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Unveiling the genetic variability, character association and principal component analysis for yield and yield contributing traits in brinjal (*Solanum melongena*) genotypes

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ABSTRACT

The experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2023 and 2024 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to assess 45 brinjal (*Solanum melongena* L.) genotypes for growth and yield related parameters. The experiment was laid out in randomized block design (RBD) with three replications. The result showed high genotypic coefficient of variance (GCV) and phenotypic coefficient of variance (PCV) values for plant height, number of primary branches/plant, length of fruit and weight of fruit and yield/plant. Whereas, the traits such as days to first flowering, days to 50% flowering, fruit girth, fruit borer infestation and number of fruits/plant exhibited medium GCV and PCV values. The registered high heritability values ranged from 94.29–99.49% and genetic advance as a percentage of the mean ranged from 19.25–70.25%. Correlation analysis on number of fruits/plant showed positive and significant association with fruit yield/plant. Principal component analysis showed four principal components with eigen values of unity and accounted for 75.81% of total variance.

Keywords: Brinjal, Correlation, Genotypes, Heritability, PCA, Variability

Brinjal (*Solanum melongena* L.) is an important vegetable crop in the Solanaceae family with a chromosome number of 2n=24. Brinjal is said to be most diverse in the region that encompasses India and IndoChina. It is grown extensively in China, India, Japan, Egypt, Turkey, Italy, Indonesia, Iraq, Syria, Spain, and the Philippines (Sidhu and Dhatt 2006). Brinjal is considered as second most economically important crop after tomato, with a total production of approximately 12.81 Mt (Indiastat 2024). Since eggplant is grown year round or three times a year, fruit are accessible on the market throughout the year long. Brinjal fruits are rich in vitamins (A, B, E, and K) and minerals. It also possesses antioxidant and phytochemical properties. It contains 7.4–9.0 mg of calcium, 0.2–0.24 mg of iron, 13.5–14 mg of magnesium, 22.5–25 mg of phosphorus and 129–130 mg of potassium (Naeem and Ugur 2019). The fruits are beneficial in treating a number of conditions, including high blood pressure, dysentery, asthma, osteoporosis, diabetes, bronchitis, heart disease, and strokes (Seneff *et al.* 2011). Eggplant in India has more diversity in terms of qualitative and quantitative characters (Swamy 2023).

A population with a high degree of variability is the potential to generate a variety with desirable traits through selection (Mahalingam *et al.* 2020). Correlation studies measure the genetic relationship of the characters and highlight the characteristics that could be used as a selection index. Plant breeders often measure a vast array of attributes, some of which may lack the discriminating power necessary for managing, describing, and assessing germplasm. Principal component analysis (PCA) is a crucial technique for determining the plant characteristics that classify the variation among the genotypes that show promise. PCA ranks the genotypes according to PC scores and determines the smallest number of components that can account for the greatest variability within the total variability (Edukondalu *et al.* 2024). Therefore, an attempt was made in this study to examine the variability and association of characters among the brinjal genotypes in order to determine the traits that contribute to high yield.

MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2023 and 2024 at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. A total of 45 brinjal genotypes gathered from various locations of

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Tamil Nadu were used as base material for this experiment (Supplementary Table 1). The experiment was laid out randomized block design (RBD) with three replications. The standard package of practices were adopted uniformly throughout the cropping period. The following observations, viz. plant height (cm), number of primary branches, days to first flowering, days to 50% flowering, days to first harvesting, fruit length (cm), fruit girth (cm), fruit weight (g), fruit borer incidence (%) number of fruit/plant and fruit yield (kg/plant) were recorded. On the basis of mean fruit borer damage all genotypes were categorized in different categories and grades (1, Immune: 0% infestation; 2, Highly resistant: 1–10% infestation; 3, Moderately resistant: 11–20%; 4, Tolerant: 21–30%; 5, Susceptible: 31–40%; 6, Highly susceptible: Above 40%) were assigned for the fruit damage (Mishra *et al.* 1988). Variability parameters, heritability and genetic advance as per cent of mean were estimated as per Johnson *et al.* (1955). The R software version 4.2.1 (R core team 2021) was used to perform an ANOVA on each quantitative trait. The significance of the treatment mean squares were assessed at the 5% and 1% probability levels. The coefficient of variation at the genotypic and phenotypic levels was computed using Burton and Devane (1953) method.

Using Lush's method (1949), the phenotypic and genotypic variance as well as the heritability (h^2) in percentage were determined. The heritability percentage was classified in accordance with the recommendations of Robinson and Cockerham (1965). Johnson *et al.* (1955) classified GAM into three categories, viz. low (0–10%); 10–20% (moderate); and more than 20% (high). As per the approach of Miller *et al.* (1958) corresponding variance and covariance components were used to evaluate the correlation coefficients at genotypic levels. Principal component analysis identifies the variable or characteristic that clusters or groups a population. Using Grapes software PCA was carried out.

RESULTS AND DISCUSSION

The pooled average performance of brinjal germplasm for growth and yield-related traits is displayed in Table 1 and Supplementary Fig. 1. The highest plant height was recorded in SM 34 (120.45 cm), while the lowest was in SM 36 (46.78 cm). The number of primary branches ranged from 13.25 in SM 24 to 2.95 in SM 38. The earliest flowering was registered in SM 11 (29.70 days). The genotype SM 35 took minimum duration for days to 50% flowering (43.17 days), which was followed SM 12 (43.26 days), SM 22 (43.83 days), SM 16 (44.64 days) and SM 11 (44.85 days). The minimum of 50.85 days taken for first harvest by the genotype SM 11, which was closely followed by 52.84 days in SM 22 and 54.33 days in SM 12. The maximum fruit length was reported in SM 22 (20.96 cm), while the smallest was observed in SM 42 (5.48 cm). The average fruit girth of 13.81 cm was recorded by the genotypes evaluated with a range from 10.36 cm (SM 6)–22.66 cm (SM 13) and 27 genotypes were found to produce slender fruits which recorded lesser values than the average.

Fruit weight/fruit was maximum in SM 13 (109.40 g) and minimum in SM 1 (36.40 g). Fruit borer infestation was minimum of 12.43% (SM 5) with mean value of 16.71%. The genotypes SM 12 (12.78%), SM 12 (13.61%) and SM 12 (13.63%) were recorded the tolerant level of less than 14% fruit borer infestation. Fruit number/plant was maximum in SM 5 (44.82), followed by SM 26 (42.94), SM 2 (42.62), SM 39 (41.23), SM 23 (40.80), SM 7 (40.45) and SM 18 (40.45). The maximum fruit yield/plant of 2.92 kg was registered by SM 5. Totally 21 genotypes excelled the average yield of 2.13 kg/plant. The genotypes SM 26 (2.88), SM 39 (2.82), SM12 (2.80), SM 23 (2.78), SM 35 (2.752) and SM 16 (2.51) recorded the desirable yield level of more than 2.5 kg/plant. Similar evaluation studies on brinjal were conducted and best performing genotypes were identified for the desirable traits by Sahu *et al.* (2022), Varshik *et al.* (2023) and Verma *et al.* (2023).

The results on variability, heritability and genetic advance as percent of mean are projected in Supplementary Table 2. The traits under investigation had higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV), suggesting that the expression of the traits was impacted by both genetic and environmental factors. These findings are in agreement with Vidhya and Kumar (2015) and Balas *et al.* (2019). According to Deshmukh (1986), there are three categories for the coefficient of variation: high (>20%), medium (10 to 20%), and low (<10%) at the phenotypic and genotypic level. In the present study high GCV and PCV values were found for plant height, number of primary branches per plant, length and weight of fruits and yield per plant. High PCV and GCV values contribute to high degree of variation hence selection is effective for improvement of traits. Whereas, the traits such as days to first flowering, days to 50% flowering, fruit girth, fruit borer infestation and number of fruits per plant exhibited medium GCV and PCV values. These results were in accordance with Thomas *et al.* (2022). For the trait days to first harvest, low GCV and PCV values were found, suggesting that selection might not be successful.

A higher percentage of additive genetic variability can result in large genetic gain, high heritability and significant genetic advancement. Heritability values are helpful in estimating the potential progress that could be achieved through selection. Singh (2000) categorized heritability values as low (<40%), medium (40–59%) and high (60–80%). The study reported high heritability values ranged from 94.29–99.49%, indicating that the genetic factors account for a substantial portion of the variation in the trait. The genetic advance as a percentage of the mean ranged from 19.25–70.25%, suggesting significant potential for improving the trait mean through selective breeding based on genetic merit. Similar reports on high heritability coupled with high GAM were reported by Barik *et al.* (2021) and Chaudhary *et al.* (2023).

Estimates of correlation coefficients on the genotypic levels in all possible combinations are given in Table 2. Plant height showed significant negative genotypic correlation

Table 1 Pooled mean performance of brinjal genotypes for different horticultural traits

Accession	PH	PB	DTFF	DFPF	DTFH	FL	FG	FW	FB	NFPP	YPP
SM 1	83.46	4.61	42.7	53.62	61.6	9.12	12.18	36.40	18.26	34.82	1.27
SM 2	75.24	3.60	35.32	46.23	56.35	9.68	13.42	56.64	16.40	42.62	2.41
SM 3	78.52	5.43	34.26	48.26	57.36	6.54	10.78	42.06	17.67	35.83	1.51
SM 4	108.52	9.22	40.71	52.84	59.75	8.46	11.84	75.24	15.64	30.83	2.31
SM 5	65.66	8.27	35.43	46.40	56.42	11.66	15.32	65.06	12.43	44.82	2.92
SM 6	71.96	6.61	38.72	51.89	61.82	11.18	10.36	48.32	14.12	39.41	1.90
SM 7	71.70	4.41	38.27	48.22	57.23	9.00	16.40	49.80	16.45	40.45	2.01
SM 8	96.60	5.83	37.13	49.20	58.38	9.40	11.36	69.42	16.87	29.03	2.02
SM 9	92.40	5.63	34.15	46.25	57.33	6.90	11.98	57.94	17.03	32.43	1.87
SM 10	100.68	3.60	42.82	55.86	61.84	9.22	16.18	71.24	18.04	32.59	2.32
SM 11	87.56	7.60	29.77	44.85	50.85	8.28	11.98	67.96	18.43	36.46	2.48
SM 12	57.34	7.27	31.14	43.26	54.33	8.50	13.26	76.50	12.78	36.66	2.80
SM 13	81.26	4.83	42.85	52.86	61.83	8.96	22.66	109.40	14.35	18.34	2.01
SM 14	68.00	7.22	42.65	55.66	63.73	6.68	11.14	56.98	16.34	39.41	2.24
SM 15	55.56	5.84	42.83	54.88	65.87	11.84	16.02	90.40	17.47	27.04	2.44
SM 16	92.56	7.22	35.62	44.64	54.63	11.56	14.98	66.44	15.90	37.81	2.51
SM 17	72.40	6.62	36.32	47.23	57.25	10.84	16.16	65.72	16.12	35.82	2.35
SM 18	66.64	9.41	34.22	48.20	57.83	12.10	14.02	60.10	15.47	40.45	2.43
SM 19	78.26	8.85	39.2	49.20	58.22	8.64	14.42	64.78	18.83	31.82	2.06
SM 20	75.90	7.60	42.22	53.22	63.24	7.98	13.44	63.14	19.47	39.27	2.48
SM 21	68.98	6.44	39.81	49.83	62.83	18.70	12.06	69.14	17.93	35.62	2.46
SM 22	72.24	8.00	33.82	43.83	52.84	20.96	11.94	63.94	16.56	39.01	2.49
SM 23	50.32	8.22	36.44	48.46	57.41	10.02	18.40	68.16	14.34	40.80	2.78
SM 24	72.02	13.25	41.24	53.27	64.3	9.42	18.80	69.14	16.34	30.62	2.11
SM 25	55.54	4.20	36.61	46.60	55.67	8.08	13.00	55.36	18.47	36.27	2.01
SM 26	78.07	6.51	49.22	60.17	70.17	8.28	12.34	67.01	14.31	42.94	2.88
SM 27	71.25	5.22	47.34	59.34	70.43	7.27	11.54	64.99	15.17	30.23	1.96
SM 28	84.47	5.78	51.35	61.34	70.34	7.15	13.47	61.22	15.00	24.02	1.47
SM 29	73.04	5.22	51.02	62.45	72.34	8.44	11.20	62.07	18.15	30.32	1.88
SM 30	69.42	4.30	50.54	62.50	73.56	14.30	15.63	54.42	19.26	35.23	1.92
SM 31	90.23	7.54	43.13	53.15	62.15	12.23	16.33	37.23	18.26	28.56	1.06
SM 32	80.25	6.30	44.44	51.30	65.32	18.43	12.89	53.43	19.67	29.23	1.56
SM 33	81.45	4.45	42.25	54.25	65.23	13.46	13.45	75.52	17.35	29.76	2.25
SM 34	120.45	8.82	36.54	46.50	55.44	8.87	12.32	64.86	18.16	37.69	2.44
SM 35	119.16	8.47	36.17	43.17	57.14	8.00	13.89	77.23	13.63	35.68	2.75
SM 36	46.78	4.65	49.33	61.23	72.21	13.52	11.30	53.01	16.33	35.76	1.90
SM 37	90.34	5.76	48.15	53.15	67.19	12.67	12.41	51.52	16.25	39.33	2.02
SM 38	63.42	2.95	49.25	60.26	70.24	14.01	15.32	59.18	18.58	31.53	1.87
SM 39	105.71	6.22	41.31	53.00	64.77	7.76	14.35	68.58	13.61	41.23	2.82
SM 40	80.23	7.92	47.53	57.57	66.51	11.15	12.43	49.17	15.75	30.27	1.49
SM 41	119.09	7.38	50.36	61.34	71.43	5.84	13.78	48.60	17.23	32.14	1.56
SM 42	80.69	6.27	35.84	47.84	58.87	5.48	14.56	57.79	20.55	35.66	2.06
SM 43	88.44	5.65	36.15	46.17	55.12	6.08	13.23	54.02	18.61	39.79	2.15
SM 44	86.45	7.49	35.12	48.47	56.11	6.40	13.21	52.31	17.45	32.18	1.68
SM 45	95.84	6.93	33.88	47.84	56.44	6.92	15.53	54.22	16.62	34.84	1.88
SEd	1.09	0.10	0.55	0.76	0.84	0.14	0.23	0.86	0.27	0.46	0.03
Mean	80.54	6.52	40.51	51.68	61.55	10.00	13.81	61.90	16.70	34.77	2.13
CD (*P*=0.05)	3.04	0.28	1.55	2.13	2.36	0.39	0.63	2.42	0.75	1.28	0.08
CV%	2.34	2.67	2.37	2.54	2.37	2.44	2.83	2.42	2.76	2.28	2.41

PH, Plant height (cm); PB, Number of primary branches; DTFH, Days to 1st harvesting; DTFF, Days to 1st flowering; DFPF, Days to 50% flowering; FL, Fruit length (cm); FB, Fruit borer incidence (%); FG, Fruit girth (cm); FW, Fruit weight (gm); NFPP, Number of fruits/plant; YPP, Yield/plant (kg/plant).

Table 2 Genotypic correlation coefficient among quantitative traits of brinjal genotypes

Quantitative traits	PH	PB	DTFF	DFPF	DTFH	FL	FG	FW	FB	NFPP	YPP
PH	1.00	0.178	-0.045	-0.112	-0.128	-0.328*	-0.091	-0.007	0.042	-0.127	-0.083
PB		1.00	-0.294*	-0.292*	-0.282*	-0.047	0.099	0.108	-0.239	0.104	0.243
DTFF			1.00	0.961**	0.974**	0.127	-0.013	-0.100	0.107	-0.373**	-0.388**
DFPF				1.00	0.975**	0.019	-0.042	-0.101	0.108	-0.374**	-0.393**
DTFH					1.00	0.127	-0.051	-0.075	0.066	-0.338*	-0.331*
FL						1.00	-0.008	0.030	0.087	0.013	0.057
FG							1.00	0.455**	-0.124	-0.278	0.112
FW								1.00	-0.343*	-0.329*	0.594**
FB									1.00	-0.198	-0.455**
NFPP										1.00	0.548**
YPP											1.00

* and **, Significant at 5 % and 1 % probability level, respectively. PH, Plant height (cm); PB, Number of primary branches; DTFF, Days to 1st flowering; DFPF, Days to 50% flowering; DTFH, Days to 1st harvesting; FL, Fruit length (cm); FG, Fruit girth (cm); FW, Fruit weight (gm); FB, Fruit borer incidence (%); NFPP, Number of fruits/plant; YPP, Yield/plant (kg/plant).

with fruit length. Number of branches per plant recorded significant negative correlation with days to 1st flowering, days to 50% flowering and days to 1st harvest. Days to 1st flowering showed a significant positive correlation with days to 50% flowering, days to 1st harvest and negative significant correlation with number of fruits/plant, yield/plant. Days to 50% flowering had positive correlation with days to 1st harvest and negative correlation with number of fruits/plant and yield/plant. Days to 1st harvest recorded significant negative correlation with number of fruits/plant and yield/plant. Fruit girth had significant positive association with fruit weight. Fruit weight recorded significant negative association with fruit borer infestation, number of fruits/plant and positive association with yield/plant. Fruit borer infestation had significant negative association with yield/plant. Number of fruits/plant recorded positive association with yield per plant. Previous studies by Sonagara *et al.* (2022) and Gangadhara *et al.* (2023) corroborated these findings.

Principal component analysis was performed to determine the source and structure of variation, as well as the contribution of observable attributes to overall variability (Mahalingam *et al.* 2020). In this study four principal components with eigenvalues greater than unity, accounting for 75.13% of total variance were chosen since it allows for a more effective reduction of dimensionality

Table 3 Eigenvalues and percentage of variation for different traits of brinjal genotypes

Component axis	Principle component characters	Eigen value	Percentage of variance	Cumulative percentage of variance	Component loading			
					1 vector	2 vector	3 vector	4 vector
1	PH	3.59	32.63	32.63	-0.046	0.124	0.545	0.380
2	PB	1.94	17.62	50.26	-0.231	-0.098	0.163	0.239
3	DTFF	1.51	13.73	63.98	0.486	-0.159	-0.087	0.195
4	DFPF	1.23	11.15	75.13	0.485	-0.150	-0.082	0.220
5	DTFH	0.87	7.88	83.01	0.477	-0.177	-0.148	0.214
6	FL	0.73	6.66	89.67	0.056	-0.085	-0.442	-0.454
7	FG	0.56	5.10	94.77	-0.044	-0.455	0.244	-0.333
8	FW	0.49	4.46	99.22	-0.135	-0.614	0.130	-0.092
9	FB	0.04	0.36	99.58	0.174	0.372	0.159	-0.452
10	NFPP	0.03	0.30	99.89	-0.271	0.229	-0.498	0.304
11	YPP	0.01	0.11	100.00	-0.344	-0.338	-0.307	0.208

PH, Plant height (cm); PB, Number of primary branches; DTFF, Days to 1st flowering; DFPF, Days to 50% flowering; DTFH, Days to 1st harvesting; FL, Fruit length (cm); FG, Fruit girth (cm); FW, Fruit weight (gm); FB, Fruit borer incidence (%); NFPP, Number of fruits/plant; YPP, Yield/plant (kg/plant).

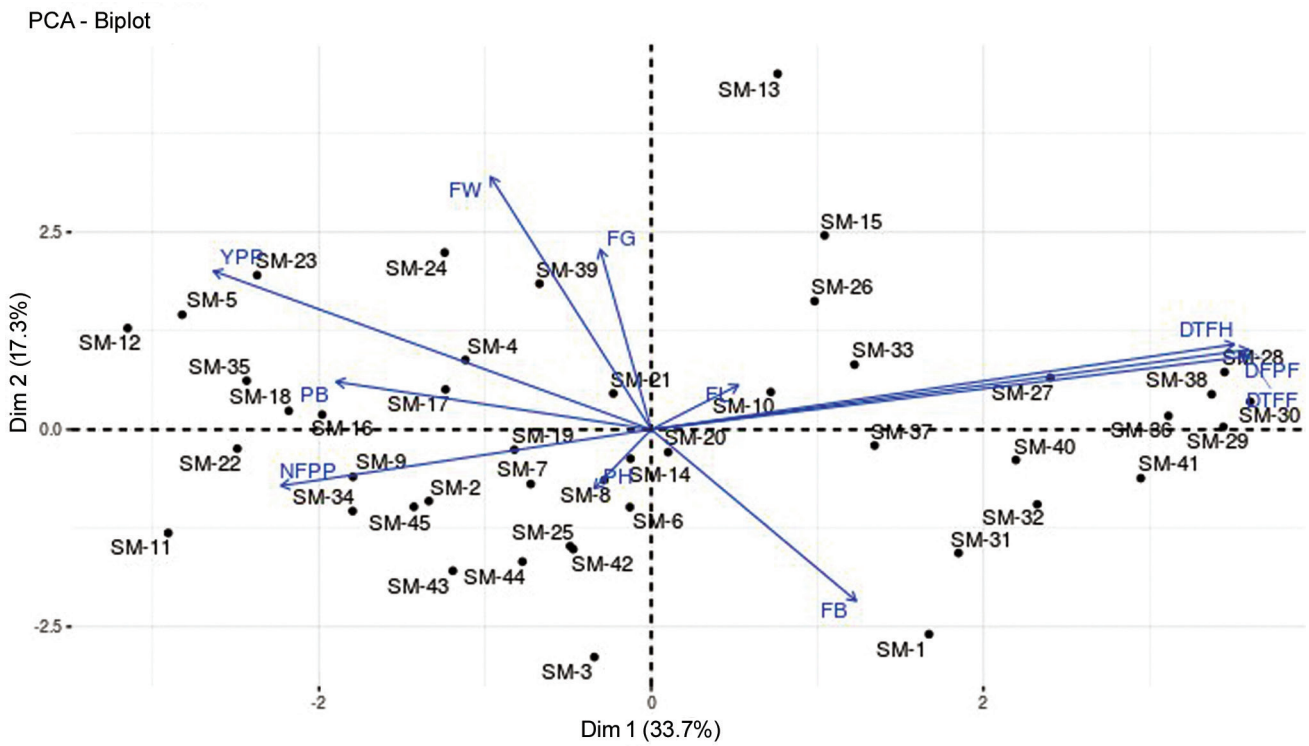

Fig. 1 Biplot of 45 brinjal genotypes.
PH, Plant height (cm); PB, Number of primary branches; DTFF, Days to 1st flowering; DFPF, Days to 50% flowering; DTFH, Days to 1st harvesting; FL, Fruit length (cm); FG, Fruit girth (cm); FW, Fruit weight (gm); FB, Fruit borer incidence (%); NFPP, Number of fruits/plant; YPP, Yield/plant (kg/plant).

and retains significant variance information. Barik *et al.* (2021) and Singh *et al.* (2024) also obtained four principal components with eigenvalues of unity contributing 83.61% and 90.30 % of total variance respectively. Among the PCs, PC1 provided a substantial share of total variance (32.63) and had an eigenvalue of 3.59. Principal components, PC2, PC3 and PC4 showed total variance percentage of 17.62, 13.73 and 11.15 with the eigenvalues 1.94, 1.51 and 1.23, respectively. Remaining components from PC5–PC10 had little or no variation since the eigenvalue is less than one (Table 3). Imsong *et al.* (2023) and Chaudhary *et al.* (2023) also supported these findings.

The PC bi-plot (Fig. 1) depicted the genotype distribution and factors, as well as the difference in traits between PC 1 and PC 2, demonstrating the way these traits contributed to genotype variation. Eigenvectors (loadings) of the four Principal components are shown in table 4. In PC1, maximum variability was accounted for the traits like days to first flowering (0.486), days to 50% flowering (0.485) and days to first harvest (0.477). In PC2 and PC3 the traits fruit borer infestation and plant height contributed to maximum variability of 0.372 and 0.545, respectively. In case of PC4 plant height (0.380) and number of fruits/plant (0.304) accounted for more variation. Studies of Imsong *et al.* (2023) and Chaudhary *et al.* (2023) reported maximum variability in the traits like number of fruits/plant, number of primary branches, days to 50% flowering, plant height and days to first harvest but in different principal components. This result indicates that variation in germplasm accessions cannot be entirely explained with only few traits. This is in conformity with Rahevar *et al.* (2021) in chilli and Jena *et al.* (2023) in turkey berry. The most significant yield contributors are the characters with high positive values in each PC, hence consideration should be given to these traits while developing high-yielding brinjal cultivars.

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