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EVALUATION OF NUTRITIONAL VALUES AND CONSTRAINTS TOWARDS INCOME GENERATING POTENTIAL OF WATER CHESTNUT (*TRAPA BISPINOSA*) IN GANGES BASIN, INDIA

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ABSTRACT
Water chestnut (*Trapa bispinosa*; Family: Trapaceae) is extensively cultivated in ponds and wetlands of Ganges Basin for food and medicinal usage. Fruits are rich source of protein, carbohydrate, fiber and minerals. Despite its multifaceted use, this plant is understudied in an economic perspective. The present study, conducted in the central part of the Ganges basin, evaluates the nutritional value of the *Trapa* fruits and identifies opportunities expanding its role in bioeconomy. Nutritional and biochemical analysis of fruits showed up to 75% carbohydrate, over 8% protein, variable amount of minerals and high overall nutritive index. Nutritional profile showed concordance with water quality of the study ponds. Economic importance of *Trapa* lies in multifaceted use of its fresh edible fruits and processed products. Processing of *Trapa* fruits generates employment and livelihood security of the rural women especially in areas with rich density of ponds and wetlands. Rich nutritional profile, pharmaceutical values and processed dry product of *Trapa* enhance its market demand. Its powder is used as a premium item during fast. The study identifies three major issues to scale- up its role in bioeconomy: a) Area under cultivation (ponds and wetlands) is rapidly shrinking due to changing land use and needs expansion and management; b) It needs expansion of processing and market access of dry items; and c) Huge biomass produced in its cultivation needs to be scientifically tested and scaled-up for use as biofertilizer.

Keywords: *Bioeconomy, Ganges Basin, Livelihood security, Nutritive value, Pharmaceuticals, Trapa*

INTRODUCTION
India is primarily an agriculture-based country known for its sufficiency of agricultural produce to meet food demand of the world's largest population. Trapa (*Trapa bispinosa*), commonly known as water chestnut is an essential aquatic crop and cultivated in the Ganges basin for its high nutritional and economic importance. Studies with *Trapa* conducted in the Ganges Basin highlights its adaptability to varying set of aquatic conditions (Sundar *et al.,* 2024). Fruits of *T. bispinosa* is rich source of carbohydrate, protein, vitamins and minerals including calcium, potassium, phosphorous and magnesium (Sundar *et al.,* 2024). Also, it contains antioxidant properties, reduces oxidative stress and improves cardiovascular health (Basu and Hemamalini, 2023; Zhang *et al.,* 2022). Fresh fruits of *Trapa,* dried nuts and flours are highly popular in Indian market (Jana, 2025). During fast, dry powder of *Trapa* (flour) is most favored supplement. However, contamination of cultivation ponds with polluted water can lead toxic bioaccumulation and potential health risks. This invites caution for up-scaling and sustainable cultivation of *Trapa* as many parts of the Ganges basin are contaminated with toxic pollutants.
Although, this plant is known for its pollution control potential (absorption of nutrients and toxicants) (Hummel and Findlay, 2006), yet toxic accumulation in fruits and unchecked supply can challenge management strategies (Palm *et al.,* 2024). This has concern because many parts of the Ganges Basin receive high amount of metal pollutants (Siddiqui and Pandey, 2019). This plant is useful in carbon

sequestration and phytoremediation (Taher *et al.,* 2023). It requires in-depth pond-based ecosystem research in ecological and toxicological perspectives as well as its food-safety concern. Also, characterization of nutritive values of this important aquatic crop is essentially needed.

Despite being rich source of carbohydrate, protein, vitamins and other dietary supplements, its widespread use as a food supplement, income generating potential and full commercialization faces multiple challenges. It requires efficient post-harvest processing and successful storage approaches. Also, inconsistent market demand and season-based harvesting constrains scaling-up and profit margins (Singh *et al.,* 2024). Furthermore, small-scale farmers with limited financial and infrastructural support are unable to scale-up cultivation and processing. Factors of market dynamics such as inadequate supply chain, lack of value addition, distribution inefficiencies, poor supply-demand linkages and price fluctuations challenge its economic sustainability in India.

This paper evaluates the nutritional properties of *T. bispinosa* and assesses its income generating potential in the Ganges Basin. The study also explores major challenges that constrains its demand as a food supplement scaling-up its role in bioeconomy in India.

MATERIALS AND METHODS

We collected samples of Trapa (*Trapa bispinosa*) from six different ponds located in the central part of the Ganges Basin. These include 1: Lucknow; 2: Prayagraj; 3: Varanasi; 4: Azamgarh; 5: Gorakhpur; 6: Buxar. Plant leaves and fruit samples were cleaned with double distilled water and dried under bright sunlight. Sun dried samples were ground to fine powder and used for dry ashing (Janani and Sondhi, 1995). In each case, plant samples were placed in muffle furnace at 400˚C and cooled at room temperature in a desiccator. The elemental composition of plant samples was estimated according to the methods described by the Association of Official Analytical Chemists (AOAC 2012). Crude protein was estimated in oven dried materials using micro Kjeldahl method. Crude fibre was determined following Henneberg and Stohmann (1960). The crude fat was extracted following Chopra and Kanwar (1996). Carbohydrate and nutritive value of *Trapa bispinosa* were assessed following Indrayan *et al*. (2005). Nutritive values were calculated as per Indrayan et al (2005).

Enzyme assay in plant samples was performed following standard protocols. Superoxide dismutase was estimated using Greiss reagent containing a mixture of sulphanilamide and phosphoric acid as described by Das *et al*. (2000). Catalase activity was assayed using potassium dichromate and glacial acetic acid mixture and expressed in terms of μmoles of H_2O_2 consumed /min /mg protein (Sinha, 1972).

Peroxide in the samples was estimated according to the method described by Addy and Goodman (1972). The activity of glutathione peroxidase and ascorbate oxidase was estimated by the method described by Rotruck *et al*. (1973) and Vines and Oberbachner (1965) respectively. Glucose-6-phosphate dehydrogenase was estimated according to Balinsky and Bernstein (1963). Cost-benefit analysis was done with data collected from societal-set-up, production sector and market sector.

RESULTS AND DISCUSSION

Central part of the Ganges basin is known for its very high fertility due to rich alluvial deposit by the Ganga River and its tributaries. This agro-climate zone supports a large densely settled human population with thriving agriculture-based economy. *Trapa* (*Trapa bispinosa)* is an important aquatic crop of the region with immense economic potential, although constrained by scale and market specific drivers. This study addresses the issue in respect of nutritional quality as well as well as its potential towards commercial expansion. The protein content in leaves and fruits although varied with site, remained substantially high. Protein in leaves was found highest at site 1 (145.00 g Kg^{-1} dry weight) and lowest at site 2 (115.80 g Kg^{-1} dry weight). Carbohydrate in leaves ranged from 550.35 g Kg^{-1} dry weight (site 1) to 650.62 g Kg^{-1} dry weight (site 3). Similarly, leaves did appear rich source of ash, crude fat and crude fibre. Leaves are produced on large scale by plants contributing in dry biomass generation. *Trapa* leaves are utilized as a biofertilizer by local people in agricultural field.

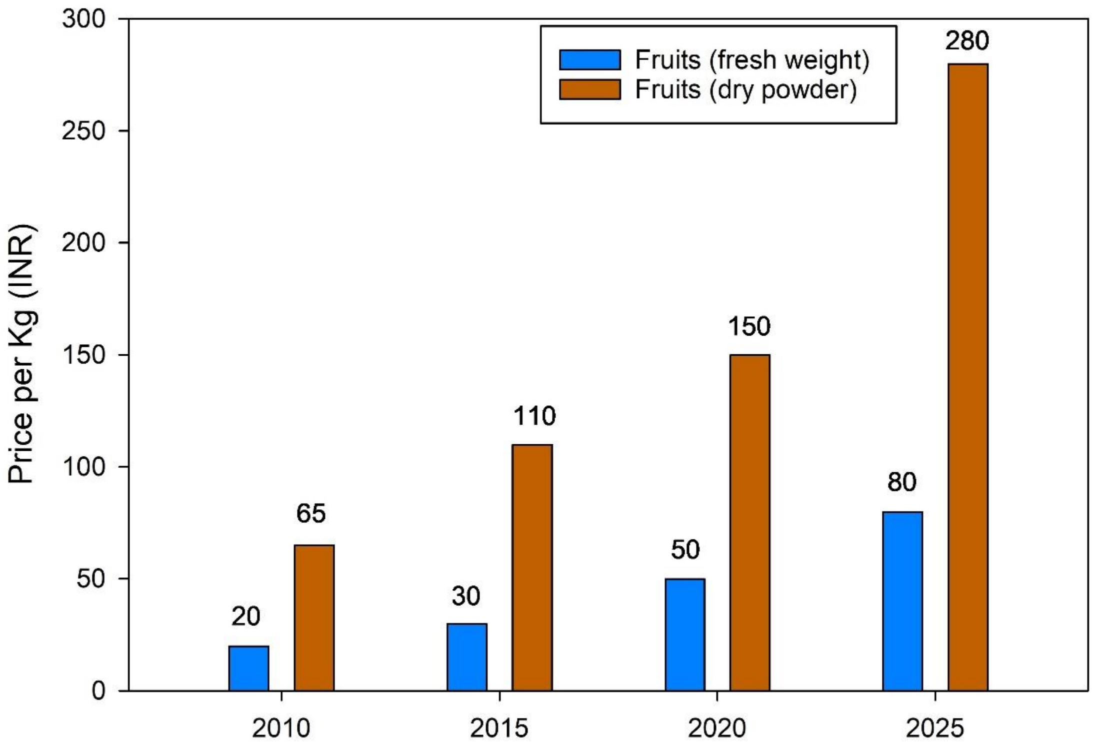

Figure 1: Price of produce of *Trapa bispinosa* in the national market (India)

Fruits of *Trapa* did appear rich source of protein (> 8 %), carbohydrate (> 75%) and crude fibre (> 3.75%) (Table 1). Nutritive value of fruits of *Trapa* was calculated based collectively on the content of protein, fat and carbohydrate. Although fruits from all the studied locations are rich in nutritive value (Table 1), it was highest (368.80 cal/100g) in the fruits collected from site 4. Table 2 shows the elemental concentrations and antioxidant enzyme in fruits collected from different study locations. Fruits of *Trapa* were found rich in calcium, zinc and iron contents which play important role as human nutritional supplements. Calcium and zinc were highest in samples of site 4. Furthermore, the study assayed antioxidant properties in terms of important antioxidant enzyme activities expressed as unit/mg protein in fruit samples (Table 2). Superoxide dismutase activity was highest (4.50 unit/mg protein) in the fruits collected from Lucknow district. Superoxide dismutase is an antioxidant enzyme functioning towards physiological defense against free radicals and reactive oxygen species (ROS). This plays important role in immunity generation in plants and human being (Stephene *et al*., 2020). Catalase and peroxidase activity were well reported in all fruits irrespective of sampling site. Both the enzymes with strong enzymatic H_2O_2 scavenging potential are crucial for suppression of toxic H_2O_2 levels (Yemelyanov, 2022).

Glutathione peroxidase was found to be the highest (4.45 unit/mg protein) in the fruit samples collected from site 4. It has been reported that glutathione peroxidase is a selenium enzyme which plays a major role in regulating the concentration of H_2O_2 and a large number of organic peroxides. Sies (1997) reported the antioxidant activity of glutathione peroxidase in fruits of Myrica. Ascorbate oxidase activity was observed in all samples. It functions as a reductant for many free radicals. Ascorbate oxidase is a multi-Cu-oxidase that catalyzes the oxidation of ascorbic acid to L-dehydroascorbic acid. It is a terminal respiratory oxidase and its biosynthesis is copper dependent (Mellidou and Kenellis, 2024). Copper and ascorbate oxidase were reported from all samples. This shows its potential role as a source of antioxidants (Asha *et al.,* 2024). Glucose-6-phosphate dehydrogenase catalyzes the production of nicotinamide adenine dinucleotide phosphate (NADPH), a reducing power for many reducing biosynthetic reactions and nitrogen assimilation

(Smith, 2023). Glucose-6-phosphate dehydrogenase activity was reported in all the samples collected from different sites, but it was particularly high at sites 1, 3 and 4.

Table: 1. Nutritive values of fruits of *Trapa bispinosa* grown in different ponds in the Ganges Basin (India). Values are mean (n = 9) ± SD

Site	Ash (%)	Moisture content (%)	Crude fat (%)	Protein (%)	Carbohydrate (%)	Crude fiber (%)	Nutritive value* (Cal/100 g)
1	5.80 ± 0.47	12.50 ± 1.02	1.92 ±0.15	6.45 ± 0.52	70.00 ± 7.20	2.75 ± 0.28	345.00 ± 34.72
2	6.20 ± 0.72	12.60 ± 1.30	1.50 ± 0.12	5.42 ± 0.44	72.00 ± 7.82	3.72 ± 0.37	337.50 ± 40.12
3	6.00 ± 0.49	13.40 ± 1.34	1.60 ± 0.17	8.46 ±0.68	75.60 ± 8.02	3.75 ± 0.42	366.75 ± 38.23
4	6.00 ±0.56	13.56 ± 1.09	1.52 ±0.14	7.30 ± 0.60	73.15 ± 5.85	3.72 ± 0.34	368.80 ± 44.24
5	5.50 ± 0.48	12.40 ± 1.23	1.52 ± 0.17	5.00 ± 0.54	72.15 ± 5.94	3.15 ± 0.28	340.00 ± 40.84
6	5.60 ± 0.53	12.46 ± 1.27	1.62 ± 0.13	6.16 ± 0.60	73.20 ± 7.42	3.00 ± 0.24	343.60 ± 33.87

*Based on protein, fat and carbohydrate (Indrayan et al., 2005)

Table: 2. Minerals and enzymatic antioxidants in *Trapa bispinosa* grown in different ponds in the Ganges Basin (India). Values are mean (n = 9) ± SD

Site	Ca (µg/g)	Zn (µg/g)	SOD (Unit/mg protein)	Glutathione Peroxidase (Unit/mg protein)	Ascorbate oxidase (Unit/mg protein)	Glu-6-PO_4 Dehydrogenase (Unit/mg protein)
1	365.00 ± 32.89	7.00 ± 0.63	4.50 ± 0.52	442.10 ± 44.22	0.004 ± 0.00037	4.56 ± 0.41
2	370.50 ± 33.34	7.10 ± 0.69	3.85 ± 0.34	440.00 ± 39.48	0.004 ± 0.00043	4.42 ± 0.39
3	380.00 ± 41.8	7.25 ± 0.59	3.50 ± 0.29	458.50 ± 48.52	0.002 ± 0.00019	4.56 ± 0.37
4	368.70 ±37.83	7.10 ± 0.74	4.23 ± 0.42	445.00 ± 38.02	0.004 ± 0.00038	4.56 ± 0.42
5	372.58 ±34.89	7.20 ± 0.85	4.25 ± 0.45	432.00 ± 47.52	0.002 ± 0.00017	4.40 ± 0.48
6	385.00 ± 42.30	7.40 ± 0.67	4.20 ± 0.38	398.80 ± 35.28	0.003 ± 0.00027	4.40 ± 0.50

Table: 3. Cost-benefit analysis of Trapa cultivation in central part of the Ganges Basin (India)

Produce	Yield (tons/ha)	Input cost (Rs/ha)	Gross Return (Rs/ha)	Benefit margin (Rs/ha)
Freshfruits	5.00 (4.5-6.5)	80,000	4,00,000	3,20,000
Dry Powder	2.00 (1.8-2.3)	3,00,000	5,80,000	2,60,000

Based on survey results of production and market sectors

Fruits of *Trapa* are potential income generating resource for rural people. Depending upon pond's fertility and cultivation practices fresh fruits yield varied between 4.5 to 6.5 tonnes/ha (Fig. 1). The fresh fruit marketing showed greater profit margin (3,20,000 INR per ha) compared to powdered produce (2,60,000 INR per ha) although the latter is more stable in the market (Table 3). Both leaves and fruits are rich source of protein, carbohydrate, fibre and minerals. Their leaves can be used for biofertilizer production on large scale. They play important role in removal of heavy metal pollutants from water bodies. Our study endorses that the Water Chestnut (*Trapa bispinosa*) is a nutritionally rich and commercially viable aquatic plant. It is highly suitable for cultivation in tropical ponds for health benefits and economic harvest along with its role in phytoremediation.

CONCLUSIONS

The study concludes that *Trapa* is a nutritionally rich aquatic crop of the Ganges basin with a large opportunity of its commercial and economic expansion. The cultivation of *Trapa* has particular rationale in enriching rural economy of the region. Despite its important role in pollution control and economic sustainability, some basic challenges in the region constrain its large scale income generating potential and profit margin. There is a need to increase cultivation area, improve storage infrastructure, and promote sustainable cultivation practices. Pond-based scientific research, farming practices coupled with multiple usage strategy will optimize water use and enhance productivity. Furthermore, addressing pollution related issues through improved water and waste water management is crucial for ensuring the safety of human consumers.

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