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Influence of plant spacing and nutritional regimes on quantitative fruit traits of water chestnut (*Trapa natans* var. *bispinosa* Roxb.)

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Abstract

A field experiment was conducted to evaluate the effect of plant spacing and nutritional regimes on fruit growth and development of water chestnut (*Trapa natans* var. *bispinosa* Roxb.). The experiment comprised two plant spacings, S₁ (1 m × 1 m) and S₂ (2 m × 1 m), and thirteen nutritional regimes. The results showed that wider spacing (S₂) significantly improved the major fruit attributes compared with closer spacing (S₁). During the year 2023 and the year 2024, S₂ recorded higher number of fruits per rosette, fruit length, fruit width, fruit weight and fruit volume. Among nutritional regimes, T₁₂ (nano zinc fortified FYM) consistently produced superior fruit characteristics, particularly fruit length, width, weight and volume, while T₁₀ (nano zinc fortified Jeevamrut) also showed comparable and better performance. The interaction between spacing and nutritional regimes was significant for most fruit characters, with S₂ × T₁₂ generally recording the highest values. The findings indicated that wider plant spacing combined with nano zinc fortified organic nutrition enhanced fruit growth and development, suggesting its potential for improving the quality and productivity of water chestnut under wetland conditions.

Keywords: Water chestnut, plant spacing, nutritional regimes, nano zinc, Jeevamrut, FYM, fruit characteristics

1. Introduction

Water chestnut (*Trapa natans* var. *bispinosa* Roxb.) is an important aquatic fruit crop in India belonging to the family Trapaceae. It is popularly known as Singhara in Hindi and is considered to have originated in India, China and Eurasia. It is a free-floating annual aquatic plant cultivated in shallow fields, ponds and swampy lands. The crop thrives in nutrient-rich water with a pH ranging from 6.7 to 8.2 (Anonymous, 2002; Bhatiwala *et al.*, 2012) [2, 3]. In India, it is extensively cultivated in Madhya Pradesh, Uttar Pradesh, Bihar, Odisha, West Bengal, Jharkhand, Karnataka and Jammu & Kashmir. It is also grown in several tropical regions including Pakistan, Sri Lanka, Indonesia and Africa, and is prevalent in Southeast Asia, southern China, Japan, Italy and tropical America. Furthermore, it has naturalized in certain regions of the eastern United States (Takano and Kadono, 2005) [16].

The fruit is used as a substitute for cereal in Indian subcontinent during fast days especially during Navratri and other sacred days when consumption of wheat flour is avoided. Chestnut flour is made by drying chestnut fruits in hot air, shelling them, picking out discolored chestnuts, and crushing them with a stone mill (Alary *et al.*, 2007) [1]. Chestnut flour can be used in gluten-free breads for its nutritional and health benefits. Traditionally, cookies are created with wheat flour. Additional grain flours or starches can enhance the flavor and structure of the finished product.

Water chestnut grows for commercial cultivation, heavy muddy soils rich in organic matter are preferred. Application of oil cakes, poultry manure and FYM/compost @ 8 t ha⁻¹ is recommended for crop growth and development (Chowdhury *et al.*, 2003) [4]. Phosphorus and potassium are essential for optimum crop performance. In West Bengal, 30-40 kg urea ha⁻¹ is recommended at transplanting followed by an additional 20 kg ha⁻¹ after 25-30 days (Jana, 2016a) [9]. Soils rich in zinc and boron improve fruit number and fruit weight. For newly cultivated fields, fertilizer application may be increased from NPK 60:20:20 kg ha⁻¹ to 60:40:30 kg ha⁻¹, while maintaining a spacing of 1 m × 2 m with a plant population of 4500-5000 plants ha⁻¹ (Jana *et al.*, 2019) [18].

Nano-fertilizers possess nanoscale dimensions and a high surface area-to-volume ratio, which facilitate efficient nutrient absorption, translocation and utilization within plants. Consequently, they improve nutrient use efficiency and reduce nutrient losses through leaching, volatilization and fixation, thereby enhancing crop productivity and sustainability (Raliya *et al.*, 2018) ^[15]. Nano-Urea enhances nitrogen use efficiency through improved nitrogen availability and uptake, resulting in increased chlorophyll synthesis, photosynthetic activity, protein formation, vegetative growth and crop productivity (Kumar *et al.*, 2021) ^[12].

Nano-Zinc plays an essential role in enzyme activation, auxin biosynthesis, chlorophyll formation and carbohydrate metabolism. Adequate zinc nutrition enhances physiological processes, photosynthetic efficiency, growth, yield attributes and quality characteristics of crops by improving nutrient utilization and metabolic activities (Tarafdar *et al.*, 2014; Raliya *et al.*, 2018) ^[17, 15]. Silver nanoparticles have been reported to enhance physiological and biochemical activities, stimulate antioxidant defense systems and improve plant tolerance to environmental stresses, thereby contributing to improved growth, development and productivity in various crops (Khan *et al.*, 2023; El-Saadony *et al.*, 2021) ^[10, 7].

Application of Jeevamrut has been shown to increase microbial population, soil biological activity, and nutrient availability in the rhizosphere, resulting in increased plant growth and yield performance. Nano-fertilizers improve nutrient delivery and nutrient usage efficiency, whereas organic nutrient sources promote nutrient cycling and soil biology. As a result, combining nano-nutrients with organic nutrient sources may increase nutrient availability, absorption efficiency, and crop yield while reducing nutrient losses (Dimkpa and Bindraban, 2018; Raliya *et al.*, 2018) ^[5, 15].

2. Materials and Methods

2.1 Experimental site

Experiment was conducted during the Kharif seasons of 2023 and 2024 at Horticulture Farm No. 1, Department of Horticulture, School of Agricultural Sciences and Technology, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, India. The experimental farm was geographically situated at 26.769559° N latitude and 80.927135° E longitude, with an elevation of approximately 121 m above mean sea level.

2.2 Experimental design and treatments

The experiment was conducted in a Factorial Randomized Block Design involving two experimental factors with three replications. Factor A comprised two plant spacing levels, namely $S_1 = 1.0 \text{ m} \times 1.0 \text{ m}$ and $S_2 = 2.0 \text{ m} \times 1.0 \text{ m}$. Factor B consisted of thirteen nutritional regimes (T_1 - T_{13}) comprising conventional fertilizer practices, reduced fertilizer doses, recommended fertilizer application, nano-fertilizers and organic nutrient sources.

The factorial combination of the two spacing levels and thirteen nutritional regimes resulted in 26 treatment combinations (2×13). Each treatment combination was replicated three times, resulting in a total of 78 experimental units. The treatments were randomly assigned within each replication to minimize experimental variability and obtain reliable estimates of treatment effects. The factorial design

enabled the evaluation of the main effects of plant spacing and nutritional regimes, as well as their interaction ($S \times T$) on the growth, yield and quality performance of water chestnut.

2.3 Nutritional treatments

A total of thirteen nutritional regimes were evaluated during the study. These treatments included control, farmer's fertilizer practice, reduced fertilizer doses, recommended dose of fertilizer (RDF), nano-fertilizers, Jeevamrut and nano-fertilizer-fortified organic nutrient sources. The details of the nutritional treatments are presented in Table 1.

Table 1: Nutritional treatments

Treatments	Application
T ₁	Control
T ₂	Fertilizer Dose as applied by farmers
T ₃	¼ FDF (Urea + DAP)
T ₄	½ FDF (Urea + DAP)
T ₅	Nano-Urea @ 4.0%
T ₆	Jeevamrut @ 10%
T ₇	RDF
T ₈	Nano silver @ 25 ppm
T ₉	Nano zinc @ 50 ppm
T ₁₀	Nano zinc fortified Jeevamrut
T ₁₁	Nano silver fortified Jeevamrut
T ₁₂	Nano zinc fortified FYM
T ₁₃	Nano silver fortified FYM

2.4 Treatment combinations and field layout

Each of the thirteen nutritional regimes was combined with both plant spacing levels, resulting in 26 factorial treatment combinations, designated as S_1T_1 to S_1T_{13} and S_2T_1 to S_2T_{13} . Under S_1 , plants were maintained at a spacing of $1.0 \text{ m} \times 1.0 \text{ m}$, whereas under S_2 , a spacing of $2.0 \text{ m} \times 1.0 \text{ m}$ was maintained. The experimental units consisted of individual ponds measuring $2.0 \text{ m} \times 1.0 \text{ m}$. A border space of approximately 0.5 m was maintained, wherever required, to minimize the influence of adjacent experimental units. Water chestnut plants were established during the third week of July, and the water depth was maintained at approximately 60-70 cm throughout the crop period. All other recommended cultural practices were kept uniform across the experimental units, except for the respective nutritional treatments imposed according to the experimental design.

3. Results and Discussion

Fruit characteristics are important indicators of productivity, marketable quality and overall performance of water chestnut. In the present investigation, plant spacing and nutritional regimes produced noticeable variations in different fruit attributes during both years of experimentation. The response of fruit characters varied with the availability of growing space, nutrient supply and their combined effects. The influence of plant spacing, nutritional regimes and their interaction on individual fruit parameters is presented and discussed in the following sections.

3.1 Number of fruits per rosette

The data presented in Table 2 revealed that the number of fruits per rosette was significantly influenced by plant spacing and nutrient management treatments during both years of experimentation. However, the interaction between

spacing and nutrient management treatments was statistically significant during the year 2023, whereas a significant interaction was observed during the year 2024.

Plant spacing significantly affected the number of fruits per rosette during both years. The wider spacing (S_2) recorded a significantly higher number of fruits per rosette, with 6.18 fruits during the year 2023 and 6.31 fruits during the year 2024, compared with 5.41 and 5.62 fruits per rosette, respectively, under closer spacing (S_1). The better performance under wider spacing may be attributed to reduced inter-plant competition for light, nutrients and space, which favoured reproductive growth and fruit initiation. Similar variation in reproductive characteristics of *Trapa natans* has been reported by Palm *et al.*, (2024) [13], who observed considerable variation in rosette development and fruit production among *Trapa* populations and emphasized the role of plant growth conditions in determining reproductive performance.

Nutrient management treatments significantly influenced the number of fruits per rosette in both years. During the year 2023, the maximum number of fruits per rosette (7.83) was recorded under T_{10} (Nano zinc fortified Jeevamrut), followed by T_{12} (Nano zinc fortified FYM) with 7.17 fruits, T_7 (RDF) and T_{13} (Nano silver fortified FYM) with 6.34 fruits each. The lowest value (4.00 fruits per rosette) was recorded under T_1 (Control).

A similar trend was observed during the year 2024. T_{10} again recorded the maximum number of fruits per rosette (7.83), followed by T_{12} (7.17), while the minimum value (4.50) was recorded under the control treatment. The superior response of T_{10} and T_{12} may be associated with the combined availability of macro-and micronutrients along

with organic nutrient sources. Zinc plays an important role in several physiological and reproductive processes, while organic nutrient sources can improve nutrient availability and overall plant growth. Puste *et al.*, (2005) [14] reported that balanced management of nitrogen and other nutrients through integrated organic and inorganic sources substantially influenced the production and quality of water chestnut under wetland conditions.

The interaction between spacing and nutrient management treatments was non-significant during the year 2023, indicating that the effect of nutrient treatments on fruit number was statistically similar across the two spacings. In contrast, the interaction was significant during the year 2024, indicating that the response of nutrient management treatments varied according to plant spacing.

During the year 2024, the maximum number of fruits per rosette (8.33) was recorded under $S_2 \times T_{10}$, followed by $S_2 \times T_{12}$ (7.67) and $S_2 \times T_7$ (7.00). The minimum value (4.33 fruits per rosette) was observed under $S_1 \times T_1$. The higher reproductive performance under wider spacing combined with nutrient supplementation suggests that adequate growing space together with balanced nutrient availability favoured fruit initiation and development. Palm *et al.*, (2024) [13] reported that nutrient availability, particularly nitrogen, can influence rosette and leaf development in *Trapa natans*, while nutrient acquisition may occur from both the sediment and water column.

Overall, the results indicated that wider spacing (S_2) and integrated nutrient management, particularly T_{10} , were favourable for increasing the number of fruits produced per rosette in water chestnut.

Table 2: Number of fruits per rosette recorded in water chestnut (*Trapa natans* var. *bispinosa* Roxb.) under different nutrient treatments and two plant spacings (S_1 and S_2) during the year 2023 and 2024

Treatments	2023			2024			
	S_1	S_2	Mean	S_1	S_2	Mean	Pooled
T_1 -Control	3.67	4.33	4.00	4.33	4.67	4.50	4.25
T_2 -Fertilizer Dose as applied by farmers	5.33	6.00	5.67	5.67	6.33	6.00	5.84
T_3 - $\frac{1}{4}$ FDF (Urea + DAP)	4.33	5.00	4.67	4.67	5.00	4.84	4.76
T_4 - $\frac{1}{2}$ FDF (Urea + DAP)	5.00	5.33	5.17	5.00	5.67	5.34	5.26
T_5 -Nano-Urea @ 4.0%	5.00	6.33	5.67	5.00	5.67	5.34	5.51
T_6 -Jeevamrut @ 10%	5.33	6.33	5.83	5.33	6.33	5.83	5.83
T_7 -RDF	6.00	6.67	6.34	6.33	7.00	6.67	6.51
T_8 -Nano silver @ 25 ppm	4.67	5.67	5.17	5.00	5.67	5.34	5.26
T_9 -Nano zinc @ 50 ppm	6.00	5.67	5.84	6.00	6.67	6.34	6.09
T_{10} -Nano zinc fortified Jeevamrut	7.33	8.33	7.83	7.33	8.33	7.83	7.83
T_{11} -Nano silver fortified Jeevamrut	5.33	6.00	5.67	5.67	6.33	6.00	5.84
T_{12} -Nano zinc fortified FYM	6.67	7.67	7.17	6.67	7.67	7.17	7.17
T_{13} -Nano silver fortified FYM	5.67	7.00	6.34	6.00	6.67	6.34	6.34
Mean	5.41	6.18	-	5.62	6.31	-	-
Factors	C.D.		SE(m)	C.D.		SE(m)	
Factor(A)	0.264		0.093	0.294		0.089	
Factor(B)	0.673		0.236	0.748		0.227	
(A X B)	N/A		0.334	1.058		0.322	

3.2 Average length of fruit (mm)

The data presented in Table 3 indicated that average fruit length was significantly influenced by plant spacing and nutrient management treatments during both years of experimentation. The interaction between spacing and nutrient management was also significant during both years, indicating that fruit length was influenced by the combined effect of spacing and nutrient regime.

Plant spacing significantly affected average fruit length during both years. Wider spacing (S_2) recorded significantly greater fruit length of 40.29 mm in the year 2023 and 40.92 mm in the year 2024, compared with 39.69 mm and 40.05 mm, respectively, under closer spacing (S_1). The greater fruit length under wider spacing may be attributed to reduced competition among plants and greater availability of assimilates for reproductive development.

Variation in fruit size is a recognized characteristic of *Trapa. Palm et al.*, (2024) ^[13] reported considerable variation in fruit dimensions among *Trapa* populations and noted that fruit size is an important component associated with productivity.

Nutrient management significantly affected average fruit length during both years. In the year 2023, the maximum fruit length (41.65 mm) was recorded under T₁₂ (Nano zinc fortified FYM), followed by T₁₀ (41.35 mm) and T₇ (40.54 mm). The minimum fruit length (38.43 mm) was recorded under T₁ (Control).

During the year 2024, T₁₂ again recorded the highest fruit length (42.13 mm), followed by T₁₀ (41.80 mm) and T₇ (41.31 mm), whereas the minimum value (38.63 mm) was recorded under the control. The consistently superior performance of T₁₂ suggests that the combination of FYM and nano zinc provided a favourable nutrient environment for fruit development. Organic nutrient sources can improve nutrient availability and nutrient-use efficiency, while zinc is involved in several enzymatic and physiological processes associated with plant growth.

Puste *et al.*, (2005) ^[14] demonstrated that integrated organic

and inorganic nutrient management significantly influenced the productivity and quality of water chestnut under wetland conditions, supporting the beneficial role of balanced nutrient management in this crop.

The interaction between spacing and nutrient management treatments was significant during both years. The highest fruit length was recorded under S₂ × T₁₂, with 41.94 mm in the year 2023 and 42.27 mm in the year 2024, followed by S₂ × T₁₀ with 41.91 and 42.24 mm, respectively. The minimum fruit length was recorded under S₁ × T₁, with 38.30 mm in the year 2023 and 38.23 mm in the year 2024.

The consistently higher fruit length under wider spacing combined with nutrient supplementation indicates that adequate plant space and improved nutrient availability jointly favoured fruit development. Dwivedi *et al.*, (2010) ^[6] reported considerable variability in fruit length, breadth, weight and volume among water chestnut germplasm, demonstrating that these physical attributes are important and variable characteristics of *Trapa natans* var. *bispinosa*. Thus, S₂ × T₁₂ emerged as the most favourable treatment combination for improving fruit length under the present experimental conditions.

Table 3: Average length of fruit (mm) recorded in water chestnut (*Trapa natans* var. *bispinosa* Roxb.) under different nutrient treatments and two plant spacings (S₁ and S₂) during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	38.30	38.56	38.43	38.23	39.02	38.63	38.53
T ₂ -Fertilizer Dose as applied by farmers	39.70	40.29	40.00	39.96	40.96	40.46	40.23
T ₃ -¼ FDF (Urea + DAP)	38.66	38.80	38.73	38.68	39.26	38.97	38.85
T ₄ -½ FDF (Urea + DAP)	39.06	39.38	39.22	39.36	39.96	39.66	39.44
T ₅ -Nano-Urea @ 4.0%	39.49	39.95	39.72	39.73	40.56	40.15	39.935
T ₆ -Jeevamrut @ 10%	39.84	40.41	40.13	40.20	41.02	40.61	40.37
T ₇ -RDF	40.09	40.99	40.54	40.66	41.96	41.31	40.925
T ₈ -Nano silver @ 25 ppm	38.92	39.20	39.06	39.12	39.78	39.45	39.255
T ₉ -Nano zinc @ 50 ppm	39.98	40.92	40.45	40.52	41.90	41.21	40.83
T ₁₀ -Nano zinc fortified Jeevamrut	40.78	41.91	41.35	41.36	42.24	41.80	41.575
T ₁₁ -Nano silver fortified Jeevamrut	39.87	40.63	40.25	40.34	41.44	40.89	40.57
T ₁₂ -Nano zinc fortified FYM	41.36	41.94	41.65	41.99	42.27	42.13	41.89
T ₁₃ -Nano silver fortified FYM	39.95	40.76	40.36	40.46	41.62	41.04	40.7
Mean	39.69	40.29	-	40.05	40.92	-	-
Factors	C.D.	SE(m)		C.D.		SE(m)	
Factor(A)	0.004	0.001		0.008		0.003	
Factor(B)	0.0010	0.003		0.021		0.007	
(A X B)	0.014	0.005		0.030		0.010	

3.3 Average width of fruit (mm)

The results presented in Table 4 showed that average fruit width was significantly influenced by plant spacing, nutrient management treatments and their interaction during both years of experimentation.

Wider spacing (S₂) resulted in significantly greater average fruit width than closer spacing (S₁) during both years. Fruit width under S₂ was 41.27 mm in the year 2023 and 41.17 mm in the year 2024, compared with 40.48 mm and 40.34 mm, respectively, under S₁. The greater fruit width at wider spacing may be attributed to reduced competition for available resources and improved partitioning of photosynthates towards developing fruits.

Nutrient management treatments significantly influenced fruit width. During the year 2023, T₁₂ recorded the maximum average fruit width (42.42 mm), followed by T₁₀ (42.22 mm), T₇ (41.55 mm) and T₉ (41.45 mm). The minimum value (39.18 mm) was recorded under T₁ (Control).

During the year 2024, the maximum fruit width was again recorded under T₁₂ (42.44 mm), followed by T₁₀ (42.10 mm), T₇ (41.50 mm) and T₉ (41.44 mm), whereas the minimum value (38.91 mm) was observed under the control. The favourable response of T₁₂ and T₁₀ indicates that integrated nutrient supply was more effective in promoting fruit development than the control or lower nutrient regimes. Puste *et al.*, (2005) ^[14] reported that appropriate combinations of organic and inorganic nutrient sources enhanced production and quality attributes of water chestnut, indicating the importance of balanced nutrient availability in aquatic food crops.

The interaction between spacing and nutrient management treatments was significant during both years. The highest fruit width was recorded under S₂ × T₁₂, measuring 42.68 mm in the year 2023 and 42.74 mm in the year 2024, followed by S₂ × T₁₀ with 42.67 and 42.54 mm, respectively. The minimum fruit width was recorded under S₁ × T₁, with

values of 38.80 mm in the year 2023 and 38.54 mm in the year 2024.

The present results are also supported by the findings of Dwivedi *et al.*, (2010) ^[6], who reported substantial variation in fruit breadth and other physical fruit characteristics among water chestnut germplasm. Their observations

confirm that fruit dimensions are important measurable attributes of *Trapa natans* var. *bispinosa*.

The results therefore suggest that wider spacing combined with efficient nutrient management, particularly $S_2 \times T_{12}$, was most favourable for improving fruit width.

Table 4: Average width of fruit (mm) recorded in water chestnut (*Trapa natans* var. *bispinosa* Roxb.) under different nutrient treatments and two plant spacings (S_1 and S_2) during the year 2023 and 2024

Treatments	2023			2024			
	S_1	S_2	Mean	S_1	S_2	Mean	Pooled
T ₁ -Control	38.80	39.56	39.18	38.54	39.28	38.91	39.05
T ₂ -Fertilizer Dose as applied by farmers	40.40	41.24	40.82	40.28	41.12	40.70	40.76
T ₃ -¼ FDF (Urea + DAP)	39.30	39.84	39.57	39.10	39.54	39.32	39.45
T ₄ -½ FDF (Urea + DAP)	39.96	40.62	40.29	39.78	40.38	40.08	40.19
T ₅ -Nano-Urea @ 4.0%	40.16	40.96	40.56	40.04	40.80	40.42	40.49
T ₆ -Jeevamrut @ 10%	40.60	41.36	40.98	40.46	41.22	40.84	40.91
T ₇ -RDF	40.92	42.18	41.55	40.82	42.18	41.50	41.53
T ₈ -Nano silver @ 25 ppm	39.66	40.18	39.92	39.44	39.98	39.71	39.82
T ₉ -Nano zinc @ 50 ppm	40.86	42.04	41.45	40.76	42.12	41.44	41.45
T ₁₀ -Nano zinc fortified Jeevamrut	41.76	42.67	42.22	41.66	42.54	42.10	42.16
T ₁₁ -Nano silver fortified Jeevamrut	40.76	41.48	41.12	40.64	41.54	41.09	41.11
T ₁₂ -Nano zinc fortified FYM	42.16	42.68	42.42	42.14	42.74	42.44	42.43
T ₁₃ -Nano silver fortified FYM	40.84	41.68	41.26	40.70	41.76	41.23	41.25
Mean	40.48	41.27	-	40.34	41.17	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.002	0.001		0.010	0.003		
Factor(B)	0.006	0.002		0.024	0.009		
(A X B)	0.008	0.003		0.035	0.012		

3.4 Average weight of fruit (g)

The data presented in Table 5 revealed that average fruit weight was significantly influenced by plant spacing and nutrient management treatments during both years of experimentation. The interaction between spacing and nutrient management was significant during the year 2023, whereas it was non-significant during the year 2024.

Plant spacing significantly affected average fruit weight during both years. Wider spacing (S_2) produced significantly heavier fruits, with an average weight of 22.08 g in the year 2023 and 22.05 g in the year 2024, compared with 20.80 g and 20.77 g, respectively, under closer spacing (S_1). The greater fruit weight under wider spacing may be associated with reduced competition among plants and improved availability of assimilates for fruit growth and filling.

The importance of fruit weight as a major physical yield component in water chestnut has also been demonstrated by Dwivedi *et al.*, (2010) ^[6], who reported substantial variation in fruit weight among water chestnut genotypes under central Uttar Pradesh conditions.

Nutrient management treatments significantly influenced fruit weight during both years. In the year 2023, T_{12} recorded the maximum average fruit weight (24.00 g), followed by T_{10} (23.34 g) and T_7 (22.84 g), whereas the minimum value (16.67 g) was observed under T_1 .

During the year 2024, T_{12} again recorded the highest average fruit weight (23.84 g), followed by T_{10} (23.34 g) and T_7 (22.67 g). The minimum fruit weight (16.34 g) was recorded under T_1 . The superior performance of T_{12} may be

attributed to the combined contribution of FYM and zinc, which provided a more favourable nutrient environment for fruit growth.

Puste *et al.*, (2005) ^[14] reported that integrated nutrient management involving organic and inorganic nutrient sources significantly improved the production of water chestnut. Their findings support the importance of balanced nutrient supply for improving productivity in aquatic food crops.

The interaction effect was significant during the year 2023 but non-significant during the year 2024. In the year 2023, the maximum fruit weight (24.33 g) was recorded under $S_2 \times T_{12}$, followed by $S_2 \times T_{10}$ (23.67 g), while the minimum value (16.00 g) occurred under $S_1 \times T_1$. During the year 2024, although numerical differences were observed among treatment combinations, the interaction was statistically non-significant; therefore, these differences should not be interpreted as statistically superior treatment combinations.

The overall response nevertheless showed that wider spacing and improved nutrient management were associated with greater fruit weight. Palm *et al.*, (2024) ^[13] also emphasized that fruit size and reproductive performance vary substantially in *Trapa*, and larger-fruited types can contribute substantially to productivity.

Hence, wider spacing (S_2) and nutrient treatment T_{12} were individually favourable for increasing fruit weight, while their interaction was statistically important only during the year 2023.

Table 5: Average weight of fruit (g) recorded in water chestnut (*Trapa natans* var. *bispinosa* Roxb.) under different nutrient treatments and two plant spacings (S₁ and S₂) during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	16.00	17.33	16.67	15.67	17.00	16.34	16.51
T ₂ -Fertilizer Dose as applied by farmers	20.67	22.00	21.34	21.00	22.33	21.67	21.51
T ₃ -¼ FDF (Urea + DAP)	17.67	20.00	18.84	17.33	20.00	18.67	18.76
T ₄ -½ FDF (Urea + DAP)	20.00	21.67	20.84	20.33	22.00	21.17	21.01
T ₅ -Nano-Urea @ 4.0%	21.00	22.67	21.84	20.67	22.00	21.34	21.59
T ₆ -Jeevamrut @ 10%	22.00	22.67	22.34	21.33	22.33	21.83	22.09
T ₇ -RDF	22.67	23.00	22.84	22.33	23.00	22.67	22.76
T ₈ -Nano silver @ 25 ppm	19.00	21.00	20.00	19.00	21.67	20.34	20.17
T ₉ -Nano zinc @ 50 ppm	21.67	22.67	22.17	22.00	23.00	22.50	22.34
T ₁₀ -Nano zinc fortified Jeevamrut	23.00	23.67	23.34	23.00	23.67	23.34	23.34
T ₁₁ -Nano silver fortified Jeevamrut	21.00	23.33	22.17	21.67	22.67	22.17	22.17
T ₁₂ -Nano zinc fortified FYM	23.67	24.33	24.00	23.67	24.00	23.84	23.92
T ₁₃ -Nano silver fortified FYM	22.00	22.67	22.34	22.00	23.00	22.50	22.42
Mean	20.80	22.08	-	20.77	22.05	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.194	0.068		0.394	0.138		
Factor(B)	0.493	0.173		1.005	0.353		
(A X B)	0.698	0.245		N/A	0.499		

3.5 Average volume of fruit (ml)

The data presented in Table 6 indicated that average fruit volume was significantly influenced by plant spacing and nutrient management treatments during both years of experimentation. The interaction between spacing and nutrient management treatments was also significant during both years, indicating that the response of fruit volume to nutrient management varied with plant spacing.

Plant spacing significantly influenced average fruit volume during both years. Wider spacing (S₂) recorded a significantly higher average fruit volume of 19.16 ml in the year 2023 and 18.84 ml in the year 2024, compared with 17.96 ml and 17.75 ml, respectively, under closer spacing (S₁). The greater fruit volume under wider spacing may be related to reduced competition among plants and greater availability of assimilates for fruit enlargement.

The importance of fruit volume as a physical quality attribute of water chestnut has been reported by Dwivedi *et al.*, (2010) [6], who observed considerable variation in fruit volume among water chestnut germplasm under central Uttar Pradesh conditions.

Nutrient management treatments significantly influenced average fruit volume during both years. During the year 2023, the maximum fruit volume (20.95 ml) was recorded under T₁₂ (Nano zinc fortified FYM), followed by T₁₀ (20.45 ml), T₇ (20.10 ml) and T₉ (19.55 ml). The minimum fruit volume (14.00 ml) was recorded under T₁ (Control).

During the year 2024, T₁₂ again recorded the maximum fruit volume (20.80 ml), followed by T₁₀ (19.90 ml), T₇ (19.20 ml) and T₉ (19.10 ml), whereas the minimum value (14.43 ml) was recorded under T₁.

The higher fruit volume under T₁₂ and T₁₀ may be attributed to improved nutrient availability and enhanced physiological activity during fruit development. Organic nutrient sources can contribute to improved nutrient availability and soil fertility, while micronutrients such as zinc are important for enzyme activity, growth regulation and reproductive development. Puste *et al.*, (2005) [14] demonstrated that integrated organic and inorganic nutrient management significantly influenced water chestnut productivity and associated quality characteristics.

The interaction between spacing and nutrient management treatments was significant during both years. In the year 2023, the highest fruit volume (21.20 ml) was recorded under S₂ × T₁₂, followed by S₂ × T₁₀ (20.80 ml), whereas the lowest value (13.50 ml) was recorded under S₁ × T₁. During the year 2024, S₂ × T₁₂ again recorded the maximum fruit volume (21.00 ml), followed by S₂ × T₁₀ (19.80 ml), while the minimum value (12.67 ml) was recorded under S₁ × T₁.

The consistent superiority of S₂ × T₁₂ indicates that wider spacing combined with nano-zinc-fortified FYM provided a favourable environment for fruit enlargement. This response is consistent with the broader evidence that fruit size and physical characteristics of *Trapa* vary with growing conditions and genotype. Palm *et al.*, (2024) [13] documented substantial variation in fruit dimensions and fresh fruit weight across *Trapa* populations, while Dwivedi *et al.*, (2010) [6] reported marked variation in fruit volume among *T. natans* var. *bispinosa* germplasm.

Thus, wider spacing (S₂), particularly in combination with T₁₂, was most favourable for increasing fruit volume under the conditions of the present investigation.

Table 6: Average volume of fruit (ml) recorded in water chestnut (*Trapa natans* var. *bispinosa* Roxb.) under different nutrient treatments and two plant spacings (S₁ and S₂) during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	13.50	14.50	14.00	12.67	16.20	14.43	14.22
T ₂ -Fertilizer Dose as applied by farmers	18.10	19.70	18.90	18.13	19.03	18.58	18.74
T ₃ -¼ FDF (Urea + DAP)	14.90	17.20	16.05	14.40	17.87	16.13	16.09
T ₄ -½ FDF (Urea + DAP)	17.20	18.80	18.00	17.30	18.67	17.98	17.99
T ₅ -Nano-Urea @ 4.0%	17.80	19.00	18.40	17.50	18.77	18.13	18.27
T ₆ -Jeevamrut @ 10%	18.20	19.70	18.95	18.20	18.90	18.55	18.75
T ₇ -RDF	19.80	20.40	20.10	19.20	19.20	19.20	19.65
T ₈ -Nano silver @ 25 ppm	16.30	18.20	17.25	16.20	18.20	17.20	17.23
T ₉ -Nano zinc @ 50 ppm	19.10	20.00	19.55	19.00	19.20	19.10	19.33
T ₁₀ -Nano zinc fortified Jeevamrut	20.10	20.80	20.45	20.00	19.80	19.90	20.18
T ₁₁ -Nano silver fortified Jeevamrut	18.80	19.80	19.30	18.60	18.90	18.75	19.03
T ₁₂ -Nano zinc fortified FYM	20.70	21.20	20.95	20.60	21.00	20.80	20.88
T ₁₃ -Nano silver fortified FYM	19.00	19.80	19.40	18.90	19.20	19.05	19.23
Mean	17.96	19.16	-	17.75	18.84	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.002	0.001		0.101	0.035		
Factor(B)	0.006	0.002		0.258	0.090		
(A X B)	0.009	0.003		0.364	0.128		

4. Conclusion

The results of the present investigation demonstrated that plant spacing and nutrient management played important roles in improving the fruit characteristics of water chestnut (*Trapa natans* var. *bispinosa* Roxb.). Across the evaluated fruit parameters, wider spacing (S₂) generally resulted in superior fruit development compared with closer spacing (S₁), as reflected by higher number of fruits per rosette, fruit length, fruit width, fruit weight and fruit volume. Among the nutrient management treatments, nano zinc fortified FYM (T₁₂) and nano zinc fortified Jeevamrut (T₁₀) consistently performed better than the control and other nutrient regimes, particularly for fruit size, weight and volume. The control treatment (T₁) generally recorded the lowest values for the studied fruit attributes, indicating the beneficial effect of adequate and balanced nutrient availability on reproductive growth and fruit development. The interaction of spacing and nutrient management further indicated that wider spacing combined with improved nutrient regimes, particularly S₂ × T₁₂ and S₂ × T₁₀, provided favourable conditions for enhanced fruit development. Overall, the findings suggest that wider plant spacing in combination with nano zinc-enriched organic nutrient sources can be considered a promising management strategy for improving the quality-related fruit attributes of water chestnut under the conditions of the present study.

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