31]. The floating leaves are rhomboid, fan-shaped, and toothed on the edges, measuring 2-6.5cm in diameter and broader than length (Zhu, 2016) [72]. The leaves have a dark green colour on the upper and reddish-purple under (Chandana *et al.*, 2013) [14]. The plant's cord-like stems are spongy and buoyant, reaching up to 16 feet in

length (although typical lengths tend to be in the 6-8 ft range). The stems are anchored to the water's bed by a channel of branched roots (Adkar *et al.*, 2014) [1].

Flowers are white and have four petals with a length of about 8mm. It is located at the centre of the rosette and begins to flower in the month of august (Singh *et al.*, 2018; Jana, 2016) [65, 31]. The fruit has a woody or bony nut 2.5 to 5 cm in diameter with two or four stout spines or horns. *Trapa bicornis* is similar to *Trapa natans*, but the fruit has two spines rather than four (Anonymous, 2022; Jana, 2016; Adkar *et al.*, 2014) [31, 1].

Table 1: Botanical and morphological description of water chestnut

Botanical classification	
Kingdom	Plantae
Division	Angiosperm (Dicotyledon)
Order	Myrtales
Family	Lythraceae
Genus	Trapa
Species	<i>Trapa Natans</i> , <i>Trapa Acornis</i> , <i>Trapa Bispinosa</i> , <i>Trapa Incisa</i> , <i>Trapa Japonica</i> , <i>Trapa Manshurica</i> , <i>Trapa Quadrispinosa</i> and <i>Trapa taiwanensis</i> .
Vernacular name	
English	Water chestnut
Hindi	Simghara, Singhada
Bengali	Paniphal
Tamil	Cimkhara
Sanskrit	Shningataka
Malayalam	Karimbolam or Vankottakkaya
Telegu	Kubjakamu / Kubyakam
Manipuri	Heikak
Japanese	Hishi
Morphological description	
Roots	Branched and submerged roots
Stem	Cord-like stems that are spongy and buoyant.
Leaves	Submerged leaves and floating leaves. Submerged leaves are long, feathery, and root like. Floating leaves are loose rosettes that are attached to petioles, or leafstalks, 5 to 10cm long. Above leaf surface is dark green, while below is reddish purple
Flowers	Four white petal flowers, with a short conical, often spinous beak in the centre through which the radicle protrudes, and two spines at two angles, with the second pair of spines often missing
Fruits	Starchy fruits with hard peels and horns.
Seeds	A single large starchy seed that is eaten as a whole.

Production and consumption scenario of water chestnut at a global level

Water Caltrops were a common sight in ancient Europe markets, where they were roasted and sold as a snack (Jana, 2016) [31]. The majority of water caltrops nowadays are found in India, China, Vietnam, Cambodia, and Laos. They have also been culturalized in Australia and the US (Poudel, 2021) [52]. In the USA, New York, Delaware, Maryland, Massachusetts, New Hampshire, Pennsylvania, Vermont, Virginia, and Washington, D.C. are the main states where the water chestnut grows (Pfungsten *et al.*, 2022) [51]. Additionally, it grows in Canada's Quebec and the Great Lakes Basin. It is also a non-native species in Siberia and the Caucas (Chechnya). Holland, Belgium, and Sweden were home to water chestnut once, but it has disappeared due to climatic changes. It is considered a cash crop in the Indian subcontinent, produced in ponds and river-fed plains following a cycle of artificial fish rearing (Hossain *et al.*, 2020) [26]. Water chestnut is also planted in an integrated farming style with fish and water fox nut farming ponds, which has a good impact on farmers' livelihoods (Singh *et al.*, 2018) [65].

The Water chestnut is divided into four regions: Asia Pacific,

North America, Latin America, Europe, the Middle East and Africa. Water chestnut consumption is highest in the Asia Pacific, owing to traditional culinary uses of the fruit, although consumption is expanding in North America, due to increased multi-culinary acceptability and increased water chestnut production techniques in portions of Florida and other U.S. states (Rupam *et al.*, 2019) [58].

Production scenario at the national level

Water chestnut is one of the most important minor fruit crops grown in India (Kundu *et al.*, 2012) [39]. About 11.6 million ha of areas are cultivated throughout India. It is locally known as Guar and can be found in three lakes of Jammu and Kashmir i.e. Dal Lake, Wular Lake, and Anchar Lake (Adil *et al.*, 2010). Bihar alone produces 75 per cent of the total country's production of water chestnut. Every year, the people of Mote Majra produced more than 65 quintals of water chestnuts from the village community pond and it is supplied to Mohali, Chandigarh, Kharar, Morinda, and Ropar and Panchkula (Anonymous, 2020).

The national capital Delhi is famous for water chestnuts. Water chestnuts can be found throughout India's east coast, including West Bengal, Jharkhand, and Bihar. Nadia and 24-

Parganas are the two districts of West Bengal that cultivate water chestnut on large scale (Maiti *et al.*, 2014) [42]. Bihar Large Red (Spine), the commercial variety of the Mithila region, Darbhanga, India, gives a higher yield of 7.0 t/ha. The maximum yield of 12.0 t/ha can be achieved by the cultivation of the Green Spineless genotype (Jana *et al.*, 2019) [32]. Regular eradication of aquatic weeds *Hydrilla* and *Sagittaria* that are common in makhana and water chestnut crops is of utmost importance during the cropping season to avoid crop-weed competition (Jana, 2016) [31]. The integrated cropping of water chestnuts and fishes (rohu, Katla, common card and mrigal) has been able to provide a better income for the farmers (Singh *et al.*, 2018) [65]. Ratanpur a city in Chhattisgarh, due to its 150 ponds is known as the city of ponds. The ponds are abundant in aquatic flora, particularly Lotus, *Nelumba nucifera*, and Indian water chestnut, *Trapa Bispinosa*, which provided food for waterfowl and waders (Shubadana *et al.*, 2014) [62]. The Bhoj Wetland (BWL), which comprises two lakes (Upper Lake and Lower Lake) is located in Bhopal, the state capital of Madhya Pradesh and here about 300 families earn their lively hood through water chestnut cultivation (Madhu *et al.*, 2011) [41].

Nutritional composition of water chestnut

Water chestnut is a highly nutritious aquatic crop that has been overlooked by food processors due to its seasonal availability of only 2-3 months per year. Water chestnuts are cholesterol and gluten-free, along with cooling and

detoxifying effects and are known to help in curing jaundice (Vishwakarma *et al.*, 2022; Jana *et al.*, 2019) [68, 32]. Water chestnut is made up of nearly 80% of moisture. It also contains ash, soluble sugar, reducing sugar, non-reducing sugar, and lipid (Bhatiwal *et al.*, 2012) [9]. It is a good source of starch and carbohydrates (Faruk *et al.*, 2012) [20]. Water chestnut is rich in polyphenol, flavonoid and antioxidants, thus possesses antibacterial, antiviral, anticancer and antioxidant properties, making them a portion of potentially nutritious food (Mann *et al.*, 2011) [44]. It is low in fat, low in sodium, high in potassium, rich in minerals like calcium, iron, zinc, and phosphorus, have a moderate amount of fibre, and are a good source of energy (Adkar *et al.*, 2014; Prashanth, 2016) [1, 54]. The free amino acids, tryptophan, glutamic acid, tyrosine, lysine, alanine, and leucine are commonly present in both varieties of water chestnut (Faruk *et al.*, 2012) [20]. *Trapa's* fruits are sweet, astringent, cooling, diuretic, and tonic in nature. It is also used to treat lumbago, sore throats, bilious diseases, bronchitis, tiredness, inflammation, vitiated pitta, burning sensations, haemorrhages, skin problems, and low back soreness (Adkar *et al.*, 2014) [1]. This medicinal plant is thought to be a significant source of novel chemical compounds with therapeutic potential (Bhatiwal *et al.*, 2012) [9]. Boiled water chestnut removes free water and toxins which could cause cough and cold. It relieves swellings and cleanses the blood (Akao *et al.*, 2011) [3]. The table shows the content of phenolic acids and their derivatives present in *Trapa natans* extract.

Table 2: Phenolic compounds their derivatives in water chestnut

Phenolic acids and their derivatives	Flavonoids	Flavonoid Glycosides	References
Gallic acid hexoside isomer 1 and isomer 2	Quercetin	Naringenin-7-O-hexoside	Aleksic <i>et al.</i> , 2018 [5]
Gallic acid	Pinobanksin	Kaempferol di-O-hexoside isomer 1	
Protocatechuic acid	Naringenin	Rutin	
p-Hydroxybenzoic acid	Rhamnetin	Kaempferol-3-O-glucoside (Astragalin)	
p-Coumaric acid hexoside		Quercetin 3-O-rhamnoside	
Caffeic acid		Quercetin 3-O-galactoside	
p-Coumaric acid			
Ellagic acid			
p-Coumaroyl-digalloyl-O-glucose			
Ferulic acid			

Pharmacological properties of water chestnut

Fruits and vegetables are well-known for being an excellent source for varieties of vitamins and minerals, as well as being beneficial in boosting protection against a variety of microbial illnesses (Ghosh *et al.*, 2021) [23]. Water chestnut is a plant with promising pharmacological action, owing to the presence of its constituents, phenols and flavonoids, which have been shown to have hepatoprotective, antioxidant, anti-inflammatory, anti-diabetic, antifungal, and antimicrobial activity (Corovic *et al.*, 2021) [16].

The extract of water chestnut has a high antibacterial activity against several pathogenic bacterial species (Biswas *et al.*, 2014) [10]. This is utilised as a nutrient, appetiser, astringent, diuretic, aphrodisiac, anti-diarrhoeal, and tonic in various Ayurveda formulations (Alam *et al.*, 2021) [4]. Fruits can also be used to make liniments to treat rheumatism, ulcers, and sunburn. It's also thought to have cancer-preventive qualities. In the treatment of eye problems, stem juice is employed (Bhatiwal *et al.*, 2012) [9].

Antimicrobial Properties

The extract of *Trapa natans* leaves is a rich source of biologically active compounds and so has potential in microbial control. The examined bacteria showed antimicrobial activity in particular. This impact was particularly strong against gram-negative bacteria, like *Pseudomonas aeruginosa* (Radojevic *et al.*, 2016) [56]. *Trapa natans* leaf extracts exhibit anti-quorum sensing activity in pathogen *P. aeruginosa* decreasing the synthesis of several virulence factors necessary for infection growth (Aleksic *et al.*, 2018) [5]. Razvy *et al.*, (2011) [57] used the disc diffusion method to test the antibacterial activity of fruit extract from two types of water chestnut (green and red) using kanamycin as a standard. The extract of the red water chestnut variety had a strong antibacterial potential (31mm) against *Bacillus subtilis*, but the green variety had the maximum antibacterial activity (12mm) against both *Staphylococcus aureus* and *Shigella sonnei*. *Trapa natans* L. fruit peel extracted in different solvents shows different antibacterial activities.

Dimethylformamide had the most effect, while petroleum ether extract had the least. *Pseudomonas aeruginosa*, *Pseudomonas vulgaris*, and *Pseudomonas pseudoalcaligenes* were completely resistant to all extracts, while *P. Putida* showed the best antibacterial activity (the best antibacterial effect was shown by 1,4-dioxane extract), followed by *P. testosterone*, and *P. Morganii*, respectively, while *P. mirabilis* was only inhibited by (1,4-dioxane, acetone, dimethylformamide, and ethanol) (Corovic *et al.*, 2021)^[16].

Anti-diabetic properties

The *Trapa natans* fruit peel extract showed anti-diabetic action in streptozotocin-induced diabetic rats. One of the most significant benefits is that the ethanolic extract of *Trapa natans* roots and its fractions can reduce the progression of hyperglycemia without causing hypoglycaemia (Das *et al.*, 2011)^[18]. The presence of ferulic acid and caffeic acid in *Trapa natans* explains its anti-hyperglycemic activity. Ferulic acid is known to minimise oxidative stress and hyperglycaemic response, but caffeic acid has a generative effect on Langerhans islets as a result of decreased expression of glucose transporter 2 in the liver, which reduces hyperglycaemia (Corovic *et al.*, 2021)^[16].

Hepatoprotective activity

The extract of *Trapa natans* fruit peel showed hepatoprotective efficacy against antitubercular drug-induced hepatotoxicity. Anti-tubercular medicines were injected intraperitoneally into rats, causing hepatotoxicity, and the number of marker enzymes confirming hepatotoxicity was evaluated. The use of *T. natans* peel extract (200 and 400 mg/kg) reduced liver marker enzymes and antioxidant parameters significantly (Hussain *et al.*, 2018)^[29]. *T. Natans* ethanolic root extract and its derived fractions also have a considerable protective impact against hepatotoxicity and lipid peroxidation, according to the study. The presence of ferulic acid and caffeic acid in *Trapa natans* extract could explain the activity because both elements are antioxidative (Kharbanda *et al.*, 2014)^[36].

Anti-inflammatory activity

Water chestnut extracts contained phenolic components such as Gallic acid. Gallic acid appears to have pharmacological effects that include antioxidant, anti-inflammatory, antiviral, and anti-cancer properties (Chuang *et al.*, 2010)^[15]. Gallic acid has a strong anti-inflammatory effect in water chestnut extract, and there is evidence that it is used to treat skin inflammatory disorders (Kim *et al.*, 2015)^[37]. A hydroalcoholic extract (500 mg/kg peroxidase) of *Trapa bispinosa* reduced fluorescent product and lipid peroxidation in the cerebral cortex of female albino mice while restoring glutathione peroxidase and catalase function (Ambikar *et al.*, 2010)^[7]. Kar *et al.*, (2010)^[33] investigated the antiulcer effect of 50 per cent ethanolic extract of *Trapa bispinosa* (Trapaceae) fruits on Wistar rats utilising pyloric ligation and aspirin plus pyloric ligation models and found that *Trapa bispinosa* is endowed with potential antiulcer activity. Samir, (2010)^[60] studied Cell-mediated delayed-type hypersensitivity reaction (DTH), humoral immune response, and per cent change in neutrophil count in rats when they were exposed to sheep red blood cells (SRBC) as antigen and discovered that an aqueous preparation of *T. bispinosa* fruit increase animal cellular and humoral responses.

Water chestnut-based fortified food products

Maternal and child malnutrition account for 45 per cent of all fatalities among children under the age of five in poor and middle-income nations (Black *et al.*, 2013)^[11]. Food fortification is an important nutrition strategy in many low and middle-income countries to combat micronutrient deficiencies and reduce their prevalence (Chadare *et al.*, 2019)^[13]. Due to nutrient deficiencies in human societies especially in certain periods of life, embracing, importing, and consumption of fortified foods is increasing (Preedy *et al.*, 2013)^[55]. Fortification of food products utilising natural resources (fruits, cereals, etc.) is one of the best strategies to boost the overall nutrient intake of food with minimal negative effects (Olson *et al.*, 2021)^[50].

Food fortification is defined as the practice of adding one or more vitamins and minerals to food to increase its nutritional quality of the food (Olson *et al.*, 2021)^[50]. Fortification is used to correct a demonstrated micronutrient deficiency in the general population (mass or large-scale fortification) or specific population groups (targeted fortification) such as children, pregnant women and the beneficiaries of social protection programmes (Whiting *et al.*, 2016)^[70].

Cookies made with a combination of soy and water chestnut flour had more protein and micronutrients. Cookies made with a 30% blend of soy and water chestnut flour were found to be the most popular, with greater nutritional quality and taste (Sharma *et al.*, 2016)^[61]. Water chestnut and ragi are said to be rich in calcium and iron and are safe for patients suffering from celiac disease due to their gluten-free properties. Calcium insufficiency induces aberrant colonic development and increases the risk of colon cancer (Dai *et al.*, 2014)^[17]. Although these are natural sources of gluten-free foods, gluten cross-contamination should be avoided during production. The development of biscuits from water chestnut and Ragi flour that are rich in iron, calcium and folic acid has helped celiac disease patients (Gupta *et al.*, 2021)^[24]. Fortification of shinghada, sabudana and rajgira flour in fasting biscuits contains more nutrition than the normal water chestnut biscuit (Kharad *et al.*, 2013)^[34].

The protein content of gluten free makhana powder biscuits was higher than that of biscuits made with potato powder in flour blends (Anuradha *et al.*, 2014)^[8]. Bakery products that are developed with water chestnut will help people in Jammu and Kashmir and Punjab overcome celiac disease and improve their socio-economic conditions (Nishar *et al.*, 2014)^[49]. The addition of water chestnut flour in wheat flour biscuits has higher fat, fibre, ash and mineral content. It also has higher phenolic and antioxidant content (Nefisha *et al.*, 2014)^[47]. Water chestnut cookies with rice flour were developed and found that 40% replacement of rice flour is the most acceptable (Demirkesen, 2016)^[19].

Low glycaemic crackers from water chestnut and barley flour were developed for diabetic patients (Hussain *et al.*, 2020)^[28]. Noodles prepared from wheat flour with the incorporation of water chestnut flour, sweet potato, and colocasia have decreased level of gluten i.e beneficial for celiac persons (Yadav *et al.*, 2014)^[71]. Elephant foot yam, taro and water chestnut flour, all rich sources of phytochemicals, could be used as functional ingredients in the development of nutritious and healthy extruded snacks (Saklani *et al.*, 2021)^[59]. Muffins from water chestnut and barley flours combination of 70:30 have a lower glycaemic index (Hussain *et al.*, 2019)^[27].

Utilization of water chestnut, sweet potato and potato in

noodles and fortification with 10% skimmed milk has higher quality in terms of nutritional characteristics as well as sensory (Tomar *et al.*, 2020) [66]. The antioxidant, anti-diabetic, and anti-obesity characteristics of functional snacks containing encapsulated resveratrol (prepared from horse-chestnut, water-chestnut and lotus-stem starch) particles were significantly higher than those of snacks containing no or free resveratrol (Ahmad *et al.*, 2021) [2]. The combination of yoghurt with various agricultural products such as litchi, sweet potato, water chestnut, and flax seed has nutritional and therapeutic advantages for human health and ensures that malnutrition in poor people is controlled (Kumari *et al.*, 2021) [38]. Fasting cookies developed by incorporating water chestnut, sweet potato, and Amaranth Grain Flour have more acceptability and provide better nutrition (Rupam *et al.*, 2019) [58].

Conclusion

Water caltrop or shinghada originated from Europe and Asia is an aquatic nut crop that has been overlooked by many researchers as its availability is seasonal. China is the leading producer of water chestnuts in the world. About 11.6 million ha of areas are cultivated throughout India. It contains a good number of vitamins and minerals along with many health benefits like antibacterial properties, anti-ulcer properties, neuroprotective properties as well as immunomodulation activities. The antioxidant concentration of water chestnut is high, with flavonoids, flavones, and total phenol content. This is utilised as a nutrient, appetiser, astringent, diuretic, aphrodisiac, cooling, anti-diarrhoeal, and tonic in various Ayurveda formulations. It is used to treat lumbago, sore throats, bilious diseases, bronchitis, tiredness, and inflammation. Fortification of water chestnut with various gluten-free flours does provide a portion of suitable food for celiac disease patients keeping them healthy.

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