OPEN ACCESS PEER REVIEW
DOI:https://doi.org/10.52756/lbsopf.2025.v04.003
Chapter- 3

Water Chestnut (*Trapa* sp.) as an Economic and Ecological Resource in Global Environment Protection and Food Security

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Keywords: Water chestnut, Food security, Environment protection, Resource, Sustainability

Abstract:

Trapa natans (water chestnut) is an annual, herbaceous aquatic species that has remained underutilized and neglected crop in this advancing global scenario of food security sustenance. The nutrients present in water chestnuts include carbohydrates, proteins, lipids, water-soluble and fat-soluble vitamins, minerals, dietary fibre, and polyphenols. Due to these nutritional comforts, the use of water chestnut both as food and herbal medicine has recently been increased, yet its physiological functions and active components remain a mystery. Water chestnut also serves as an important ecological indicator of global warming and its carbon sequestration potential has been studied as a function of its optimized growth. Water chestnut as environmental resource further involves phytoremediation of municipal wastewater, bio-control of cyanobacterial bloom due to its high phenolic content, antioxidant and anti-microbial properties. Water chestnut can provide ecosystem services like removing inorganic nitrogen from water, but its invasive nature requires careful management. Sustainable practices related to water chestnut production involve minimizing its negative environmental impacts while promoting its economic benefits. Therefore, in order to promote more environmentally and climate-conscious food production for sustainability, it is imperative to gather comprehensive information on underutilized food crops for future research.

Introduction

Water Chestnut is an underutilized and neglected freshwater aquatic plant characterized with high nutritional value which can achieve food, nutrition and livelihood security (Adkar et al., 2014; Rehman et al., 2024; Singh et al., 2024). Its human usage started as a ritual component or as a decorative and ornamental purpose, but from 1870s it served as food in

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Dr. Somnath Das, Dr. Ashis Kumar Panigrahi, Dr. Jayanta Kumar Das and Dr. Donrie Purcell (eds.), Life as Basic Science: An Overview and Prospects for the Future Volume: 4. ISBN: 978-81-989555-2-4; DOI: https://doi.org/10.52756/lbsopf.2025.v04;pp. 38-51; Published online: 15th Sep. 2025
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North America (Naylor, 2003). Due to their nutritional and pharmacological benefits, people should be properly educated for its inclusion in daily diet. Water chestnut falls under genus Trapa and is a polymorphic group containing about 20 species (Karg, 2006) (Table 1).

Table 1. Botanical Classification.

Kingdom	Plantae
Sub Kingdom	Tracheobionta
Family	Trapaceae, Lythraceae, Hydrocaryaceae or Onagraceae
Genus	Trapa
Species	*Trapa natans* L.

The medicinal quality is distributed all over the plant parts with special emphasis on the stem juice used for treating eye ailments. Besides, high starch (16%), protein (2%), mineral (calcium, potassium, sodium, zinc) and vitamins of fruit and kernel have been studied for their diuretic, aphrodisiac, nutrient, appetizer, astringent, coolant, anti-diarrhoeal property. Overall, the plant serves as a major analgesic, anti-inflammatory, anti-diabetic, and anti-microbial source aiming to heal the stomach, genito-urinary system, liver, kidney, and spleen. Phytochemical composition includes appreciable quantity of saponins, phenols, alkaloids, H-donation and available flavonoids (Adkar et al., 2014).

The environmental role includes biocontrol of cyanobacterial bloom and arsenic removal using phytoremediation mechanism (Kumar and Chopra, 2018; Xu et al., 2020). Additionally, it has the potential to sequester atmospheric carbon in tropical ponds through their optimized biomass production (Nandy et al., 2018).

Considering the growing concern for food security in our country as well as globally it is very much essential that the understudy of the water chestnut and its significant role should be taken to a new height of scientific investigation (Das et al., 2011). The carbon research pertaining to sequestration, allocation, and partitioning in *Trapa* sp. can generate novel solution for climate-conscious food production for sustainability.

Characteristics study

T. natans is an annual, herbaceous aquatic species that persists in 60cm deep water. The branched and submerged root of the plant which emerges from the propagating seed hull assists the stem to anchor in the mud. The cord-like stem(1-5cm) is spongy in nature, buoyant (Adkar et al., 2014) and generates numerous branches. Each branch terminates in a rosette. The leaves are morphologically narrow, submerged or floating in nature (Majee et al., 2013). The plant bears white flowers with four petals (8mm) and green sepals (Singh et al., 2018) that develop into a mature fruit. After pollination, the flowers submerge to facilitate the formation of fruit. The fruit is a single-seeded, triangular, horned nut-like structure with hard peels known as "turbinate drupe" (diameter 2-3cm) that develops underwater (Jana, 2016). The seed has two asymmetric cotyledons: a large, starchy cotyledon inside the endocarp and a small, scale-like cotyledon. The Asian variety of Chinese and Indian has high rosette density resulting in high yield.

Growth requirements

Although the species is disturbance-tolerant, even in high sewage nutrient condition, but its seeds fail to germinate in salinity exceeding 0.1%. Therefore, the guidelines regarding water and soil quality, fertilizer composition and dose should be strictly followed for cultivation at different climatic zones. New ponds require twice the amount of fertilizer over that used in old ponds which receive nutrients from decomposed biomass of the previous crop (Table 2) (Singh et al., 2018).

Table 2. Growth requirements of *Trapa* sp. (Hummel and Kiviat, 2004).

Parameters	Requirement
Salt Concentration	<0.1%
Growing medium	Slow-flowing shallow water bodies (1.2 to 1.8m depth) or in 0.3 to o.45m deep shallow agricultural fields. Zero water fluctuations.
Water quality	Water temperature-12-15ºC (fruit germination) and 20ºC (flower development); pH-7.9-8.6, Alkalinity-13.5-31mg/l, Hardness-7.2-26mg/l, Ca-1.65-7.31mg/l, Mg-0.52–2.25mg/l, Free CO_2 3.4 – 16.7mg/l, Chloride – 6.21–13.82mg/l, dissolved oxygen–2.41–9.26mg/l
Soil quality	pH-7.25; Electrical Conductivity=0.3dSm-1, Organic-C=0.52%, Available-N=265 kg/ha, Available-P=33 kg/ha, Available-K=440kg/ha, Available-Fe=51mg/kg, Available-M=25mg/kg, Available-Cu=2.35mg/kg, Available-Zn=0.48mg/kg
Fertilizer application	Farmyard manure (FYM)=8t/ha, Urea=30-40kg/ha, NPK=60:20:20 kg/ha (old field), NPK=60:40:30 kg/ha (newly cultivated field)

Water chestnut seedlings are transplanted in the month of May/June in a perennial pond. After the second week of germination, the first and second cotyledons with the hypocotyl appear followed by secondary roots from the hypocotyls in the third week. Unbranched roots grow down toward the substrate while a filamentous root reaches up and out. Its fruits are harvested from November to January (Fig. 1) (Razvy et al., 2011).



Figure 1. Cultivated and harvested Trapa sp. in water bodies of Nadia district, West Bengal.

Global production and consumption scenario

The average worldwide annual production of chestnut is 2,261,589 tonnes from 603,076acres of land (Jana, 2018; Rajput and Singh, 2023), showing an increasing trend from 1980 to 2019 (Fig. 2). China is the world's largest producer, producing 1,879,031 tonnes/year followed by Bolivia with 84,813 tonnes (Lahiri, 2018) of production.

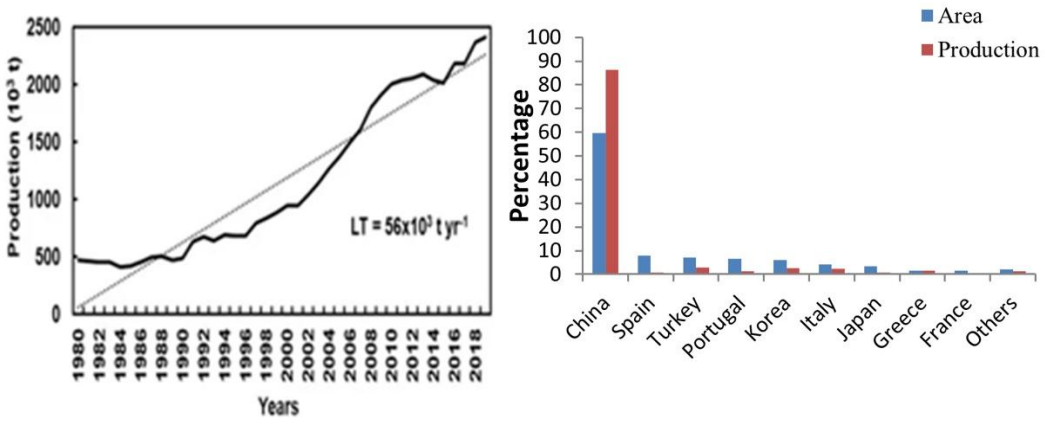


Figure 2. Annual country-wise (FAO, 2018) global production of *Trapa* sp.

Water chestnut is consumed in different ways in different countries. In Europe, it is consumed as a roasted snack. In the Asia-Pacific region, it is used as a fruit in many culinary dishes. The multi-culinary acceptability is rising in the USA due to its improved production techniques.

Production scenario at the national level

In India, water chestnut is considered a cash crop (Hossain et al., 2020). Bihar is the largest producer with maximum cultivation area followed by Madhya Pradesh (2018-2019 report) (Fig. 3). The national total production is 67,600 tonnes from 16,900ha (Jana, 2022). Nowadays, it is cultivated along with fox-nut and fish to improve the farmers' livelihood profile (Singh et al., 2018).

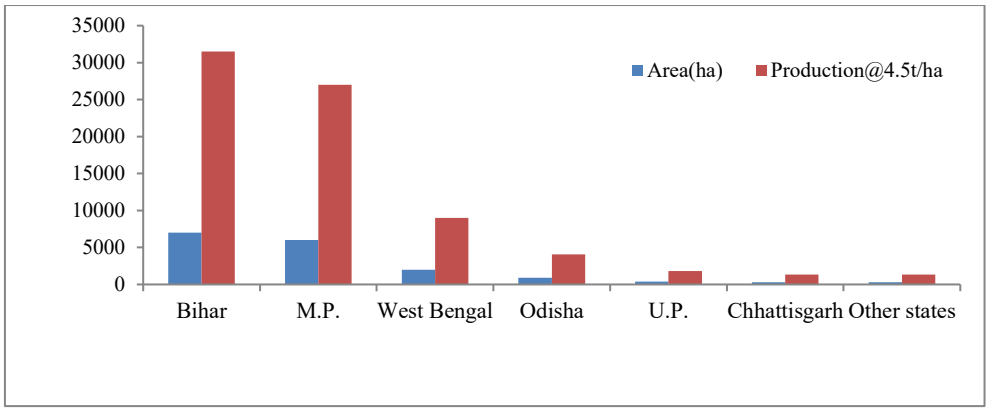


Figure 3. State-wise area and production of water chestnut in India.

The spineless new varieties of red and green cultivars yielded 50-120% more fruit weight of 27.5 and 30.7g, respectively than indigenous varieties and annual production of 12 and 10tonnes/ha, respectively, in Bihar, India. In West Bengal, water chestnut is cultivated in districts like Nadia and 24-Parganas, on a large scale (Maiti and Kundu, 2014). In Madhya Pradesh, it is cultivated in Bhoj Wetland, Bhopal, supporting 300 families (Verma and Negandhi, 2011).

Nutritional aspects

Each and every part of the plant possesses nutritional values (Singh et al., 2018), supplying carbohydrates, proteins, lipids, water, and fat-soluble vitamins, minerals, dietary fibres, and polyphenols (Fig. 4), etc., with excellent therapeutic benefit.

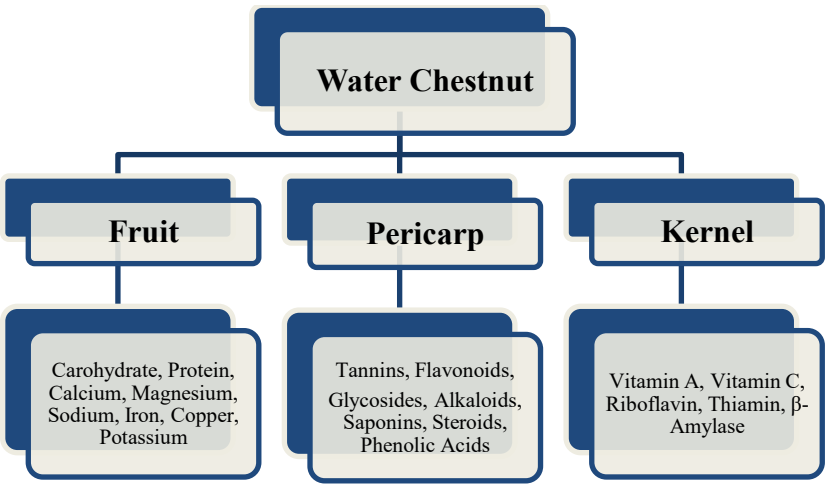


Figure 4. Nutrients in different parts of Water Chestnut (Alam et al., 2021).

Nutritional content of green variety yields (Faruk et al., 2012) 50% more β-carotene content than red (Table 3).

Table 3. Nutritional content of two varieties of water chestnut (Alfasane et al., 2011).

Sl. No.	Nutrient	Green-Variety	Red-Variety
	pH	5.88	5.11
1	Moisture (%)	62.50	62.70
	Dry-matter(%)	11.5	17.3
2	Ash (%)	1.04	1.30
3	Crude-Fibre (%)	2.13	2.27
4	Total-Soluble-Sugar (%)	0.92	0.90
5	Reducing-Sugar (%)	0.33	0.30
6	Non-Reducing Sugar (%)	0.59	0.60
7	Starch (%)	8.70	8.20
8	Lipid (%)	0.84	0.83
9	Protein (mg)	0.28	0.25
10	β-carotene (mg)	60.00	92.00

11	Vitamin C (mg)	1.10	0.90
12	Potassium (%)	5.22	5.32
13	Sodium(%)	0.64	0.59
14	Calcium (%)	0.25	0.26
15	Phosphorous (%)	6.77	6.77
16	Sulphur (%)	0.38	0.32
17	Iron (ppm)	200.00	200.00
18	Copper (ppm)	430.00	450.00
19	Manganese (ppm)	90.00	110.00
20	Zinc (ppm)	600.00	650.00
21	Total phenol (mg)	0.50	0.60

The free amino acids, glutamic acid, tryptophan, tyrosine, alanine, lysine and leucine are commonly found in both varieties. In addition, green contains cysteine, arginine, and proline, and the red variety contains asparagine and glutamine.

Pharmacognostic characters

Anti-oxidant property

The fruit pericarp contains tannins (12 mg/kg), flavonoids (70 mg/kg), glycosides, alkaloids, saponins, steroids, and phenolic compounds (19mg/kg). Saponins and phytosterols are present in the seed extract (Wen-Jing et al., 2009). Aqueous extract of the fruit portrays antioxidant activity as evident by OH- scavenging activity (Song et al., 2007). 500mg/kg of the extract reduced lipid peroxidation and increased the catalase and glutathione peroxidase production as a result of aging-related brain damage (Kar et al., 2004).

Analgesic property

Agrahari et al. (2010) confirmed the analgesic effect of water chestnut at dosages of 200 and 400mg/kg against the standard drug pentazocine administered at a dosage of 30mg/kg. There was significant ($p < 0.01$) analgesic activity at the both dosages.

Anti-inflammatory property

Lipopolysaccharide (LPS), a component of the cell wall of gram-negative bacteria, induces the activation of monocytes and macrophages, as well as the production of pro-inflammatory cytokines (Latorre et al., 2010). Water chestnut extract inhibited LPS-induced secretion of IL-6, RANTES, IL-12 and thus reduces the chances of inflammation. In another study, the pericarp and seed extract of fruits at the dosages of 200 and 300mg/kg were administered to carrageenan-induced hind paw oedema to analyse the anti-inflammatory role. Pericarp displayed stronger anti-inflammatory activity than the seed (Patel et al., 2012).

Anti-diabetic property

Anti-diabetic efficiency of the methanolic extract of water chestnut fruit peels was observed in streptozotocin-induced diabetic Wistar rats. Oral glucose tolerance improved both at dosages of 100 and 200mg/kg. Fasting blood glucose level, which was elevated due to administration of streptozotocin, got lowered (Fig. 5) (Das et al., 2011).

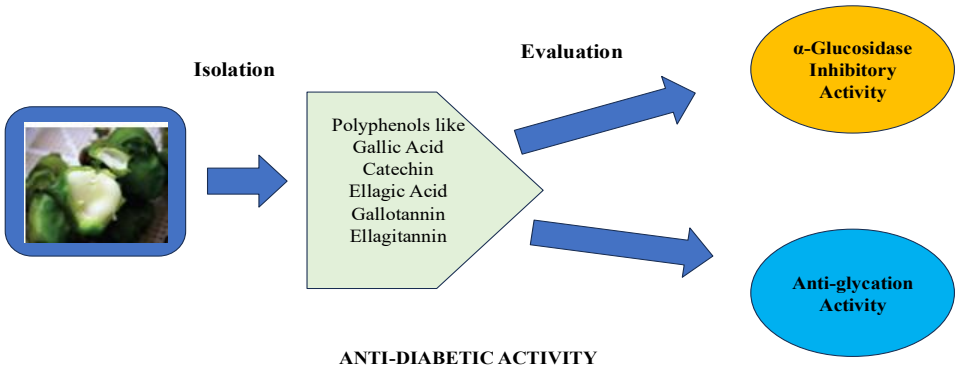


Figure 5. Anti-diabetic effect.

Anti-microbial property

The antimicrobial properties of red and green varieties of water chestnut fruit were studied using the agar disc-diffusion method (Patel et al., 2011). The anti-bacterial activity of the green variety is maximum against the microorganism *Staphylococcus aureus* and *Shigella sonnei* while that of the red variety was against *Bacillus subtilis* (Shishkin et al., 1974). The fruit peel also showed bactericidal action. *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).

Anti-ulcer activity

Using pyloric ligation singly or with aspirin revealed anti-ulcer activity of a 50% ethanolic fruit extract in Wistar rats (Kumari et al., 2021). Anti-ulcer effects were shown by maintaining the harmony in the gastrointestinal tract.

Neuropharmacological Activity

Administration of different doses of hydroalcoholic extract of water chestnut to laboratory animals increases the discrimination index, as depicted by the object recognition test, and decreases spontaneous locomotory activity and latency memory, which may be due to an increase in the cholinergic function (Vyawahare and Ambikar, 2010).

Nootropic Activity

Methanolic extract of water chestnut, at a dosage of 500mg/kg motivated learning memory in mice. The possible mechanism underlying this is that water chestnut contains appreciable amounts of antioxidants which eliminate the oxygen free radicals producing anti-aggregative effects and improving erythrocyte plasticity. These effects improve the blood flow, its rheological properties and also brain metabolism (MajeeChandana et al., 2013).

Immunomodulatory Activity

The immunomodulatory study was performed in rats by using sheep red blood cells as an antigen. The humoral immune response, percent change in neutrophil count, cell-mediated

delayed type hypersensitivity reaction, and macrophage phagocytosis were studied. After treating the rats with the extract of water chestnut fruits, it was found that it improved these characteristics, thus confirming its immunomodulatory effect (Ambikar et al., 2010).

Fortified food products

Different types of cookies were made with water chestnut flour, combined with soy flour (Sharma and Devi, 2021) and ragi to increase the protein, iron, and calcium content. The healthier part is its gluten-free characteristic (Gupta and Awasthi, 2021). Addition of chestnut flour to traditional wheat or rice flour biscuits has been shown to improve fat, fibre, ash, mineral, polyphenol, and antioxidant content (Hegazy et al., 2014; Demirkesen, 2016). A mixture of water chestnut and barley flours was used to prepare crackers and lower glycaemic index muffins in the ratio of 70:30 for diabetic patients (Hussain et al., 2020; Hussain et al., 2019). A mixture of wheat flour, water chestnut flour, sweet potato and colocasia was employed in noodle preparation, which was beneficial for celiac disease patients (Yadav et al., 2014). Another noodle preparation mixture contained water chestnut flour in addition to sweet potato, potato and 10% skim milk powder (Tomar et al., 2020). Snacks prepared from horse chestnut, water chestnut, and lotus stem starch particles with encapsulated resveratrol showed excellent antioxidant, anti-obesity, and anti-diabetic properties (Ahmad and Gani, 2021). Formulated yoghurt using litchi, sweet potato, water chestnut and flaxseed was a nutritionally improved food for poor people suffering from malnutrition (Kumari et al., 2021).

Economic resource

The economic resource potential of cultivating *Trapa natans* is clearly reflected in its expenditure-income ratio, which is 1:3.07, benefitting the farmers to earn Rs 2.07 per rupee invested in *Trapa* sp. cultivation (Thakur and Churpal, 2022). Although China ranked first in annual harvest quantity but the total economic return of $9661.1/tonne from this crop is maximum for Korea. Among other countries like Turkey, Italy Bolivia, Japan, Portugal, Greece, the valuation varied between $933.9 (China) and $2870.5 (Japan) per ton.

Environmental impact and resource

Water quality degradation

Dense growth of *T. natans* has severely reduced the dissolved oxygen level either below 5 mg/l (51%) or below 2.5 mg/l (30%) and inhibited the light penetration (0.5%) to only 0.2m in the Hudson River (Caraco and Cole, 2002). High biomass of *Trapa natans* (504±91g dry weight/m^2) conducts a two-way nutrient exchange through adsorbing from soil and releasing them in the water column during autumn and winter after their death and decomposition (Choi et al., 2016). This leads to a high underwater phosphorus and low oxygen zone (Kato et al., 2016).

Biodiversity loss

The shaded characteristic of the *Trapa* sp. is capable of limiting the growth of many submerged plant communities, especially epiphyton communities, which in their native stage grow many times higher. The competitive advantage of *Trapa* sp. over the submerged communities is mostly asymmetric and when it exceeds the threshold level, the submerged communities face a severe population crash (Kagami et al., 2019). The situation may improve with the harvesting of *Trapa* sp., but in the long run, it has a negative impact on other communities also (Yuan et al., 2021).

Invasiveness and other environmental risk impact

The natural benthic communities and nutrient regime are irreversibly modified by the invasive growth of *Trapa* sp. Socio-economically the negative impact ranges from livelihood to tourism and transportation. Outcompeting other vegetation increases with eutrophication and high nutrients induce their growth, monopolize resources, disrupt the ecological balance, and make them the dominant species.

Phytoremediation role

The invasive nature of *Trapa* sp. can label their growth both as a useful as well as a nuisance event in an aquatic ecosystem. While dense growth results in massive nutrient uptake from the nutrient polluted water thus reclaiming it to reduce eutrophication conditions, the nutrient release after the death of this huge biomass can be of serious concern. They may also remove heavy metals from the water and thus can be a potential phytoremediation agent (Hummel and Kiviat, 2004).

Carbon sequestration role

Aquatic macrophyte is a group of plants which has a tremendous potential to sequester carbon directly from the environment (Jana, 2019) and are increasingly recognized as a sustainable, environment-friendly green tool to lower carbon footprint (Nandy et al., 2018). The physiological role of *Trapa* sp. in carbon sequestration, allocation and partitioning depends on the key drivers of plant strategies and habitat nutrient contents (Diaz et al. 2004). Nutrients can modulate plant traits within a given species through phenotypic plasticity or local adaptation.

Exogenous introduction of compressed CO_2 into the *Trapa* sp. infested system did not change the number of leaves but varied the growth of *Trapa* sp. significantly among treatments with different CNP ratios. The carbon content of leaves that remained 35.50% in control was reduced to 31.30% and 27.87% as the ratio of P to N in the added fertilizer was reduced from 25:02:01 to 101:08:01 (Fig. 6). Of the total amount of carbon in *Trapa* sp., contribution was maximum by the fruit (38–41%), followed by leaf (27–35%) and root (23–32%) among tissues in different ratio treatment. Since fruits are a major source of propagation in flowering plants and a sink of carbon, the investment of carbon was greater in fruits than in leaves or roots. It is proposed that carbon allocation and partitioning in water chestnut were primarily regulated by nutrient-dependent growth at ambient CO_2 that was adequate for their photosynthetic

requirement. The competitive performance of *Trapa* sp. under a nutrient-rich environment and resource mobilization capacity in a nutrient-limited situation was indicated.

The highest phosphorus content in all the tissues (fruit, leaf and root) was observed in the CNP ratio of 101:08:01 in comparison with other ratios applied. Dry weight or total carbon content of water chestnut increased with increasing levels of water phosphate in the optimal CNP ratio but declined thereafter. Thus, water chestnut may be promoted for mass cultivation using the recommended culture protocol that would help trap atmospheric carbon, provide nutritional security, employment generation, and resource utilization.

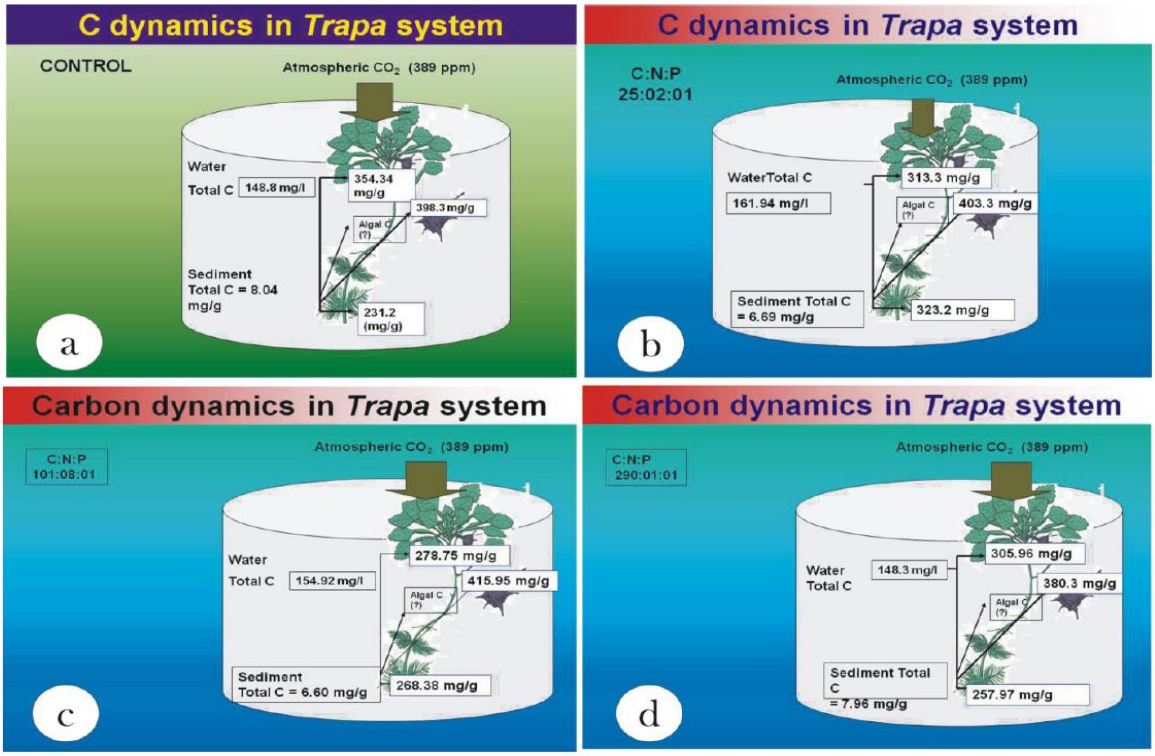


Figure 6. Carbon partition in water chestnut cultured in different CNP ratio treated tanks and control.

Conclusion

Mass production of water chestnut using a vast number of unused small water bodies and derelict waters is a win-win strategy toward mitigation of global warming, nutritional security, empowerment and resource utilization. Scientifically manipulated and managed agriculture practice involving both land as well as aquatic food crops in increased CO_2 levels can generate a potential positive socio-economic feedback effect.

The benefits of global warming as an adaptation strategy may be projected in terms of economic output by harvesting these food crops using the standardized protocol (CNP ratio of 101:08:01), which would ensure nutritional protection, entrepreneurship development, and

employment generation, along with resource utilisation and carbon capturing. *Trapa* sp. exhibits excellent bioremediation capabilities and can be utilized for cleaner production.

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HOW TO CITE

Susmita Lahiri, Saurav Kumar Nandy, Sujoy Kumar Bag, Avery Sengupta, B.B. Jana, Jatindranath Bhakta and Ashis Kumar Panigrahi (2025). Water Chestnut (*Trapa* sp.) as an Economic and Ecological Resource in Global Environment Protection and Food Security. © International Academic Publishing House (IAPH), Dr. Somnath Das, Dr. Ashis Kumar Panigrahi, Dr. Jayanta Kumar Das and Dr. Donrie Purcell (eds.), *Life as Basic Science: An Overview and Prospects for the Future Volume: 4*, pp. 38-51. ISBN: 978-81-989555-2-4. doi: https://doi.org/10.52756/lbsopf.2025.v04.003