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Interactive effects of plant spacing and nutritional management on physicochemical quality attributes of water chestnut (*Trapa natans* var. *bispinosa* roxb.)

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Abstract

The present investigation was conducted during the Kharif seasons of the year 2023 and 2024 at the Horticulture Research Farm No. 1, Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, to study the effects of plant spacing and nutritional management on the physicochemical quality of water chestnut. The experiment was conducted in a factorial Randomized Block Design with two plant spacings, S₁ (1 m × 1 m) and S₂ (2 m × 1 m), and thirteen nutritional regimes, with three replications. Fruit quality was evaluated through total soluble solids (TSS), fruit pH, reducing sugars, non-reducing sugars and total sugars. Wider spacing (S₂) recorded higher values for all the quality parameters than closer spacing (S₁) in both years. Among the nutritional treatments, nano zinc fortified FYM (T₁₂) gave the best results, followed by nano zinc fortified Jeevamrut (T₁₀), while the control showed the lowest values. The interaction between spacing and nutrition was significant for the studied quality parameters. The combination S₂ × T₁₂ consistently produced better fruit quality in both years. Therefore, wider spacing combined with nano zinc fortified FYM can be considered suitable for improving the quality of water chestnut under Lucknow conditions.

Keywords: Water chestnut, plant spacing, nutritional regimes, nano zinc, and fortified FYM.

Introduction

Water chestnut (*Trapa natans* var. *bispinosa* Roxb.) is an edible aquatic angiosperm locally called as "Singhara". This is a significant aquatic warm season crop. This submerged rooted plant is commonly found on the water surface of lakes, tanks, and pools in India, particularly in Punjab, Bihar, Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, and some parts of Uttarakhand (Puste, 2004; Takano and Kadono, 2005) [12, 15]. In India, the water chestnut species *Trapa bispinosa* and *Trapa quadrispinosa* are frequently farmed. For commercial cultivation soil should be heavy, muddy and rich in organic matter. Organic manures in form of oil cakes, poultry manure and compost/FYM @ 8 t/ha are recommended development of for water growth chestnut and crop (Choudhary *et al.*, 2003). Significant amount of phosphorus and potassium is needed for optimum growth of the crop. In West Bengal, application of 30-40 kg urea/ha during transplantation and another 20 kg/ha is recommended after 25-30 days of transplanting (Jana, 2016a) [7]. Soil rich in Zn and B result in increased number of fruits and fruit weight. For newly cultivated field, the fertilizer dose can be modified from NPK @ 60:20:20 kg/ha to NPK @ 60:40:30 kg/ha and planting distance should be maintained at 1m x 2m to give an optimum plant population of 4500 5000 plants/ha (Jana *et al.*, 2019) [7]. Chemical fertilizers like Urea and Diammonium phosphate are applied at three times the recommended doses. To overcome this the farmers, treat the fruit with a bleaching agent to improve its appearance so that the market acceptability is high. It is hypothesized that varying doses of chemical fertilizers, Nano urea, and Jeevamrut could improve the performance of the crop without affecting its overall yield (Meena *et al.*, 2023) [8]. The floating leaves are arranged in a rosette and are broadly rhomboid, triangular, deltoid or ovate in shape (Hummel and Kiviat, 2004) [4]. The leaves are sharply serrated with distinct venation and short hairs. Submerged leaves are alternate, finely divided and may reach up to 15 cm in length (Bitonti *et al.*, 1996; Mehrhoff *et al.*, 2003) [1, 9]. The petioles possess a spongy structure that aids flotation. The plant bears white flowers with four petals and four sepals. Fruits are single-seeded horned

nut-like structures that develop underwater and attain a width of approximately 3 cm (Mehrhoth *et al.*, 2003) ^[9]. The stem is flexible, measuring 1–5 m in length, and remains anchored in the sediment through roots arising from the propagating seed hull. Traditionally, water chestnut is consumed after boiling. It is used for the preparation of sweets and chapatti, while sun drying and oven drying are common preservation methods. Being low in calories and rich in nutrients, it has gained importance as a healthy food. The nut is gluten-free, cholesterol-free and rich in potassium, magnesium and dietary fibre. (Hummel and Kiviat, 2004) ^[4]. Water chestnut is a valued commodity in the culinary business due to its distinct flavour (Parker and Waldron, 1995) ^[11].

Materials and Methods

Experimental site

Experiment was conducted during the Kharif seasons of the year 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 is geographically located at 26.769559° N latitude and 80.927135° E longitude, with an elevation of approximately 121 m above mean sea level.

Experimental design and treatments

The experiment was conducted in a Factorial Randomized Block

Design comprising two experimental factors and three replications. Factor A represented plant spacing, consisting of two levels: S₁ = 1.0 m × 1.0 m and S₂ = 2.0 m × 1.0 m. Factor B comprised thirteen nutritional regimes (T₁–T₁₃) involving conventional fertilizers, reduced fertilizer doses, recommended fertilizer application, nano-fertilizers and organic nutrient sources. The factorial combination of two spacing levels with thirteen nutritional regimes resulted in 26 treatment combinations (2 × 13). Each treatment combination was replicated three times, giving a total of 78 experimental units. The treatments were randomly allocated within each replication to minimize experimental variation and provide unbiased estimates of treatment effects. The factorial arrangement allowed assessment of the individual effects of spacing and nutritional regimes and their interaction (S × T) on the performance of water chestnut.

Nutritional treatments

Thirteen nutritional regimes were evaluated in the experiment. The treatments consisted of a control, farmer's fertilizer practice, reduced fertilizer doses, recommended dose of fertilizer, nano-fertilizers, Jeevamrut and nano-fertilizer-enriched organic nutrient sources. Details of fertilizers doses and their application are presented in Table 2.1.

Table 1: Details of fertilizers doses and their application

Treatment	Nutritional regimes	Quantity applied
T ₁	Control	No fertilizer application
T ₂	Fertilizer Dose as applied by farmers (120:60:60) kg/ha.	Urea 42 g. + DAP 26.1 g. MOP 20 g.
T ₃	¼ FDF (Urea + DAP)	Urea 10.5 g. + DAP 6.5 g.
T ₄	½ FDF (Urea + DAP)	Urea 21g. + DAP 13 g.
T ₅	Nano-Urea @ 4.0 %	1.5 ml Nano-Urea
T ₆	Jeevamrut @ 10%	1.5 ml Jeevamrut
T ₇	RDF	Urea 19.3 g. + DAP 17.4 g. + MOP 10. g.
T ₈	Nano silver @ 25 ppm	25 mg foliar spray
T ₉	Nano zinc @ 50 ppm	50 mg foliar spray
T ₁₀	Nano zinc fortified Jeevamrut	Jeevamrut (10%) + Nano zinc 50 mg
T ₁₁	Nano silver fortified Jeevamrut	Jeevamrut (10%) + Nano silver 25 mg
T ₁₂	Nano zinc fortified FYM	FYM 1.6 kg + Nano zinc 50 mg
T ₁₃	Nano silver fortified FYM	FYM 1.6 kg + Nano silver 25 mg

Treatment combinations and field layout

Each nutritional regime was combined with both spacing levels to generate 26 factorial treatment combinations, viz., S₁T₁ to S₁T₁₃ and S₂T₁ to S₂T₁₃. Under S₁, plants were maintained at a spacing of 1.0 m × 1.0 m, whereas under S₂, a spacing of 2.0 m × 1.0 m was maintained. The experimental units consisted of individual ponds of 2.0 m × 1.0 m dimensions. A border space of approximately 0.5 m was maintained wherever required to minimize interference between 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. Except for the prescribed nutritional treatments, other recommended cultural practices were maintained uniformly across all experimental units.

Results and Discussion

The results pertaining to the physicochemical quality attributes of water chestnut revealed that both plant spacing and nutritional management had a significant influence on fruit quality during the two years of experimentation. The quality attributes, namely total soluble solids, fruit pH, reducing sugars, non-reducing sugars and

total sugars, exhibited considerable variation in response to different plant spacings and nutritional regimes. The observed variations indicated that the spatial arrangement of plants and nutrient supply played an important role in modulating the physicochemical composition and quality characteristics of water chestnut fruits. The individual and interactive effects of plant spacing and nutritional management on the respective quality attributes are presented and discussed in the following sections.

Total soluble solids

The data presented in Table 3.1 revealed that total soluble solids (TSS) of water chestnut fruits were significantly influenced by plant spacing and nutritional regimes during the year 2023 and 2024. The interaction between plant spacing and nutritional regimes also exerted a significant effect on TSS during both years. The variation in TSS observed among the treatments indicated that both spatial availability and nutrient supply played an important role in determining the soluble solids content of water chestnut fruits. Plant spacing significantly influenced the TSS of water chestnut fruits during both years. During the year 2023, significantly higher TSS was recorded under wider spacing S₂ (2

m × 1 m), with a value of 6.16 °Brix, compared with 5.57 °Brix under closer spacing S₁ (1 m × 1 m). Similarly, during the year 2024, S₂ recorded higher TSS (6.32 °Brix) than S₁ (6.00 °Brix). The higher TSS under wider spacing may be attributed to better availability of growth resources and reduced competition among plants, which could have favoured assimilate accumulation in developing fruits. The present findings are in agreement with the observations of Dwivedi *et al.*, (2011) ^[3], who reported considerable variation in TSS among water chestnut genotypes, ranging from 4.33 to 10.55 °Brix, indicating substantial variation in this important fruit-quality trait in *Trapa natans* var. *bispinosa*. Nutritional regimes significantly affected TSS during both years. During the year 2023, the highest TSS was recorded with T₁₂ (Nano zinc fortified FYM) at 7.61 °Brix, followed by T₁₀ (Nano zinc fortified Jeevamrut) at 7.26 °Brix, whereas the lowest value was recorded under T₁ (Control) at 4.62 °Brix. During the year 2024, the highest TSS was again recorded under T₁₂, with 7.87 °Brix, followed by T₁₀ with 7.11 °Brix, while the lowest TSS was observed under T₁ (5.09 °Brix). The superior performance of T₁₂ may be associated with the combined contribution of FYM and nano zinc. Organic manure can provide nutrients progressively and improve the nutrient-supplying environment, whereas zinc is involved in several physiological and enzymatic processes associated with plant growth and metabolism. Consequently, improved nutrient availability may have enhanced photosynthetic productivity and the subsequent accumulation of soluble constituents in the fruit. The beneficial influence of balanced nutrient management on production and quality of water chestnut

has also been reported by Puste *et al.*, (2005) ^[12], who demonstrated that integrated organic and inorganic nutrient management significantly influenced production and nutritional quality of aquatic food crops, including water chestnut. The interaction between plant spacing and nutritional regimes was significant during both years. During the year 2023, the maximum TSS was recorded with the combination S₂ × T₁₂ (2 m × 1 m + Nano zinc fortified FYM), registering 8.31 °Brix, followed by S₂ × T₁₀, which recorded 7.72 °Brix. The minimum value was recorded under S₁ × T₁, with 4.30 °Brix. A similar trend was observed during the year 2024. The highest TSS was again recorded under S₂ × T₁₂, with 8.02 °Brix, followed by S₂ × T₁₀ with 7.27 °Brix, whereas the lowest value was observed under S₁ × T₁, with 4.94 °Brix. The consistently superior performance of the S₂ × T₁₂ combination suggests that wider spacing combined with nano zinc fortified FYM provided a favourable environment for nutrient utilization and accumulation of soluble solids in the fruits. The occurrence of considerable variation in TSS among water chestnut genotypes has previously been documented by Dwivedi *et al.*, (2011) ^[3], while the direct assessment of °Brix as an important physicochemical quality parameter of *Trapa natans* fruits has also been reported by Rehman *et al.*, (2024) ^[13]. Overall, the results indicated that wider spacing (S₂) and T₁₂ (Nano zinc fortified FYM) were most effective in improving TSS of water chestnut fruits. Among the interaction combinations, S₂ × T₁₂ consistently recorded the highest TSS during both years, indicating the potential of this combination for improving fruit quality.

Table 2: TSS recorded in water under different nutrient treatments and two plant spacings during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	4.30	4.94	4.62	4.94	5.24	5.09	4.86
T ₂ -Fertilizer Dose as applied by farmers	5.15	5.59	5.37	5.59	5.94	5.77	5.57
T ₃ -¼ FDF (Urea + DAP)	4.90	5.29	5.10	5.29	5.64	5.47	5.29
T ₄ -½ FDF (Urea + DAP)	5.13	5.39	5.26	5.39	5.86	5.63	5.45
T ₅ -Nano-Urea @ 4.0 %	5.30	5.85	5.58	5.85	6.12	5.99	5.79
T ₆ -Jeevamrut @ 10%	5.39	5.89	5.64	5.89	6.19	6.04	5.84
T ₇ -RDF	5.62	6.01	5.82	6.01	6.34	6.18	6.00
T ₈ -Nano silver @ 25 ppm	5.20	5.73	5.47	5.73	5.96	5.85	5.66
T ₉ -Nano zinc @ 50 ppm	6.12	6.95	6.54	6.31	6.65	6.48	6.51
T ₁₀ -Nano zinc fortified Jeevamrut	6.79	7.72	7.26	6.95	7.27	7.11	7.19
T ₁₁ -Nano silver fortified Jeevamrut	5.73	6.12	5.93	6.12	6.44	6.28	6.11
T ₁₂ -Nano zinc fortified FYM	6.90	8.31	7.61	7.72	8.02	7.87	7.74
T ₁₃ -Nano silver fortified FYM	5.86	6.23	6.05	6.23	6.54	6.39	6.22
Mean	5.57	6.16	-	6.00	6.32	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.024	0.009		0.013	0.004		
Factor(B)	0.062	0.022		0.032	0.011		
(A X B)	0.088	0.031		0.045	0.016		

pH of the fruit

The data presented in Table 3.2 revealed that fruit pH of water chestnut was significantly influenced by plant spacing, nutritional regimes and their interaction during the year 2023 and 2024. The observed differences in fruit pH among nutritional treatments indicate that nutrient management can influence the physicochemical characteristics of developing fruits. Fruit pH is an important quality-related physicochemical parameter and has been directly evaluated in *Trapa natans* fruits in recent research. Rehman *et al.*, (2024) ^[13] specifically investigated pH and °Brix among water chestnut fruit types, confirming their relevance as physicochemical quality attributes. Plant spacing significantly influenced fruit pH during both years. During the year 2023, the wider spacing S₂ (2 m × 1 m) recorded a higher fruit pH of 5.54,

compared with 5.43 under S₁ (1 m × 1 m). Similarly, during the year 2024, S₂ recorded a higher mean fruit pH of 5.51, compared with 5.42 under S₁. Nutritional regimes significantly influenced fruit pH during both years. During the year 2023, the highest fruit pH was recorded under T₁₂ (Nano zinc fortified FYM) at 5.86, followed by T₁₀ (Nano zinc fortified Jeevamrut) at 5.80. The lowest fruit pH was observed under T₁ (Control) at 5.14. During the year 2024, the same trend was observed. The highest fruit pH was recorded under T₁₂, with a value of 5.82, followed by T₁₀, with 5.76, whereas the lowest value was recorded under T₁ (5.13). The relatively higher pH under T₁₂ and T₁₀ may be associated with improved nutrient availability and balanced metabolic activity during fruit development. The contribution of organic and inorganic nutrient sources towards improved production and

quality characteristics in water chestnut has been documented by Puste *et al.*, (2005)^[12]. The present results are also relevant to the findings of Rehman *et al.*, (2024)^[13], who demonstrated varietal differences in physicochemical properties, including pH and °Brix, of water chestnut fruits. Their study confirms that pH can vary among water chestnut materials and therefore represents a useful physicochemical quality parameter.

The interaction between plant spacing and nutritional regimes significantly influenced fruit pH during both years. During the year 2023, the highest fruit pH was recorded under $S_2 \times T_{12}$, with a value of 5.92, followed by $S_2 \times T_{10}$, which recorded 5.88. The lowest value was recorded under $S_1 \times T_1$, with 5.13. During the year 2024, $S_2 \times T_{12}$ again recorded the highest fruit pH (5.90), followed by $S_2 \times T_{10}$ (5.84), whereas the lowest value was observed under $S_1 \times T_1$, with 5.12. Although S_2 generally

produced higher fruit pH than S_1 , slight reversals were observed in 2024 under T_2 , T_3 and T_4 . Therefore, the response should not be described as uniformly higher under S_2 for every nutritional treatment. The consistently superior performance of $S_2 \times T_{12}$, however, indicates that the combination of wider spacing with nano zinc fortified FYM was particularly effective in enhancing fruit pH under the conditions of the present investigation.

Overall, the results indicated that fruit pH was significantly affected by plant spacing and nutritional regimes. Wider spacing (S_2) and T_{12} (Nano zinc fortified FYM) generally resulted in higher fruit pH, while the interaction $S_2 \times T_{12}$ produced the maximum value during both years. These findings suggest that appropriate integration of plant spacing and nutrient management can modify important physicochemical quality characteristics of water chestnut fruits.

Table 3: pH of the fruit recorded in water chestnut under different nutrient treatments and two plant spacings during 2023 and 2024

Treatments	2023			2024			
	S_1	S_2	Mean	S_1	S_2	Mean	Pooled
T_1 -Control	5.13	5.15	5.14	5.12	5.13	5.13	5.14
T_2 -Fertilizer Dose as applied by farmers	5.30	5.33	5.32	5.27	5.24	5.26	5.29
T_3 -¼ FDF (Urea + DAP)	5.22	5.26	5.24	5.21	5.19	5.20	5.22
T_4 -½ FDF (Urea + DAP)	5.27	5.32	5.30	5.25	5.23	5.24	5.27
T_5 -Nano-Urea @ 4.0 %	5.39	5.57	5.48	5.38	5.55	5.47	5.48
T_6 -Jeevamrut @ 10%	5.41	5.59	5.50	5.40	5.57	5.49	5.50
T_7 -RDF	5.47	5.60	5.54	5.48	5.58	5.53	5.54
T_8 -Nano silver @ 25 ppm	5.35	5.37	5.36	5.35	5.36	5.36	5.36
T_9 -Nano zinc @ 50 ppm	5.50	5.65	5.58	5.50	5.64	5.57	5.58
T_{10} -Nano zinc fortified Jeevamrut	5.71	5.88	5.80	5.67	5.84	5.76	5.78
T_{11} -Nano silver fortified Jeevamrut	5.54	5.67	5.61	5.54	5.65	5.60	5.61
T_{12} -Nano zinc fortified FYM	5.79	5.92	5.86	5.74	5.90	5.82	5.84
T_{13} -Nano silver fortified FYM	5.56	5.71	5.64	5.56	5.71	5.64	5.64
Mean	5.43	5.54	-	5.42	5.51	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.001	0.001		0.005	0.002		
Factor(B)	0.004	0.001		0.012	0.004		
(A X B)	0.005	0.002		0.017	0.006		

Reducing sugar (%)

The data presented in Table 3.3 revealed that reducing sugar content of water chestnut fruits was significantly influenced by plant spacing, nutrient management and their interaction during both years of experimentation. Plant spacing significantly affected reducing sugar content in both years. During 2023, S_2 (2 m × 1 m) recorded higher reducing sugar content (1.73%) than S_1 (1 m × 1 m) (1.60%). Similarly, in 2024, S_2 recorded 1.74% compared with 1.61% under S_1 . The higher value under wider spacing may be attributed to reduced plant competition and better availability of growth resources, favouring assimilate production and translocation towards developing fruits. Nutrient management significantly influenced reducing sugar content. In 2023, the highest value was recorded under T_{12} (Nano zinc fortified FYM) (2.14%), followed by T_{10} (Nano zinc fortified Jeevamrut) (2.00%), while T_1 (Control) recorded the lowest value (1.36%). A similar trend was observed in 2024, with T_{12} recording 2.15%, followed by T_{10} (2.01%), whereas T_1 recorded the minimum (1.37%). The superior response under T_{12} may be associated with improved nutrient availability and physiological activity resulting from the combined effect of FYM and nano zinc. The present findings are supported by Babu and Dwivedi, (2012)^[3], who reported reducing sugar values ranging from 1.30 to 2.06% among water chestnut cultivars. Singh *et al.*, reported

about 1.27% reducing sugar in fresh water chestnut kernel, confirming its importance as a biochemical quality attribute.

The interaction between plant spacing and nutrient management was significant in both years. The highest reducing sugar content was recorded under $S_2 \times T_{12}$, with 2.22% in 2023 and 2.23% in 2024, followed by $S_2 \times T_{10}$ with 2.08 and 2.09%, respectively. The lowest values were recorded under $S_1 \times T_1$, with 1.30% in 2023 and 1.31% in 2024. Wider spacing produced higher reducing sugar content than S_1 across all nutrient treatments, indicating a consistent advantage of S_2 for sugar accumulation. The consistently superior performance of $S_2 \times T_{12}$ may be attributed to the combined effect of wider spacing and improved nutrient availability, which favoured photosynthesis, assimilate translocation and sugar accumulation in developing fruits. The findings are also in accordance with Dwivedi *et al.*, (2011)^[3], who reported considerable variation in biochemical and physicochemical fruit attributes among *Trapa natans* var. *bispinosa* genotypes. Overall, wider spacing S_2 and T_{12} (Nano zinc fortified FYM) resulted in higher reducing sugar content, while $S_2 \times T_{12}$ recorded the maximum values in both years. Thus, their combined application appeared favourable for improving reducing sugar content and biochemical quality of water chestnut fruits.

Table 4: Reducing sugar (%) recorded in water chestnut under different nutrient treatments and two plant spacings during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	1.30	1.41	1.36	1.31	1.42	1.37	1.37
T ₂ -Fertilizer Dose as applied by farmers	1.48	1.58	1.53	1.49	1.59	1.54	1.54
T ₃ -¼ FDF (Urea + DAP)	1.37	1.51	1.44	1.38	1.52	1.45	1.45
T ₄ -½ FDF (Urea + DAP)	1.41	1.56	1.49	1.42	1.57	1.50	1.50
T ₅ -Nano-Urea @ 4.0 %	1.53	1.63	1.58	1.54	1.64	1.59	1.59
T ₆ -Jeevamrut @ 10%	1.56	1.71	1.64	1.57	1.72	1.65	1.65
T ₇ -RDF	1.57	1.73	1.65	1.58	1.74	1.66	1.66
T ₈ -Nano silver @ 25 ppm	1.48	1.63	1.56	1.49	1.64	1.57	1.57
T ₉ -Nano zinc @ 50 ppm	1.75	1.86	1.81	1.75	1.87	1.81	1.81
T ₁₀ -Nano zinc fortified Jeevamrut	1.92	2.08	2.00	1.93	2.09	2.01	2.01
T ₁₁ -Nano silver fortified Jeevamrut	1.62	1.75	1.69	1.63	1.76	1.70	1.70
T ₁₂ -Nano zinc fortified FYM	2.05	2.22	2.14	2.06	2.23	2.15	2.15
T ₁₃ -Nano silver fortified FYM	1.71	1.82	1.77	1.72	1.83	1.78	1.78
Mean	1.60	1.73	-	1.61	1.74	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.007	0.002		0.007	0.002		
Factor(B)	0.018	0.006		0.017	0.006		
(A X B)	0.025	0.009		0.024	0.008		

Non-reducing sugar (%)
The data presented in Table 3.4 revealed that non-reducing sugar content in water chestnut fruits was significantly influenced by plant spacing, nutrient management and their interaction during both year 2023 and 2024. Plant spacing significantly affected non-reducing sugar, with S₂ (2.94%) recording higher values than S₁ (2.91%) in 2023, while the corresponding values in 2024 were 2.95 and 2.92%, respectively. The higher value under S₂ may be associated with comparatively better availability of growth resources and reduced plant competition. Nutrient management significantly influenced non-reducing sugar content. Among the treatments, T₁₂ (Nano zinc fortified FYM) recorded the maximum value of 3.70% in 2023 and 3.71% in 2024, followed by T₁₀ (Nano zinc fortified Jeevamrut) with 3.56 and 3.57%, respectively, whereas the minimum was recorded under T₁ (Control), with 2.24 and 2.25%. The higher non-reducing sugar under T₁₂ may be attributed to the combined effect of FYM and nano zinc in improving nutrient availability and carbohydrate metabolism. Similar variation in non-reducing sugar among water chestnut genotypes was reported by Babu and Dwivedi, (2012) ^[3], who recorded values up to 2.73%. Singh *et al.*, (2010) ^[14] also reported substantial non-reducing sugar content in fresh water chestnut kernel. The interaction between plant spacing and nutrient management was significant in both years. The highest non-reducing sugar was recorded with S₂ × T₁₂ (3.74% in 2023 and 3.75% in 2024), followed by S₂ × T₁₀ (3.59 and 3.60%), while the lowest value was observed under S₁ × T₁ (2.24% in both years). Although S₂ generally recorded higher values, the response varied with nutrient treatment, as equal or slightly lower values under S₂ were observed in T₁, T₄, T₇ and T₉. Overall, wider spacing combined with nano zinc fortified FYM (S₂ × T₁₂) was most favourable for enhancing non-reducing sugar content in water chestnut fruits.

Table 5: Non-reducing sugar (%) recorded in water chestnut under different nutrient treatments and two plant spacings during the year 2023 and 2024

Treatments	2023			2024			
	S ₁	S ₂	Mean	S ₁	S ₂	Mean	Pooled
T ₁ -Control	2.24	2.24	2.24	2.24	2.25	2.25	2.25
T ₂ -Fertilizer Dose as applied by farmers	2.69	2.71	2.70	2.70	2.72	2.71	2.71
T ₃ -¼ FDF (Urea + DAP)	2.58	2.67	2.63	2.59	2.68	2.64	2.64
T ₄ -½ FDF (Urea + DAP)	2.69	2.69	2.69	2.70	2.70	2.70	2.70
T ₅ -Nano-Urea @ 4.0 %	2.73	2.77	2.75	2.74	2.78	2.76	2.76
T ₆ -Jeevamrut @ 10%	2.75	2.77	2.76	2.76	2.78	2.77	2.77
T ₇ -RDF	2.81	2.79	2.80	2.82	2.80	2.81	2.81
T ₈ -Nano silver @ 25 ppm	2.71	2.75	2.73	2.72	2.76	2.74	2.74
T ₉ -Nano zinc @ 50 ppm	3.46	3.44	3.45	3.47	3.45	3.46	3.46
T ₁₀ -Nano zinc fortified Jeevamrut	3.52	3.59	3.56	3.53	3.60	3.57	3.57
T ₁₁ -Nano silver fortified Jeevamrut	2.93	2.95	2.94	2.94	2.96	2.95	2.95
T ₁₂ -Nano zinc fortified FYM	3.66	3.74	3.70	3.67	3.75	3.71	3.71
T ₁₃ -Nano silver fortified FYM	3.06	3.10	3.08	3.07	3.11	3.09	3.09
Mean	2.91	2.94	-	2.92	2.95	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.004	0.002		0.003	0.001		
Factor(B)	0.011	0.004		0.009	0.003		
(A X B)	0.016	0.005		0.013	0.004		

Total sugars (%)
The data presented in Table 3.5 revealed that total sugars content of water chestnut fruits was significantly influenced by plant spacing and nutritional regimes during the year 2023 and 2024. The interaction between plant spacing and nutritional regimes also exerted a significant effect on total sugars content during both

years. The variation in total sugars content observed among the treatments indicated that spatial arrangement and nutritional management influenced sugar accumulation in developing water chestnut fruits. Plant spacing significantly influenced the total sugars content of water chestnut fruits during both years. During the year 2023, significantly higher total sugars content was recorded under wider spacing S_2 (2 m $\times$ 1 m), with a value of 4.67%, compared with 4.51% under closer spacing S_1 (1 m $\times$ 1 m). Similarly, during the year 2024, S_2 recorded higher total sugar content (4.69%) than S_1 (4.52%). The higher total sugars content under wider spacing may be associated with reduced competition among plants for available resources, which could have favoured assimilate production and its subsequent accumulation in developing fruits. Variability in biochemical attributes of water chestnut, including sugar content, has previously been reported among different collections of *Trapa natans* var. *bispinosa* by Babu and Dwivedi, (2012) [3]. The considerable variability in biochemical characteristics of water chestnut has also been recognized in subsequent literature. Nutritional regimes significantly affected total sugar content during both years. During the year 2023, the highest total sugar content was recorded with T_{12} (Nano zinc fortified FYM) at 5.84%, followed by T_{10} (Nano zinc fortified Jeevamrut) at 5.55%, whereas the minimum value was recorded under T_1 (Control) at 3.59%. A similar trend was observed during the year 2024, where T_{12} again recorded the highest total sugar content (5.86%), followed by T_{10} (5.57%), while the minimum value (3.61%) was observed under T_1 (Control). The comparatively higher total sugar content under T_{12} may be associated with the improved nutrient-supplying environment resulting from the combination of FYM and nano zinc. Organic manure can contribute to the gradual supply of nutrients and improvement of the growing environment, while zinc is an essential micronutrient involved in several physiological and enzymatic functions of plants. Such improved nutritional conditions may favour photosynthetic assimilate production and carbohydrate accumulation in developing fruits.

The observed values are within the range of total sugar concentrations reported for water chestnut in earlier studies. Singh *et al.*, (2010) [14] reported 5.63 $\pm$ 0.04% total sugars in fresh water chestnut kernel, while Babu and Dwivedi, (2012) [3] reported variation in total sugar content among water chestnut collections from the Lucknow region. The interaction between plant spacing and nutritional regimes was significant during both years. During the year 2023, the highest total sugar content was recorded with $S_2 \times T_{12}$ (2 m $\times$ 1 m + Nano zinc fortified FYM), registering 5.96%, followed by $S_2 \times T_{10}$, which recorded 5.67%, whereas the minimum value was recorded under $S_1 \times T_1$ (Control), with 3.54%. A similar trend was observed during the year 2024. The highest total sugar content was again recorded under $S_2 \times T_{12}$, with 5.98%, followed by $S_2 \times T_{10}$ with 5.69%, whereas the minimum value was observed under $S_1 \times T_1$, with 3.55%. The consistently higher total sugar content under $S_2 \times T_{12}$ may indicate that wider spacing, when combined with nano zinc fortified FYM, provided a favourable nutritional and spatial environment for assimilate accumulation and sugar formation in developing fruits. The present findings are comparable with previously reported sugar concentrations in water chestnut. Singh *et al.*, (2010) [14] recorded 5.63% total sugars in fresh water chestnut kernel, while the recent *International Biological Flora: Trapa natans* review summarized reported wet-basis sugar concentrations of approximately 4.80–5.63%, highlighting the variability of this quality attribute in the crop. Overall, the results indicated that wider spacing S_2 (2 m $\times$ 1 m) was superior to S_1 for total sugar accumulation, while T_{12} (Nano zinc fortified FYM) recorded the highest total sugar content among the nutritional regimes. Among the interaction combinations, $S_2 \times T_{12}$ consistently recorded the highest total sugar content during both years, followed by $S_2 \times T_{10}$, whereas $S_1 \times T_1$ recorded the minimum value. Thus, the combination of wider spacing with nano zinc fortified FYM showed considerable potential for improving the biochemical quality of water chestnut fruits.

Table 6: Total sugars (%) recorded in water chestnut under different nutrient treatments and two plant spacings during the year 2023 and 2024

Treatments	2023			2024			
	S_1	S_2	Mean	S_1	S_2	Mean	Pooled
T_1 -Control	3.54	3.65	3.59	3.55	3.67	3.61	3.60
T_2 -Fertilizer Dose as applied by farmers	4.17	4.29	4.23	4.19	4.31	4.25	4.24
T_3 - $\frac{1}{4}$ FDF (Urea + DAP)	3.96	4.18	4.07	3.96	4.20	4.08	4.08
T_4 - $\frac{1}{2}$ FDF (Urea + DAP)	4.10	4.25	4.18	4.12	4.27	4.19	4.19
T_5 -Nano-Urea @ 4.0 %	4.25	4.40	4.33	4.27	4.42	4.35	4.34
T_6 -Jeevamrut @ 10%	4.31	4.48	4.39	4.33	4.50	4.41	4.40
T_7 -RDF	4.38	4.52	4.45	4.40	4.54	4.47	4.46
T_8 -Nano silver @ 25 ppm	4.19	4.38	4.29	4.21	4.40	4.31	4.30
T_9 -Nano zinc @ 50 ppm	5.21	5.30	5.26	5.22	5.32	5.27	5.27
T_{10} -Nano zinc fortified Jeevamrut	5.43	5.67	5.55	5.45	5.69	5.57	5.56
T_{11} -Nano silver fortified Jeevamrut	4.55	4.70	4.63	4.57	4.72	4.65	4.64
T_{12} -Nano zinc fortified FYM	5.71	5.96	5.84	5.73	5.98	5.86	5.85
T_{13} -Nano silver fortified FYM	4.77	4.92	4.84	4.79	4.94	4.86	4.85
Mean	4.51	4.67	-	4.52	4.69	-	-
Factors	C.D.	SE(m)		C.D.	SE(m)		
Factor(A)	0.010	0.003		0.009		0.003	
Factor(B)	0.024	0.009		0.022		0.008	
(A X B)	0.034	0.012		0.031		0.011	

Conclusion

The results of the present investigation demonstrated that plant spacing and nutritional management played an important role in determining the quality attributes of water chestnut fruits. Wider plant spacing S_2 (2 m $\times$ 1 m) consistently resulted in better values of total soluble solids, fruit pH, reducing sugar, non-reducing

sugar and total sugars than closer spacing S_1 (1 m $\times$ 1 m), indicating a favourable effect of adequate growing space on fruit quality. Among the nutritional regimes, nano zinc fortified FYM (T_{12}) emerged as the most effective treatment, followed by nano zinc fortified Jeevamrut (T_{10}), whereas the control treatment recorded comparatively lower values for these quality parameters.

The significant interaction between spacing and nutritional regimes further indicated that the response of water chestnut quality attributes depended on their combined application. The combination of wider spacing with nano zinc fortified FYM ($S_2 \times T_{12}$) consistently produced superior quality attributes during both years of experimentation. Therefore, under the agro-climatic conditions of Lucknow, the integration of wider plant spacing with nano zinc fortified FYM may be considered a promising nutritional and spatial management strategy for improving the quality of water chestnut fruits.

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