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RESEARCH ARTICLE

Characterization of water chestnut (*Trapa natans* L.) genotypes for yield and nutritional traits using PCA analysis

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Abstract

Yield and its contributing attributes are mostly targeted in improvement programmes, so the existence of variability has prime importance in plant breeding. In the present study, 36 genotypes of water chestnut were assessed with principal component analyses (PCA) based on morphological and quality traits to select genotypes and traits for future breeding programmes. Based on the PCA with 21 traits, 21 components were formed; however, 9 PCs had more than 1 Eigenvalue with a variability of 74.3%. So, these nine PCs were used for further investigation. The first principal component exhibited maximum variability of the total variations present. PC1 correlated with the number of leaves per plant, number of fruit-nut per plant, single fresh nut weight, dried shelled nut weight, Zn content in rind, Fe content in shelled nut, Mn content in shelled nut and rind and fresh nut yield per plant, while PC2 dominated by Fe content in shelled nut, Mn content in shelled nut and Mn content in rind and TSS. PC3 correlated with traits like the number of fruit-nut per plant, leaf width, fruit pedicel length, TSS, 10 fresh nut weight and Fe content in the rind. PC4 reflected positive factor loading by fruit pedicel length, dried 10 nut rind weight and Zn content in rind. PC5 correlated with single shelled nut weight and number of fruit-nut per plant high with positive factor loading. PC6 correlated with leaf width, dried single-shelled nut, 10 fresh nut weight. PC7 positively correlated with factor loading values with single-shelled nut weight, dried 10 nut rind weight and number of leaves per plant. PC8 correlated with traits like 10 fresh nut weight, Fe content in shelled nut and number of fruit nut per plant.PC9 positively correlated with high values to leaf width, number of fruit-nut per plant and number of leaves per plant. Therefore, the important traits coming jointly from diverse PCs and contributing towards elucidation variability may be kept into consideration during the utilization of these traits in the improvement programmes of water chestnut.

Keywords: *Trapa natans*, Water chestnut, PCA, Eigenvalues, Variance, Correlation.

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Introduction

Water chestnut (*Trapa* sp.) is a common aquatic herb distributed in various parts of the world. Water chestnut is native to Eurasia and can be found in tropical and warm temperature regions (Hummel and Kiviat, 2004). It has been commercially cultivated for edible fruits-nut in water bodies of low, flat lands or lakes in India, China and Italy (Daniel et al., 1983). Enhancing agricultural productivity in waterlogged areas is becoming more relevant for food security due to increasing pressure on arable land. About 11.6 million hectares of land in India are affected directly or otherwise due to the problem of water logging impeding agricultural productivity (Jana, 2020; Dwivedi et al., 2011; Babu & Dwivedi., 2012). Several useful but neglected crops have the potential to grow under waterlogged conditions (Babu et al., 2011; Jana, 2020). Water chestnut has immense potential to grow in areas where water remains stagnant for at least six months in a year to a depth of up to 0.5 m (Dubey et al., 2022). Mainly grown in railway track-side or highway track-side depressions, this crop is a livelihood option for many marginal farmers in India (Singh et al., 2018). However, this neglected crop is generally cultivated without an improved package of practices and a lack of better germplasm/ varieties. Hence, their productivity remains low (Chandana et al., 2013; Dubey et al., 2019). For improvement of the yield of water chestnuts, it is imperative to understand critical morphological and quality characteristics contributing towards yield (Pasala and Rajithasri, 2022; Dubey et al., 2019; 2021). It is grown primarily for human consumption, either as a vegetable, dried to make flour to prepare flattened bread called chapatti, or in the form of dishes of various types depending on individual taste (Dubey et al., 2017, 2019; Pasala & Rajithasri, 2022). The nut is the fruit of water chestnut. Each of the nuts has a spine with several barbs (Hussain et al., 2018). On the water's surface, each plant has submerged leaves that are feather-like and oppositely paired along the stem and waxy floating leaves that are triangular and form a rosette (Dubey et al., 2021). Water chestnuts bloom in mid-to-late July and their nuts mature a month later (Dubey et al., 2020). Nuts are sweet, astringent, cooling, diuretic, and tonic (Babu et al., 2011; Dubey et al., 2021). This plant is thought to be a significant source of new chemical substances with potential therapeutic applications (Chaudhary, 2012; Dubey et al., 2021). Water chestnut production in India is led by Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Bihar, Jharkhand, West Bengal and Odisha (Hoque, 2019). Recently, the first high-yielding variety, Swarn Lohit (red, thornless), was developed at ICAR-National Research Center for Makhana, Darbhanga, Bihar (Singh et al., 2024). Nuts with different husk colors like green, red, or purple and blending of red and green colors are also recognized. *Kanpuri*, *Jaunpuri*, *Desi Large*, *Desi small,* etc., are the names of some types of water chestnuts referred to by the growers in West Bengal and other parts of eastern India (Dubey et al., 2019).

Yield is dependent on traits that are affected by a number of factors and environments. Hence, a technique known as principal component analysis (PCA) was used to identify and minimize the number of traits for effective selection. Principal component analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components (Chatfield & Collis, 1980; Esposito et al., 2007). The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. The objectives of the PCA are to discover or to reduce the dimensionality of the data set and to identify new meaningful underlying variables (Jollife, 2002; Esposito et al., 2007). The mathematical technique used in PCA is called eigen analysis. In the present investigation, we solved the eigenvalues and eigenvectors of a square symmetric matrix with sums of squares and cross products. The eigenvector associated with the largest eigenvalue has the same direction as the first principal component. The eigenvector associated with the second largest eigenvalue determines the direction of the second principal component. Multivariate statistical methods have been successfully used to classify quantitative and qualitative variations in many crop species like tomato (Sinha et al., 2021), pea (Patel et al., 2023), chickpea (Kumar et al., 2021), rice (Lakshmeesha et al*.,* 2024). An excellent way to see the results of PCA is through graphics Biplot (Gabriel, 1971), specifically the connections between the ordinations of the rows (generally samples) and of the columns (typically markers) of the data table. The Biplot represents both ordinations simultaneously. In the present study, we carried out a PCA to determine which variable contributed more with its variance to the total variance observed in the water chestnut accessions. For this, 21 characteristics were measured during 2020-21 on 36 water chestnut genotypes on the basis of PCA to identify important morphological and quality traits under open field aquatic conditions under an improvement program for yield and quality of water chestnut, and this is the first report based on the application of PCA in the characterization of water chestnut genotypes.

Materials and Methods

Thirty-six water chestnut genotypes (Table 1) were augmented from different locations as landraces and evaluated during 2020-21 in the research field of the ICAR-Indian Institute of Vegetable Research Varanasi, India (83º53´E longitude and 18º52´N latitude). The experiment was arranged in a randomized block design with three replications in water ponds of (3.0 x 2.0 m) size. The experimental pond was disked and leveled. About 10 tons of well-decomposed manure was mixed in the soil. 35 cm long seedlings were planted at a spacing of 2 x1 m row-to-row and plant-to-plant spacing. Each pond had five tagged plants of one accession in the middle of the pond to avoid border effects. Fertilizer was applied at 80N–60P–60K kg per hectare. The N was from urea, P was from single superphosphate, and K was from muriate of potash. One-third of the N and all of the P and K were applied prior to planting and the remaining N was applied in two equal splits at 30 and 45 days after planting by top dressing. Manual weeding was done until the final harvest and irrigation was used to maintain the water level in ponds at 30 days intervals from mid-December to early June. 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 include a number of leaves/plant, number of nut/plant, pedicel length (cm), leaf length (cm), leaf width (cm), Fruit nut pedicel length (cm), number of the spine, single fresh nut weight (g), single shelled nut weight(g), single dried shelled nut weight (g), TSS (%), 10 fresh nut weight (g),10 fresh nut rind weight (g), 10 dried nut rind weight (g), Zn content in shelled nut (ppm),

Table 1: List of water chestnut accessions used in the experiment

Genotype	*Source*	*Genotype*	*Source*	*Genotype*	*Source*
VRWC-1	IC No. 631688, NBPGR, New Delhi, India	VRWC-13	Ghaziabad, Uttar Pradesh, India	VRWC-25	Lucknow, Uttar Pradesh, India
VRWC-2	IC No.631689, NBPGR, New Delhi, India	VRWC-14	Sultanpur, Uttar Pradesh, India	VRWC-26	Basti, Uttar Pradesh, India
VRWC-3	IC No. 631690, NBPGR, New Delhi, India	VRWC-15	Ghazipur, Uttar Pradesh, India	VRWC-27	Pratapgarh, Uttar Pradesh, India
VRWC-4	IC No. 631691, NBPGR, New Delhi, India	VRWC-16	Mau, Uttar Pradesh, India	VRWC-28	Kausambi, Uttar Pradesh, India
VRWC-5	Varanasi, Uttar Pradesh, India	VRWC-17	Jaunpur, Uttar Pradesh, India	VRWC-29	Prayagraj, Uttar Pradesh, India
VRWC-6	Meerut, Uttar Pradesh, India	VRWC-18	Chandauli, Uttar Pradesh, India	VRWC-30	Jaunpur, Uttar Pradesh, India
VRWC-7	Aligarh, Uttar Pradesh, India	VRWC-19	Varanasi, Uttar Pradesh, India	VRWC-31	Lucknow, Uttar Pradesh, India
VRWC-8	Meerut, Uttar Pradesh, India	VRWC-20	Mirzapur, Uttar Pradesh, India	VRWC-32	Saharanpur, Uttar Pradesh, India
VRWC-9	Bhadohi, Uttar Pradesh, India	VRWC-21	Varanasi, Uttar Pradesh, India	VRWC-33	Mirzapur, Uttar Pradesh, India
VRWC-10	Ghazipur, Uttar Pradesh, India	VRWC-22	Prayagraj, Uttar Pradesh, India	VRWC-34	Sultanpur, Uttar Pradesh, India
VRWC-11	Jaunpur, Uttar Pradesh, India	VRWC-23	Jaunpur, Uttar Pradesh, India	VRWC-35	Meerut, Uttar Pradesh, India
VRWC-12	Jaunpur, Uttar Pradesh, India	VRWC-24	Amethi, Uttar Pradesh, India	VRWC-36	Ghaziabad, Uttar Pradesh, India

Zn content in rind (ppm), Fe content in shelled nut (ppm), Fe content in rind (ppm), Mn content in shelled nut (ppm), Mn content in rind (ppm) and fresh nut yield per plant (g). Standard procedures using AAS (LABINDIA/AA8000) with slight modifications were adopted for the estimation of minerals Zn, Fe and Mn in dried shelled nut and rind of water chestnut (Dubey et al., 2021). Mean values of all observations were used for Principal Components Analysis using OPSTAT software (Sheoran et al., 1998).

Results and Discussion

Principal component analysis is a simple nonparametric method. Variables, mean values, variance, standard deviation and standard error for different traits were estimated and are presented in Table 2, which depicts wide variation among genotypes for targeted traits. The purpose of the PCA is to obtain a small number of factors that account for maximum variability out of the total variability. Based on the PCA with 21 traits of 100% diversity, it formed 21 components; however, 9 PCs had more than 1 Eigenvalue, which signifies maximum variation among the variables with a diversity percentage of 74.3% (Table 2). Brejda et al. (2000) suggested that the eigenvalue of more than 1 showed at least 10% variation. Thus, elevated eigenvalues were measured as the best representative of system attributes in principal components. Saputra et al. (2017) also found 14 components in their study. Nine PCs, i.e., PC 1 (3.062), PC 2 (2.345), PC 3 (2.136), PC 4 (1.813), PC 5 (1.621), PC 6 (1.450), PC7 (1.384), PC8 (1.150) and PC9 (1.088) showed greater than 1eigen values. So, these nine PCs were used for further investigation. The first principal component explained 14.2% while PCA2, PCA3, PCA 4, PCA 5, PCA 6, PCA 7, PCA 8, and PCA 9 principal components exhibited 10.9, 9.9, 8.4, 7.5, 6.7, 6.4, 5.3 and 5.0% of the total variation, respectively (Figure 1). Sehgal et al. (2021) and Chernet et al. (2014) also reported 6 PC with 85.72 and 83.03% of the total variation, respectively, in their experiments. Iqbal et al.(2014), Saputra et al. (2017), and Ibrahim and El-Mansy (2021) reported 3 PCs, 8 PCs and 2 PCs with more than 1 Eigen-value contributing 81.72, 90.96 and 81.3% of total variability respectively in their experiments. Tsagaye et al. (2019) and Rai et al. (2017) reported 5 PCs with more than 1 Eigen-value contributing 78.1 and 76.64% of total variability in tomatoes. Four genotypes, VRWC 3, VRWC 4, VRWC 7 and VRWC13, were plotted on the same left portion of the PCA diagram, indicating that they are closely related genotypes. We identified another group that consisted of VRWC 1, VRWC 2, VRWC 5, VRWC6, VRWC 16 and VRWC18 on the lower right portion of the diagram. Thus, the traits coming from 9 PCs show a high degree of genetic variation and add genetic diversity between the genotypes, which could be exploited in water chestnut improvement programmes. The contributions of morphological and quality traits for the PC are shown in Table 3. Morphological traits such as single fresh nut weight (0.422), Fe content in shelled nut (0.329), Zn content in rind(0.362), Mn content in

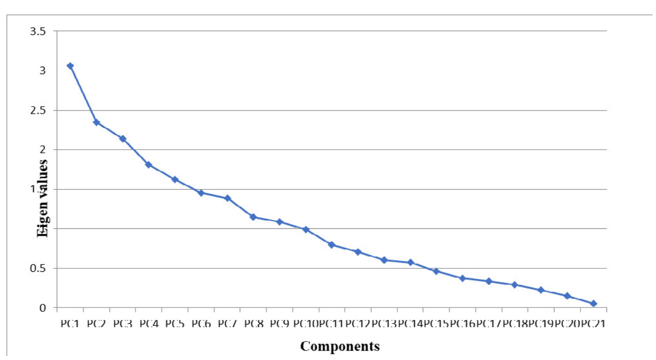

Figure 1: Scree plot for component analysis

Table 2: Mean, variances for different variables of water chestnut genotypes

Character	*Mean*	*Variance*	*Standard Deviation*	*Standard Error*
No of leaves/plant	36.78	21.549	4.642	0.774
No of fruit/plant	12.89	3.187	1.785	0.298
Pedicel length	15.06	6.379	2.526	0.421
Leaf length	4.64	0.195	0.441	0.074
Leaf width	5.58	0.196	0.443	0.074
Fruit pedicel length	5.56	0.406	0.638	0.106
No of spines	2.50	0.371	0.609	0.102
Per fresh nut weight	12.44	0.525	0.725	0.121
Shelled per nut weight	8.06	0.275	0.524	0.087
Dry per shelled nut weight	1.91	0.006	0.080	0.013
TSS	6.75	0.126	0.355	0.059
10 fresh nut weight	201.56	422.425	20.553	3.425
10 fresh shelled nut weight	49.16	9.180	3.030	0.505
Dried 10 nut rind weight	5.02	0.338	0.581	0.097
Zinc content in Shelled nut	39.88	9.356	3.059	0.510
Zn content in rind	67.84	1376.264	37.098	6.183
Fe content in shelled nut	167.14	1056.657	32.506	5.418
Fe content in rind	919.83	74691.701	273.298	45.550
Mn content in shelled nut	38.11	18.964	4.355	0.726
Mn content in rind	237.76	3788.431	61.550	10.258
Fresh nut yield per plant	539.86	16641.437	129.002	21.500

rind(0.312), number of fruit-nut per plant (0.202), Mn content in shelled nut (0.221),10 fresh nut weight(0.176), dried 10 nut rind weight(0.164), fresh fruit-nut yield per plant (0.118) and number of leaves per plant (0.049) showed maximum positive contribution towards genetic divergence and the remaining parameters showed negative loadings in PC 1. In PC 2, Fe content in shelled nut (0.405), Mn content in shelled nut(0.400), Zn content in shelled nut (0.363), Mn content in rind (0.350), dried 10 nut rind weight (0.216), single shelled nut weight (0.197), dried single shelled nut weight (0.154), single fresh nut weight (0.081) and fresh nut yield per plant (0.017) represent maximum positive factor loading. In PC 3, positive factor loading observed with leaf width (0.348), TSS(0.301), Fe content in rind (0.301), dried 10 nut rind weight (0.272), 10 fresh shelled nut weight (0.240), pedicel length (0.137), leaf length (0.116), single dried shelled nut weight (0.135) and Mn content in rind (0.041) and negligible and or negative contribution made by rest of the traits. PC 4 reflected positive factor loading by fruit pedicel length(0.363), dried 10 nut rind weight (0.289), Zn content in shelled nut (0.259), Zn content in rind (0.226), Fe content in shelled nut (0.225), number of spines (0.218), number of leaves per plant (0.212), 10 fresh shelled nut weight (0.183), TSS (0.164),10 fresh nut weight (0.148), single fresh nut weight (0.131) and leaf length (0.078) and negative contribution by rest of the traits. PC 5 correlated with single-shelled nut weight (0.440), number of fruit-nut (0.292), pedicle length (0.278), number of spines (0.271), leaf width (0.194) and fruit pedicel length (0.075) with positive factor loading whereas negative contribution by rest of the traits. In PC 6, fresh fruit nut yield per plant (0.433), leaf width (0.424), 10 fresh nut weight (0.403), dried single-shelled nut weight (0.360), pedicel length (0.192), leaf length (0.147) and TSS (0.119) showed maximum positive contribution. In PC 7,

Table 3: Eigen values, variability % and cumulative % of water chestnut genotypes

Principal Components	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Variability %	14.2	10.9	9.9	8.4	7.5	6.7	6.4	5.3	5.0
Cumulative %	14.2	25.0	34.9	43.3	50.8	57.5	63.9	69.3	74.3
Eigen values	3.062	2.345	2.136	1.813	1.621	1.450	1.384	1.150	1.088

Table 4: Contribution of first nine principal components to variation in water chestnut genotypes

Character	*PC1*	*PC2*	*PC3*	*PC4*	*PC5*	*PC6*	*PC7*	*PC8*	*PC9*
No of leaves/plant	0.049	-0.181	0.014	0.212	-0.500	0.048	0.223	-0.313	0.207
No of fruit/plant	0.202	-0.044	0.331	-0.096	0.292	0.320	0.138	0.132	0.319
Pedicel length	-0.111	-0.106	0.137	-0.136	0.278	0.192	-0.030	-0.624	-0.329
Leaf length	-0.220	-0.275	0.116	0.078	0.010	0.147	-0.054	-0.052	0.171
Leaf width	0.024	-0.061	0.348	0.131	0.194	0.424	-0.196	0.016	0.364
Fruit pedicel length	0.136	-0.006	0.276	0.363	0.075	-0.049	-0.273	0.159	-0.340
No of spines	-0.168	-0.106	-0.285	0.218	0.271	0.009	0.057	-0.341	0.192
Per fresh nut weight	0.422	0.081	0.040	0.180	-0.002	0.068	-0.013	-0.034	-0.114
Shelled per nut weight	0.028	0.197	-0.195	-0.067	0.440	-0.022	0.429	0.094	-0.148
Dry per shelled nut weight	0.222	0.154	0.135	-0.319	-0.074	0.360	-0.108	-0.006	-0.442
TSS	-0.087	0.135	0.301	0.164	-0.012	0.119	0.556	-0.064	-0.145
10 fresh nut weight	0.176	0.104	-0.235	0.148	-0.072	0.403	0.140	0.318	-0.056
10 fresh shelled nut weight	-0.111	-0.301	0.240	0.183	-0.337	0.064	0.181	0.062	-0.285
Dried 10 nut rind weight	0.164	0.216	0.272	0.289	0.115	-0.317	0.257	-0.122	0.011
Zinc content in Shelled nut	-0.371	0.363	-0.008	0.259	-0.043	0.017	-0.001	-0.103	0.092
Zn content in rind	0.362	-0.220	-0.143	0.226	0.102	0.055	-0.148	-0.072	-0.269
Fe content in shelled nut	0.329	0.405	0.036	0.225	-0.085	0.110	-0.139	0.183	-0.000
Fe content in rind	0.071	-0.038	0.301	-0.470	-0.146	-0.182	0.173	0.101	0.073
Mn content in shelled nut	0.221	0.400	0.070	-0.048	-0.173	0.051	-0.264	-0.279	0.085
Mn content in rind	0.312	0.350	0.041	-0.160	-0.163	0.028	-0.010	-0.274	0.069
Fresh nut yield per plant	0.118	0.017	-0.353	-0.053	-0.205	0.433	0.217	-0.060	-0.002

Table 5: Principal factor scores of different water chestnut genotypes in nine principal factors

Genotypes	*PC 1*	*PC 2*	*PC 3*	*PC 4*	*PC 5*	*PC 6*	*PC 7*	*PC 8*	*PC 9*
VRWC 1	4.231	0.610	-0.230	0.344	-0.465	4.063	1.459	-0.082	0.596
VRWC 2	-0.057	-2.234	-0.446	-1.564	-0.789	-0.628	-1.215	-0.699	0.231
VRWC 3	-3.583	0.719	-3.155	0.699	1.248	0.728	1.304	-1.087	-0.173
VRWC 4	-1.010	1.853	-0.896	-2.923	1.385	0.638	-0.475	2.329	-0.676
VRWC 5	3.129	1.797	-1.331	-0.805	1.753	0.329	-0.790	0.198	-1.826
VRWC 6	1.186	0.384	-0.299	-2.263	3.232	-0.425	-0.141	-2.247	2.517
VRWC 7	-2.348	0.758	-0.676	0.227	1.718	-1.161	-0.003	-0.522	0.197
VRWC 8	-2.954	-0.529	-0.230	-1.324	0.542	0.852	0.327	1.137	-1.110
VRWC 9	2.746	-0.018	-0.903	1.271	1.022	-3.330	0.374	0.863	-0.202
VRWC 10	0.667	-1.207	-0.862	-0.506	-1.374	-0.961	-0.879	-0.418	1.052
VRWC 11	0.816	3.438	0.008	0.138	-0.690	-0.141	0.026	-0.060	0.409
VRWC 12	-0.932	-0.170	0.325	0.165	-0.238	0.760	0.372	0.872	1.851
VRWC 13	0.518	-1.716	-0.582	1.649	0.137	-0.373	0.473	1.400	-0.986
VRWC 14	0.621	-0.772	0.130	-0.880	0.639	-0.098	3.078	0.169	-0.606
VRWC 15	-1.403	1.478	1.518	1.358	-1.255	-0.699	1.502	0.975	-0.416
VRWC 16	-0.046	1.374	-2.098	1.046	-1.642	0.338	0.300	0.527	0.041

VRWC 17	2.068	-0.472	0.134	-0.149	-1.667	-0.509	-0.264	0.340	-0.002
VRWC 18	1.237	-2.306	-0.901	-0.463	-2.045	0.006	1.032	1.506	1.798
VRWC 19	-2.395	-0.402	-1.941	2.319	0.533	-0.277	0.153	0.245	0.758
VRWC 20	-0.096	1.798	-0.582	-0.940	-1.811	-1.291	-0.777	0.713	1.136
VRWC 21	0.975	-0.459	-1.223	0.364	0.349	0.946	-2.208	-0.509	0.172
VRWC 22	1.281	0.223	2.042	-1.332	0.338	0.389	0.393	-1.011	-0.254
VRWC 23	-2.752	-0.915	0.629	-0.507	-0.619	1.988	-2.218	-0.325	-0.394
VRWC 24	-1.303	-0.378	1.506	-0.681	0.853	0.687	0.740	1.812	0.234
VRWC 25	1.750	-0.887	0.417	3.039	0.703	1.538	-1.494	-0.673	-1.667
VRWC 26	1.390	-0.525	-1.028	-0.746	0.373	0.100	1.996	-0.964	-0.719
VRWC 27	-0.668	2.718	1.566	0.047	-1.684	-0.381	1.055	-1.864	-1.476
VRWC 28	-1.858	-0.492	3.223	-0.184	-0.887	-0.464	0.696	-1.894	-0.353
VRWC 29	-0.233	-3.170	0.660	1.021	-0.295	0.894	-0.211	-0.599	0.319
VRWC 30	-0.039	-2.218	0.033	-1.548	-0.851	-0.959	0.800	-1.074	-0.106
VRWC 31	-0.179	1.605	-1.769	1.835	-1.099	-0.940	-0.618	-1.523	-0.002
VRWC 32	-0.968	1.168	0.261	-1.938	-1.878	0.563	-1.539	0.259	-0.815
VRWC 33	0.654	-1.225	-0.391	-0.587	0.349	-1.329	-1.981	0.364	-1.203
VRWC 34	-0.159	-2.147	1.777	0.532	1.547	-0.990	0.282	0.571	-1.39
VRWC 35	1.556	0.442	1.201	2.085	1.384	0.873	-0.354	0.207	1.785
VRWC 36	1.273	1.879	4.112	1.200	1.183	-0.737	-1.195	1.061	1.284

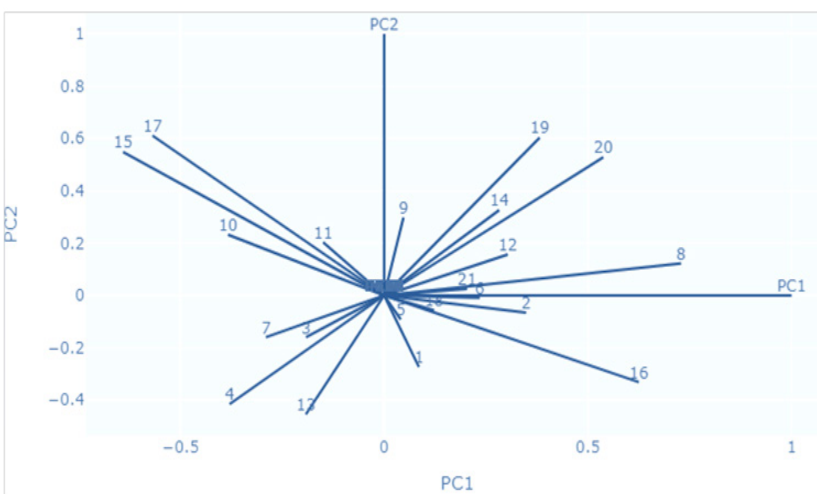

Figure 2: PCA score plot of PC1 and PC2 of 36 water chestnut genotypes

TSS (0.556), single shelled nut weight (0.429), dried 10 nut weight (0.257), number of leaves per plant (0.223), 10 fresh shelled nut weight (0.181), 10 fresh nut weight (0.140) and number of fruit-nut per plant (0.138) showed maximum positive contribution. In PC8, 10 fresh nut weight (0.318), Fe content in shelled nut (0.183), fruit pedicel length (0.159) and number of fruit-nut (0.132) showed maximum positive factors. In PC 9, leaf width (0.364), number of fruit-nut per plant (0.319), number of leaves per plant (0.207), number of spines (0.192) and leaf length (0.171) showed positive contribution and rest traits showed negative contribution (Table 4). Positive contribution indicated significant variation in the number of fruit-nut per plant, fresh fruit-nut weight, shelled nut weight, 10 fresh nut weight, fresh fruit-nut yield per plant, Zn, Fe and Mn content in shelled nut and Fe, Zn and Mn content in rind so it plays an important role for selection on the basis of these important traits. Sehgal et al. (2021) reported that total fruits per plant and days to first fruiting contributed more positively to PC in tomatoes. Hussain et al. (2018) reported that the traits of plant height,

Table 6: Correlation matrix in water chestnut genotypes

Character	*NFP*	*PL*	*LL*	*LW*	*FPL*	*NS*	*PFNW*	*SPNW*	*DPSNW*	*TSS*	*10NFW*	*10FSNW*	*10DNRW*	*ZCSN*	*ZCR*	*FeCSN*	*FeCR*	*Mn CSR*	*MnCR*	*FNYPP*
NLP	-0.072	-0.072	0.056	-0.006	-0.095*	-0.020	0.136*	-0.265**	-0.203	0.116*	-0.036	0.351**	-0.001	-0.039	0.059	-0.105	-0.049	0.020	-0.021	0.188**
NFP	1.00	0.036	-0.034	0.470**	0.054	-0.105	0.249**	0.068	0.025	0.189**	0.098	-0.037	0.108	-0.269**	0.043	-0.259**	0.178*	0.074	0.078	-0.127**
PL		1.00	0.177**	0.156*	-0.034	0.119*	-0.102	0.057	0.269*	0.082	-0.218	0.025	-0.042	0.060	0.043	-0.127	0.028	-0.065	-0.072	-0.067
LL			1.00	0.165*	0.001	0.165*	-0.216*	-0.224**	0.058	-0.018	0.003	0.205**	-0.069	0.103*	-0.126*	-0.011	0.048	-0.313**	-0.279**	-0.101**
LW				1.00	0.204	-0.090	0.036	-0.146	-0.015	0.088	-0.078	0.060	0.029	-0.050	0.033	0.137*	-0.052	0.033	-0.038	-0.046
FPL					1.00	-0.063	0.276**	-0.176*	-0.057	0.081	0.043	0.141*	0.310	-0.088	0.205**	0.017	-0.059	0.148**	-0.078	-0.184**
NS						1.00	-0.226*	0.116*	-0.144	-0.059	-0.005	-0.057	-0.063	0.190*	-0.047	-0.059	-0.366	-0.127	-0.254**	0.095
PFNW							1.00	0.065	-0.210*	-0.034**	0.199**	-0.130	0.259	-0.247**	0.456**	-0.199*	-0.051	0.249**	0.356**	0.124**
SPNW								1.00	-0.020	0.122	0.109*	-0.279**	0.168	-0.019	-0.034	0.076	-0.085	-0.075	-0.010	0.125
DPSNW									1.00	0.117	-0.046	0.107	-0.285	0.153*	-0.343**	0.298**	0.093	0.088	0.029	0.022
TSS										1.00	-0.014	0.227**	0.288	0.268**	-0.171*	0.150	0.066	-0.086	0.041	-0.031
10NFW											1.00	-0.048	-0.006	-0.006	0.223	-0.002	-0.155*	0.082	0.195*	0.395**
10FSNW												1.00	0.014	-0.098	0.005	-0.025	0.049	-0.250**	-0.272**	-0.086
10DNRW													1.00	0.096	0.028	0.022	0.089	0.212*	0.271**	-0.219**
ZCSN														1.00	-0.448	0.779**	-0.269**	0.034	-0.066	-0.134*
ZCR															1.00	-0.403	-0.274*	0.005	0.086	0.100
FeCSN																1.00	-0.258*	0.155*	-0.129	-0.093
FeCR																	1.00	0.064	0.146*	-0.070
Mn CSR																		1.00	0.587**	0.084
MnCR																			1.00	0.114**
FNYPP																				1.00

*,** significant at 5% and 1% level , respectively, where No of leaves/plant (NLP); No of fruit/plant (NFP); Pedicel length (PL),; Leaf length (LL); Leaf width (LW); Fruit pedicel length (FPL); No of spines (NS); Per fresh nut weight (PFNW); Shelled per nut weight (SPNW); Dry per shelled nut weight (DPSNW); TSS; 10 nut fresh weight (10NFW); fresh shelled nut weight (10 FSNW); Dried 10 nut rind weight (10 DNRW); Zinc content in Shelled nut(ZCSN); Zn content in rind (ZCR); Fe content in shelled nut(FeCSN); Fe content in rind(FeCR); Mn content in shelled nut(Mn CSR); Mn content in rind (MnCR); Fresh nut yield per plant (FYNPP).

fruit length and fruit width contributed more positively to PC in tomatoes. Kumar et al. (2017) reported that fruit yield per plant contributed more positively to PC in tomatoes. Positive contribution indicates the importance of these traits for altering quality traits of fruit-nut, so it plays an important role in selection on the basis of fruit quality, particularly mineral compositions. Traits coming jointly from different PCs have an affinity to stay together, which may be utilized in a breeding programme to create improvement for yield and quality of fruit- nuts of water chestnut. From Table 3, it is observed that genotypes *viz*., VRWC 1, VRWC 5, VRWC 6, VRWC 9, VRWC 10, VRWC 11, VRWC 13, VRWC 14, VRWC 17, VRWC 18, VRWC 22, VRWC 25, VRWC 26, VRWC 35 and VRWC 36 made maximum contributions to variation. In Figure 2, the score plot obtained revealed the clear separation, which pointed out the variations among the water chestnut genotypes. The correlation matrix studied in the present investigation showed that the number of fruit-nut yields per plant is positively correlated with the number of leaves per plant, single fresh nut weight, single shelled nut weight, 10 fresh nut weight and Mn content in rind (Table 5). These traits could not be ignored during the selection for water chestnut improvement programs. The summation of these results may provide information about the importance of the characters studied among all accessions analyzed. Our study provides better insight regarding the relationship between various characters (Table 6) determining either the number and yield of fruit nut per plant and provides information on the likely interest of a particular accession as a donor for initial breeding to develop stable and quality high yielding varieties of water chestnut.

Conclusion

The present research revealed nine principal components, explained 74.3% of the total variations, thus suggested that water chestnut traits as number of leaves per plant, number of fruit-nut per plant, single fresh nut weight, dried single shelled nut weight, 10 fresh nut weight, TSS, fresh nut yield per plant and among quality traits specifically minerals viz., Zn content in rind, Fe content in shelled nut, Mn content in shelled nut and rind were the principal discriminatory traits. Therefore, the important traits coming jointly from diverse PCs and contributing towards elucidation variability may be kept into consideration during the utilization of these traits in breeding/improvement programmes of water chestnut genotypes.

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सारांश

उपज और उपज में योगदान देने वाले गुणों को सुधार कार्यक्रम में सबसे अधिक लक्षित किया जाता है, इसलिए विविधता की उपस्थिति पौध प्रजनन में अत्यधिक महत्वपूर्ण है। वर्तमान अध्ययन में, सिंघाड़ा की 36 जीनोटाइप्स का मूल्यांकन किया गया, जो भविष्य के प्रजनन कार्यक्रम के लिए जीनोटाइप्स और गुणों का चयन करने के लिए गुणवत्ता लक्षणों के आधार पर प्रमुख घटक विश्लेषण (PCA) के साथ किया गया। 21 लक्षणों के साथ PCA के आधार पर 21 घटक बनाए गए, हालांकि, 9 पीसी में 1 से अधिक Eigen value था और विविधता का 74.3% था। इसलिए, इन नौ पीसी का आगे की जांच के लिए उपयोग किया गया। पहला प्रमुख घटक कुल भिन्नताओं में से अधिकतम भिन्नता प्रदर्शित करता है। पीसी 1 पौधे पर पत्तियों की संख्या, पौधे पर फल-नट की संख्या, ताजे नट का एकल वजन, सूखे छिलके वाले नट का वजन, छिलके में जस्ता (Zn) की सामग्री, छिलके वाले नट में लौह (Fe) की सामग्री, छिलके और नट में मैंगनीज (Mn) की सामग्री और पौधे पर ताजे नट की उपज के साथ सहसंबद्ध था जबकि पीसी 2 ने छिलके वाले नट में लौह की सामग्री, छिलके वाले नट में मैंगनीज की सामग्री, छिलके में मैंगनीज की सामग्री और TSS (कुल घुलनशील ठोस) का प्रभुत्व था। पीसी 3 के लक्षणों के साथ सहसंबद्ध था जैसे कि पौधे पर फल-नट की संख्या, पत्ती की चौड़ाई, फल की डंठल की लंबाई, TSS, 10 ताजे नट का वजन और छिलके में लौह की सामग्री। पीसी 4 ने फल की डंठल की लंबाई, 10 सूखे नट के छिलके का वजन और छिलके में जस्ता की सामग्री के द्वारा सकारात्मक कारक भार को प्रतिबिंबित किया। पीसी 5 पौधे पर एकल छिलके वाले नट के वजन और फल-नट की संख्या के साथ सकारात्मक कारक भार के साथ सहसंबद्ध था। पीसी 6 पत्ती की चौड़ाई, सूखे एकल छिलके वाले नट, 10 ताजे नट के वजन के साथ सहसंबद्ध था। पीसी 7, एकल छिलके वाले नट के वजन, 10 सूखे नट के छिलके के वजन और पौधे पर पत्तियों की संख्या के साथ सकारात्मक रूप से सहसंबद्ध था। पीसी 8 के लक्षणों के साथ सहसंबद्ध था जैसे 10 ताजे नट का वजन, छिलके वाले नट में लौह की सामग्री और पौधे पर फल-नट की संख्या। पीसी 9, पत्ती की चौड़ाई, पौधे पर फल-नट की संख्या और पौधे पर पत्तियों की संख्या के उच्च मूल्यों के साथ सकारात्मक रूप से सहसंबद्ध था। इसलिए, विभिन्न पीसी से संयुक्त रूप से आने वाले महत्वपूर्ण लक्षण और विविधता को स्पष्ट करने में योगदान करने वाले लक्षणों को सिंघाड़ा के सुधार कार्यक्रम में इन लक्षणों के उपयोग के दौरान ध्यान में रखा जा सकता है।