DOI : 10.58993/ijh/2024.81.4.9

Indian J. Hortic. 81(4), December 2024: 392-401

Delineating the genetic variability, inter-relationship and morphological variations in water chestnut for nut yield and mineral composition

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ABSTRACT

The fresh, edible fruit-nut of the water chestnut, an annual herb found in water, is an important aquatic crop. There is an enormous variation in water chestnut growth and yield, which is not extensively recorded in India. The yield performance of 23 water chestnut lines was examined in the present investigation. Crop variability contributes to the effective application of plant characteristics in the creation of stable and productive cultivars. The present study was conducted in 2020-2021 on water chestnut (*Trapa* spp.) accessions in order to assess the degree of genetic variability and yield character relationships. The genotypic coefficient of variation and heritability estimations were high for Zn, Mn and Fe content in rind, number of spines per nut, pedicel length, 10 dried nut rind weight, number of leaves per plant, number of nuts per plant, leaf length and fresh nut yield per plant. The following traits showed low heritability estimates and genotypic coefficients of variation: leaf width, nut pedicel length, weight of a single fresh nut, weight of a single shelled nut, and TSS. Fresh nut yield per plant was positively and significantly associated with the number of leaves per plant and the weight of 10 fresh nuts. To improve fruit-nut yield in water chestnut, selection criteria such as number of leaves per plant, number of nuts per plant, fruit pedicel length, fresh nut weight, TSS, 10 fresh nut weight and 10 fresh nut rind weight could be applied in different crop improvement programmes of water chestnut.

Key words: *Trapa* spp., chestnut, accessions, heritability estimates, coefficients of variation, correlation.

INTRODUCTION

Water chestnut (*Trapa* spp.) is cultivated worldwide, particularly in low-lying areas and lakes in China, India, and Italy, where it is valued for its edible fruit-nuts (Lam *et al.*, 15). While primarily grown in India and China, water chestnut is also widespread across Eastern and Southeast Asia (Suriyagoda *et al.*, 20). Common species include *Trapa bispinosa*, *Trapa incisa*, *Trapa japonica*, *Trapa manshurica*, *Trapa natans*, *Trapa quadrispinosa*, and *Trapa taiwanensis*. In India, China, and Japan, *T. natans*, *T. bispinosa* and *T. japonica* are the most common and manageable species (Lam *et al.*, 15). Despite having a lower yield than domesticated species, *T. japonica* was a significant food source during the Jomon period in Japan, which lasted from approximately 14,000 BCE to 300 BCE (Suriyagoda *et al.*, 20). Today, *T. natans* is often considered an indicator of aquatic ecosystem health or a pest plant. Uncontrolled growth can result in dense mats that disrupt recreational activities, clog water channels, and create unfavorable conditions for native flora and fauna. Approximately 11.6 million hectares in India are impacted by waterlogging, directly or indirectly inhibiting agricultural productivity (Jana, 13). Such areas pose challenges for conventional crops due to excess water, low-lying topography, and submersion sensitivity (Babu and Dwivedi, 2). Water chestnuts are mainly grown in depressions near railroads or highways but are cultivated with minimal improved agronomic practices and germplasm, resulting in low production (Chandana *et al.*, 6). Understanding the key morphological and physiological traits affecting yield is essential for improving water chestnut productivity (Pasala and Rajithasri, 17). According to Dubey *et al.* (8), water chestnuts typically flower in mid- to late July, with nuts maturing about a month later. The nuts possess astringent, cooling, diuretic, sweet, and tonic properties (Babu *et al.*, 3). Native to Eurasia, water chestnuts thrive in warm tropical climates, and in India, states like Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Odisha are top producers. Despite many accessions grown throughout India, significant efforts to improve them for enhanced productivity and yield are lacking. Crop improvement is needed to increase fresh nut production and productivity. Developing high-yielding cultivars through genetic restructuring of the germplasm is essential. Since genotypic coefficients of variability do not provide a complete estimate of heritable variation, heritability estimation is necessary. High heritability indicates consistent genetic expression, and genetic gain is

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crucial alongside heritability for assessing the impact of selection (Hanson and Earle, 12).

Given the lack of significant advancements in improving water chestnut accessions for yield and mineral composition, this study aims to delineate genetic variability, interrelationships, and morphological variations in *Trapa* spp. to identify traits contributing to higher productivity and nutritional value.

MATERIALS AND METHODS

Two species, *T. natans* and *T. bispinosa*, were collected in different states of India in order to assess genetic variation (Table 1). Furthermore, twenty-three water chestnut accessions from both species were evaluated during 2020-2021 in the ponds of Research Farm, ICAR-Indian Institute of Vegetable Research, Varanasi, India (83º53´E longitude and 18º52´N latitude). The experiment was arranged in randomized block design (RBD) with three replications. The pond was prepared by disking and leveling. About 10 tons of well-decomposed manure was mixed in the soil. Thirty-five cm long seedlings were planted at a spacing of 2 x1 m row-to-row and plant-to-plant spacing during March 2020. Each pond had five tagged plants of one accession in the middle of the pond to avoid border effects. Fertilizer was applied at 80 N, 60 P, 60 K kg per hectare. The N was supplied through urea, P through single superphosphate and K through muriate of potash. One-third of the N and all of the P and K were applied prior to planting, and the

Table 1. List of water chestnut accessions with their sources, botanical name and local name used in experiment.

Line	Collection site	Botanical name	Local name	Time of first flowering	Days to flowering	Time for the canopy fall
VRWC-1	IC No. 631688, NBPGR, New Delhi, India	*Trapa natans*	*Singhara*	4 June, 2020	76	12 October, 2020
VRWC-2	IC No.631689, NBPGR, New Delhi, India	*Trapa natans*	*Singhara*	8 June, 2020	84	22 October, 2020
VRWC-3	IC No. 631690, NBPGR, New Delhi, India	*Trapa natans*	*Singhara*	12 June, 2020	76	24 October, 2020
VRWC-4	IC No. 631691, NBPGR, New Delhi, India	*Trapa natans*	*Singhara*	9, June, 2020	69	21 October, 2020
VRWC-5	Varanasi, Uttar Pradesh, India	*Trapa natans*	*Singhara*	14, June, 2020	84	23 October, 2020
VRWC-6	Mirzapur, Uttar Pradesh, India	*Trapa natans*	*Paniphal*	5 July, 2020	86	7 November,2020
VRWC-7	Meerut, Uttar Pradesh, India	*Trapa natans*	*Paniphal*	8 July, 2020	93	8 December,2020
VRWC-8	Aligarh, Uttar Pradesh, India	*Trapa natans*	*Singhara*	10 July, 2020	94	6 December,2020
VRWC-9	Meerut, Uttar Pradesh, India	*Trapa natans*	*Singhara*	6 July, 2020	107	8 December,2020
VRWC-10	Bhadohi, Uttar Pradesh, India	*Trapa natans*	*Paniphal*	9 July, 2020	109	7 January,2021
VRWC-11	Ghazipur, Uttar Pradesh, India	*Trapa natans*	*Singhara*	12 July, 2020	98	6 January,2021
VRWC-12	Jaunpur, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	30 May, 2020	90	5 November,2020
VRWC-13	Azamgarh, Uttar Pradesh, India	*Trapa bispinosa*	*Paniphal*	8 July, 2020	89	12 January,2021
VRWC-14	Ghaziabad, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	15 August,2020	93	8 January,2021
VRWC-15	Sultanpur, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	9 July,2020	98	21 December,2020
VRWC-16	Ghazipur, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	7 August,2020	112	3 January,2021
VRWC-17	Mau, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	24 May, 2020	114	24 October,2020
VRWC-18	Jaunpur, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	30 May, 2020	115	23 Novemebr,2020
VRWC-19	Chandauli, Uttar Pradesh, India	*Trapa natans*	*Paniphal*	2 June, 2020	132	23 October,2020
VRWC-20	Varanasi, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	17 June, 2020	124	5 October,2020
VRWC-21	Mirzapur, Uttar Pradesh, India	*Trapa natans*	*Paniphal*	23 May, 2020	102	5 Novemebr,2020
VRWC-22	Varanasi, Uttar Pradesh, India	*Trapa bispinosa*	*Singhara*	25 May, 2020	141	4 October,2020
VRWC-23	Prayagraj, Uttar Pradesh, India	*Trapa bispinosa*	*Paniphal*	4 August,2020	83	2 January, 2021

Time of the first flower and the beginning of foliage yellowing are given by calendar days, and in the number of days from the date of transplanting (9 February).

remaining N was applied in two equal splits at 30 and 45 days after planting by top dressing. Precipitation ranges from 4 mm in the driest month (December) to 280 mm in the wettest one (August) during the crop period. Data on horticultural traits were collected. Data included number of leaves/plant (NLP), number of nuts/plant (NNP), pedicel length (PL- cm), leaf length (LL- cm), leaf width (LW- cm), nut pedicel length (NPL- cm), number of spines (NS), single fresh nut weight (SFNW- g), single shelled nut weight (SSNW- g), single dried shelled nut weight (SDSNW-g), TSS (%), 10 fresh nut weight (10 FNW-g),10 fresh nut rind weight (10FNRW-g), 10 dried nut rind weight (10DNRW-g), Zn content in shelled nut (Zn SN-ppm), Zn content in rind (Zn R-ppm), Fe content in shelled nut (Fe SN- ppm), Fe content in rind (FeR- ppm), Mn content in shelled nut (MnSN-ppm), Mn content in rind (MnR- ppm) and fresh nut yield per plant (FNYPP-g). Data were subjected to analysis for mean, coefficients of variation, heritability (*b*s) and genetic advance with formulae of Burton and De Vane (5), Johnson *et al.* (14) and Singh and Chaudhary (19). Correlation coefficients among all possible character combinations were estimated formulae of Al-Jibouri *et al.* (1) and standard procedure using AAS (LABINDIA/AA8000) with slight modifications were adopted for estimation of minerals Zn, Fe and Mn in dried shelled nut and rind of water chestnut. Version 2.0 of the OPSTAT package was used to examine the data. The least squares analysis was conducted using Pearson's correlation coefficient, the correlation (r^2) was further examined, and $p = 0.05$ was used to indicate significance. In accordance to Singh and Chaudhary (19), the total variance components were divided into distinct components using ANOVA, with the assumption that the mean square of each source of variation is equal to their expected mean squares (Table 2). The coefficient of variation and variance component were used to estimate the amount of variability as per Johnson *et al.* (14). On the other hand, the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were also calculated according to the formula suggested by Singh and Chaudhary (19). These estimates of variations were classified as low when values were less than 10%, medium when values were between 10 and 20 % and high when values were greater than 20% (Johnson *et al.*, 14). According Falconer (9), the estimate of heritability (h^2 b) in the broad sense is given as a percentage of the ratio of the genotypic variance to the phenotypic variance and values less than 40% were categorized as low, values between 40 and 59% as medium, values between 60 and 79 as moderately high, and values greater than 80% as extremely high. As per the procedure described by

Table 2. Analysis of Variance, Mean, Coefficient of variation and least significant differences for important horticultural traits in water chestnut genotypes.

Source of variation	DF	NLP	NNP	PL	LL	LW	NPL	NS	SFNW	SSNW	SD SNW	TSS	10 FNW	10 FNRW	10 DNRW	Zn SN	Zn R	Fe SN	FeR	MnSN	MnR	FNYPP
Replication	2	15.75	2.10	1.42	0.07	0.12	2.58	0.23	0.77	0.02	0.09	0.33	220.34	3.01	4.86	4.46	28.00	0.42	49112.75	15.22	73.56	6844.90
Genotype	22	54.58**	6.59**	26.39**	0.97**	0.57**	1.70**	0.37**	2.91**	0.77**	0.17**	0.56**	785.69**	20.85**	12.66**	18.88**	3989.03**	3683.49**	86153.68**	26.33**	11726.98**	23640.26**
Error	44	1.85	0.67	1.63	0.10	0.07	0.57	0.39	1.18	0.06	0.08	0.14	70.62	1.64	1.59	2.63	10.70	0.15	31587.40	12.33	157.95	2600.60
Mean		35.58	12.8	14.85	4.59	5.51	6.04	2.57	12.24	8.11	2.05	6.61	204.78	48.86	7.63	40.09	70.70	164.32	980.27	37.48	235.99	579.77
CV%		1.81	9.34	9.51	6.99	5.06	5.77	4.3	9.65	2.81	8.76	2.2	3.0	2.81	9.53	3.78	3.68	6.96	18.73	11.53	5.95	7.37
LSD 0.01		1.10	1.96	2.2	0.53	0.45	0.59	1.09	1.93	0.38	0.64	0.24	10.23	2.23	0.89	2.5	4.27	19.19	296.62	7.31	23.34	71.96

*Source of variation significant at 1%, analysis of variance; No. of leaves/plant (NLP), Number of Nut/plant (NNP), Pedicel length (PL), Leaf length (LL), Leaf width (LW), Nut pedicel length (NPL), Number of spines (NS), Single fresh nut weight (SFNW), Single shelled nut weight (SSNW), Single dried shelled nut weight (SDSNW), TSS, 10 fresh nut weight (10 FNW),10 fresh nut rind weight (10FNRW), 10 dried nut rind weight (10 DNRW), Zn content in shelled nut (Zn SN), Zn content in rind (Zn R), Fe content in shelled nut (Fe SN), Fe content in rind (FeR), Mn content in shelled nut (MnSN), Mn content in rind (MnR), Fresh nut yield per plant (FNYPP).

Allard (2), the expected genetic advance (GA) for each trait at 5% selection intensity (K = 2.06) was calculated. Furthermore, using a method developed by Comstock and Robinson (7), expected genetic advance as a percentage of the mean (GAM) is computed to compare the degree of the predicted advance of various qualities under selection. In accordance with Johnson *et al.* (14) GAM values less than 10% were considered low, values between 10% and 20% were considered medium and values more than 20% were considered high.

RESULTS AND DISCUSSION

Mean squares and genetic parameter estimates of water chestnut accessions varied for the studied horticultural traits (Table 2). Analysis of variance indicated that mean squares for accessions were significant for all characters. Significant differences among accessions in most of the traits indicated the existence of inherent genetic variability among accessions (Fig. 1). The observed variability among accessions was mostly due to the number of leaves/plants, pedicel length, 10 fresh nut weight, 10 fresh nut rind weight, Zn content in shelled nut and rind, Fe content in shelled nut, and Mn content in rind (Table 3). Large genetic variation among accessions is needed for effective and successful selection for improvement. High genotypic variance for the number of leaves/plants, number of nuts/plants, pedicel length, number of spines per nut, 10 dried nut rind weight, Zn content in rind, and Mn content in rind occurred, indicating that the genotypic component of variation was the major contributor to total variation. The PCV was highest in Zn, Fe, and Mn content in rind, followed by the number of spines per nut and 10 dried nut rind weight. High PCV indicated the ability to select traits for improvement due to a considerable amount of variability. A comparatively low PCV was observed for leaf width, single shelled nut weight, TSS, 10 fresh fruit nut weight, and Zn content in shelled nut, which is indicative of less possibility for improvement. The GCV provides a measure of genetic variability present in characters. The highest estimates of GCV were for Zn content in rind, followed by Mn content in rind and the number of spines per nut. A high GCV indicates the presence of exploitable genetic variability for these traits. A narrow range of difference between PCV and GCV indicates that these traits are mostly governed by genetic factors, with minimal environmental influence on the phenotypic expression of traits. It may be possible to select these traits based on phenotypic values. The GCV values are not enough to determine the level of genetic variability among genotypes. The GCV can be investigated with the use of heritability estimates. Whereas coefficients of variation measure the magnitude of variability present in a population, heritability indicates the reliability with which a genotype will be evaluated by phenotypic expression. High heritability (bs) estimates for the number of leaves per plant, pedicel length, single shelled nut weight, 10 fresh nut weight, Zn content in rind, Fe content in shelled nut, and Mn content in rind indicated minimal environmental influence in the expression of these characters. High heritability estimates indicated that the characters would exhibit a high response to selection (Table 4). Similar results were also reported by Gond *et al.* (11) in their water chestnut experiments. Correlation coefficient analysis indicated that fresh nut yield per plant was positively and significantly correlated with the number of leaves per plant and 10 fresh nut weight (Table 5). These associated characters were in the desirable direction; selection for these traits may improve nut yield per plant. These results agree with Beigh *et al.* (4) for water chestnut. The number of nuts per plant, pedicel length, fresh nut weight, TSS, and 10 fresh nut rind weight also had a positive association with fresh nut yield per plant, so these traits could not be ignored during selection for higher nut yield per plant. Shelled nut weight and 10 dried nut rind weight had a negative association with fresh nut yield per plant (Table 5). Similar results were also reported by Suriyagoda *et al.* (20) in their experiments on water chestnut. The mineral contents of shelled nut and shelled nut rind ranged as follows: Zn in shelled nut (37.97-45.27 ppm); Zn in shelled nut rind (30.2-129.2 ppm); Fe in shelled nut (120.2-206.6 ppm); Fe in shelled nut rind (467.0-1133.2 ppm); Mn in shelled nut (33.3-52.2 ppm); and Mn in shelled nut rind (145.4-327.0 ppm) in 100 g of dried nut and rind of water chestnut (Fig. 2-4). The present study has demonstrated that the rind of water chestnut could be an important source of minerals, which is suitable for incorporation into the human diet. In conformity with the present findings, Pasala *et al.* (17) also reported variations in the biochemical composition of the nut of water chestnut for minerals. Based on average performance and mineral composition, the genotypes VRWC-1, VRWC-4, VRWC-9, and VRWC-13 were found to be promising for fresh nut yield per plant and other horticultural traits. The present results represent a baseline for breeding for further improvement programs. Landraces of water chestnut need to be extensively investigated to improve cultivars (Dubey *et al.*, 8).

Genetic improvement, together with the technological development of agricultural methods, has led to the replacement of local varieties by a few uniform modern cultivars (Morico *et al.*, 16). Some present resources may not be suitable for

Table 3. Mean performance of water chestnut genotypes for nut yield and yield-attributing traits.

Genotype	NLP	NNP	PL	LL	LW	NPL	NS	SFNW	SS NW	SD SNW	TSS	10 FNW	10 FNRW	10 DNRW	Zn SN	Zn R	Fe SN	FeR	MnSN	MnR	FN YPP
VRWC1	39.3	18.0	15.8	4.7	6.1	6.9	2.3	14.0	7.9	2.4	6.9	265.0	48.8	5.8	37.97	127.2	160.3	1035.2	44.0	327.0	800.0
VRWC2	33.7	13.3	16.2	4.4	4.8	5.3	2.7	12.0	6.9	3.0	6.7	200.0	49.9	7.3	38.30	62.8	123.0	1155.5	52.2	194.9	500.0
VRWC3	37.7	12.0	16.9	4.4	5.1	5.7	3.0	11.2	8.8	2.3	6.5	213.3	46.3	5.1	44.87	54.8	200.6	467.0	35.4	147.4	660.0
VRWC4	25.7	12.7	14.0	3.9	5.8	5.3	2.0	13.3	9.0	1.9	6.6	212.3	44.1	4.8	39.93	29.8	196.3	1077.5	33.3	201.7	535.0
VRWC5	30.0	13.0	17.0	4.1	5.3	5.6	2.7	12.8	8.9	2.0	6.6	213.3	43.5	7.3	38.80	128.0	158.3	863.3	40.2	263.6	616.6
VRWC6	31.3	14.0	18.0	4.8	6.2	6.5	2.7	11.5	9.1	2.4	6.6	193.7	42.7	5.1	38.13	64.8	120.2	1081.9	41.7	321.1	496.6
VRWC7	28.7	13.3	17.0	4.6	4.9	5.7	3.0	8.5	8.6	2.0	6.6	195.3	50.1	5.2	45.27	55.8	199.6	1086.3	38.7	191.9	480.0
VRWC8	32.7	10.7	17.0	4.8	5.3	5.9	2.7	11.2	8.7	2.0	6.9	197.7	48.0	5.5	40.23	29.5	195.3	1013.0	35.2	146.8	616.6
VRWC9	31.0	9.7	11.3	4.2	5.2	5.9	2.3	13.3	8.7	2.5	6.8	196.3	46.1	7.3	38.47	129.2	156.0	866.7	36.8	267.9	660.0
VRWC10	34.0	11.3	11.3	5.6	5.3	5.8	2.3	12.5	7.5	2.0	6.5	196.7	46.1	4.9	38.80	64.8	127.6	1048.7	36.9	267.2	700.0
VRWC11	35.7	12.0	12.0	4.2	5.3	6.0	2.3	12.2	7.8	2.1	7.3	198.0	43.2	5.0	44.27	54.1	203.3	1027.0	37.1	321.1	660.0
VRWC12	38.0	12.7	13.0	5.0	6.0	5.8	2.7	12.3	8.1	2.0	6.6	204.0	50.7	4.9	38.90	30.2	198.0	1079.6	38.4	191.6	626.7
VRWC13	36.3	13.0	11.7	4.4	5.3	6.9	3.0	13.5	8.2	1.9	7.2	202.0	50.7	4.8	38.1	129.20	156.3	846.5	35.8	149.1	513.3
VRWC14	31.7	15.0	14.0	4.6	4.5	5.8	2.7	11.8	8.4	2.3	7.2	200.7	52.2	7.6	38.3	64.20	120.2	866.7	36.8	262.9	654.3
VRWC15	36.0	13.0	12.7	5.6	5.1	5.9	2.0	12.2	8.1	2.5	7.1	223.7	50.8	5.0	45.2	58.17	200.3	1107.4	36.9	255.2	500.0
VRWC16	38.0	12.0	11.0	4.9	5.2	6.9	3.0	12.3	8.3	2.7	6.9	230.3	50.1	5.1	40.9	31.87	195.0	756.6	37.8	261.6	670.0
VRWC17	38.7	12.3	11.0	4.7	5.3	5.8	2.3	12.5	7.6	3.0	6.6	206.3	49.3	4.9	38.4	122.20	156.8	1007.5	38.4	321.8	550.0
VRWC18	36.3	14.0	7.7	4.2	5.4	6.6	2.3	12.2	7.9	2.3	6.5	209.3	50.3	5.3	38.1	53.53	121.0	1113.0	40.2	193.3	603.3
VRWC19	35.0	11.0	15.0	5.2	5.4	6.9	2.3	11.8	8.2	2.3	6.8	208.0	49.5	5.0	42.2	54.17	201.0	846.5	33.9	145.4	565.3
VRWC20	35.3	11.0	12.0	3.8	5.4	6.0	2.3	11.5	7.6	2.7	6.7	194.0	48.0	4.9	40.2	29.87	195.0	1133.2	40.2	266.6	600.0
VRWC21	32.7	12.7	13.7	3.8	5.6	6.9	2.3	12.7	7.6	2.7	6.3	193.7	50.3	6.1	38.1	128.20	138.0	524.5	41.7	266.6	536.6
VRWC22	32.0	14.0	17.1	4.7	5.8	6.9	2.3	11.8	7.9	2.0	6.1	198.0	48.6	5.0	38.1	63.5	123.3	1122.1	38.7	321.1	600.0
VRWC23	31.3	12.0	18.8	5.6	5.9	7.6	2.3	12.3	7.5	2.4	6.4	205.6	50.4	8.0	42.0	54.8	206.6	1007.5	35.2	193.3	500.0
SEM±	0.35	0.69	0.77	0.19	0.16	0.21	0.38	0.68	0.13	0.22	0.09	3.59	0.78	0.31	0.88	1.5	6.73	104.07	2.57	8.19	25.25
CV %	1.81	9.34	9.51	6.99	5.06	5.77	4.3	9.65	2.81	8.76	2.2	3.0	2.81	9.53	3.78	3.68	6.96	18.73	11.53	5.95	7.37
CD %	1.10	1.96	2.2	0.53	0.45	0.59	1.09	1.93	0.38	0.64	0.24	10.23	2.23	0.89	2.5	4.27	19.19	296.62	7.31	23.34	71.96

No. of leaves/plant (NLP), Number of Nut/plant (NNP), Pedicel length (PL), Leaf length (LL), Leaf width (LW), Nut pedicel length (NPL), Number of spines (NS), Single fresh nut weight (SFNW), Single shelled nut weight (SSNW), Single dried shelled nut weight (SDSNW), TSS, 10 fresh nut weight (10 FNW), 10 fresh nut rind weight (10FNRW), 10 dried nut rind weight (10 DNRW), Zn content in shelled nut (Zn SN), Zn content in rind (Zn R), Fe content in shelled nut (Fe SN), Fe content in rind (FeR), Mn content in shelled nut (MnSN), Mn content in rind (MnR), Fresh nut yield per plant (FNYPP).

Fig. 1. Representative pictures showing variation in different water chestnut genotypes under investigation.

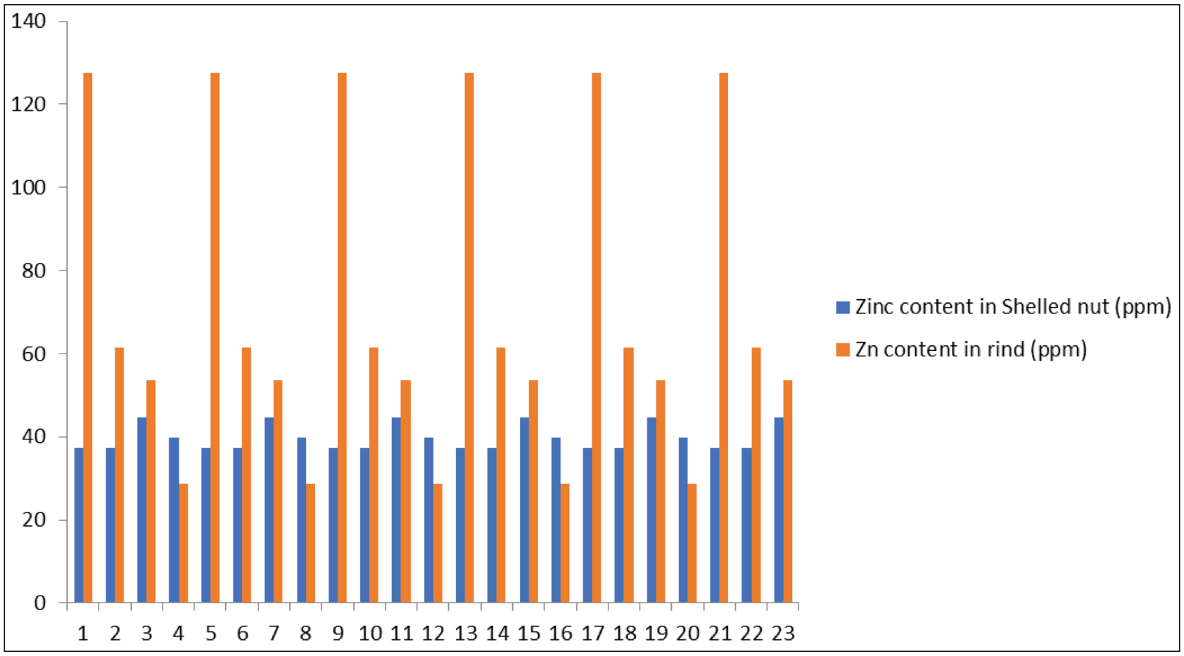

Fig. 2. Zn content in shelled nut and rind of water chestnut genotypes.

Table 4. Genetic parameters for yield and its component characters in water chestnut genotypes.

Character	Mean	Variance		Coefficient of variation		Heritability (bs) %	Genetic advance (GA)	Genetic advance as percentage of mean (GAM)
		Phenotypic	Genotypic	PCV %	GCV %			
No. of leaves/plant	15	12.36	11.98	10.35	10.19	96.94	9.0	24.96
No. of nut /plant	11	3.79	2.37	15.29	12.11	62.70	3.2	25.31
Pedicel length	17.8	9.54	7.75	21.95	19.78	81.21	6.6	47.06
Leaf length	3	0.37	0.27	13.21	11.20	71.99	1.2	25.10
Leaf width	2.3	0.23	0.15	8.78	7.17	66.78	0.8	15.48
Nut pedicel length	3	0.49	0.36	11.3	9.72	73.96	1.4	22.07
No. of spines per nut	2	0.38	0.06	24.57	23.34	34.58	0.2	9.46
Single fresh nut weight	11.5	2.08	0.7	11.86	6.9	33.86	1	10.69
Single shelled per nut weight	2.5	0.35	0.3	7.29	6.73	85.16	1.3	16.4
Dry per shelled nut weight	1.1	0.2	0.05	19.36	9.84	25.8	0.3	13.19
TSS	1.3	0.1	0.08	4.82	4.29	79.09	0.07	10.06
10 Fresh nut weight	98	278.31	239.69	8.07	7.49	86.13	37.9	18.34
10 Fresh fruit rind weight	11.96	8.93	7.09	6.19	5.51	79.35	6.3	12.96
10 Dried nut rind weight	4	1.30	1.00	20.02	17.61	77.36	2.3	40.89
Zinc content in shelled nut	9.00	8.08	5.77	7.08	5.98	71.49	5.4	13.35
Zn content in rind	102.40	1341.25	1334.53	51.96	51.82	99.50	96.2	136.47
Fe content in shelled nut	115.00	1214.25	1078.29	20.80	19.60	88.80	81.7	48.77
Fe content in rind	799.40	55766.23	23273.27	24.54	15.85	41.73	260.2	27.04
Mn content in shelled nut	24.90	28.96	9.21	13.96	7.88	31.81	4.5	11.73
Mn content in rind	206.00	4032.98	3831.80	26.65	25.98	95.01	159.3	66.85
Fresh nut yield per plant	350.00	7150.62	5045.64	14.37	12.07	70.56	157.5	26.78

standard cultivars in terms of productivity and plant characteristics, but their genetic content needs to be conserved to prevent genetic erosion (Dubey *et al.*, 8). Water chestnut has diverse health benefits, making it a valuable dietary addition for promoting overall health (Dubey *et al.*, 8). Further research should focus on elucidating the mechanism of action of its bioactive constituents and exploring its full therapeutic potential in clinical settings. Besides, this wonderful neglected aquatic vegetable crop has various commercial applications that underscore its potential in the food, supplement, and cosmetic industries. In this

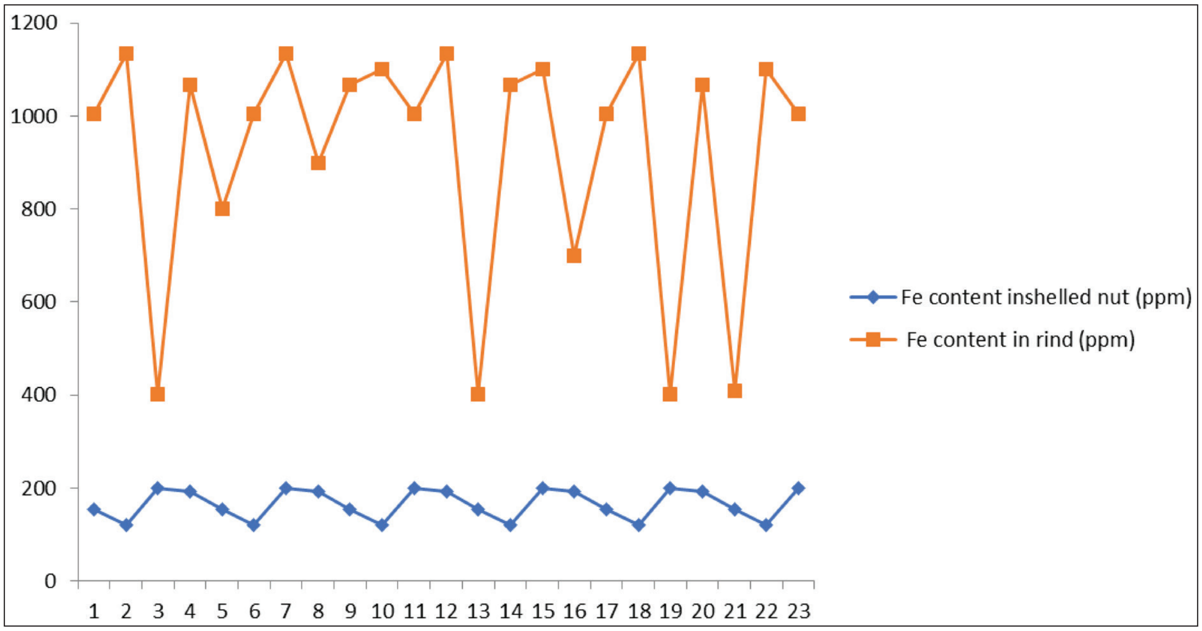

Fig. 3. Fe content in shelled nut and rind of water chestnut genotypes.

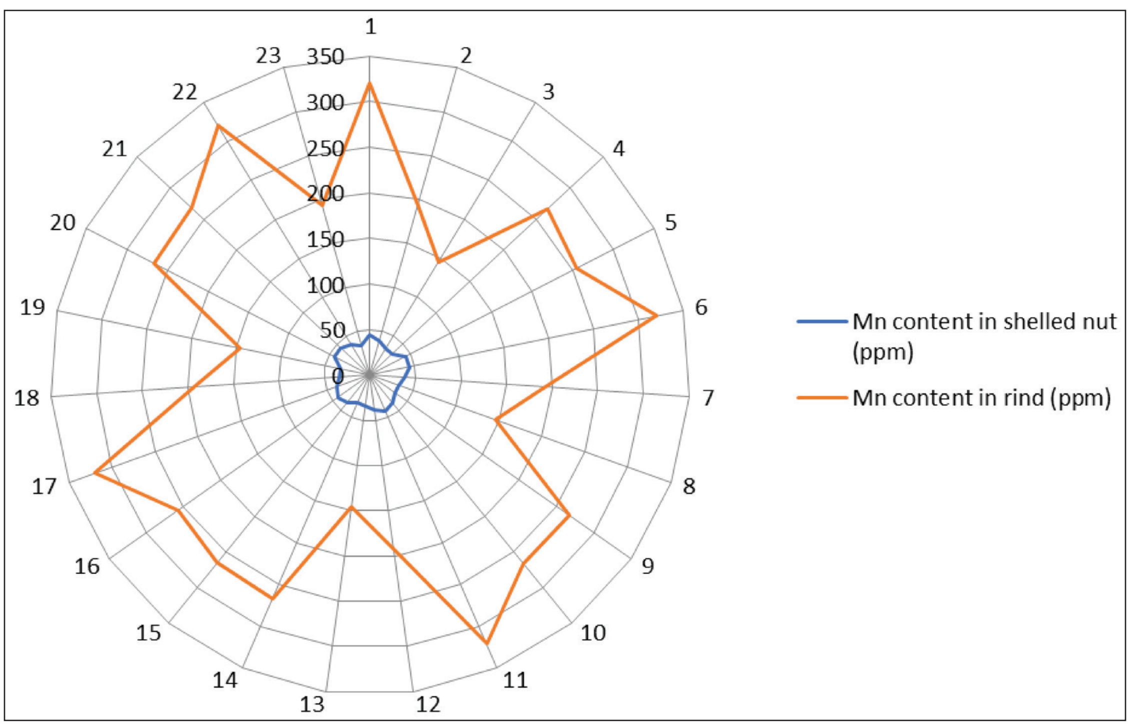

Fig. 4. Mn content in shelled nut and rind of water chestnut genotypes.

Table 5. Correlation of coefficients among horticultural traits in water chestnut genotypes.

Character	No. of leaves/ plant	No. of nuts/ plant	Fruit pedicel length	Fresh nut weight	Shelled nut weight	Dried shelled nut weight	TSS	10 Fresh nut weight	10 fresh nut rind weight	10 dried nut rind weight	Fresh nut yield/ plant
No. of leaves/plant	1	0.136	-0.090	-0.030	-0.308	-0.231	0.171	0.374	0.342	-0.121	0.457*
No. of nuts /plant		1	0.058	0.221	0.078	0.197	0.097	0.529*	0.289	0.313	0.302
Fruit pedicel length			1	-0.197	-0.069	0.018	-0.034	0.064	-0.048	-0.104	0.274
Fresh nut weight				1	0.036	-0.239	-0.104	0.297	-0.212	0.126	0.236
Shelled nut weight					1	0.107	0.254	0.146	-0.338	0.526**	-0.063
Dried shelled nut weight						1	0.121	0.108	-0.203	0.000	0.059
TSS							1	0.250	0.135	-0.241	0.174
10 Fresh nut weight								1	0.144	0.149	0.457*
10 fresh nut rind weight									1	0.116	0.145
10 dried nut rind weight										1	-0.003
Fresh nut yield/plant											1

*,** Significant at 5 and 1%, respectively.

experiment, we identified the yield components that have agronomical, biotechnological, and economical importance. Thus, the results presented here for important horticultural traits, *viz*., the number of leaves/plants, pedicel length, number of fruits/plants, single shelled nut weight, and Fe, Zn, and Mn content in rind, would be useful for subsequent water chestnut improvement. Looking ahead, water chestnuts could soon gain greater recognition for their health benefits as consumers increasingly encounter terms like 'antioxidant' and 'mineral.

AUTHORS' CONTRIBUTIONS

Execution of field/lab experiments and data collection and preparation of the original manuscript (RKD); conceptualization & designing of the experiments (RKD, JD); analysis of data and interpretation (RKD, NR); editing of the manuscript (TKB).

DECLARATION

The authors declare that there is no conflict of interest.

ACKNOWLEDGEMENTS

The researchers are very thankful to the ICAR, New Delhi, India for providing all the facilities for the present investigation.

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Received : September, 2024; Revised : December, 2024; Accepted : December, 2024