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MULTIVARIATE EVALUATION OF YIELD, BIOCHEMICAL AND MINERAL TRAITS IN BRINJAL (*Solanum melongena* L.) LANDRACES FOR NUTRITIONAL IMPROVEMENT AND BIOFORTIFICATION

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ABSTRACT

Brinjal (*Solanum melongena* L.) exhibits considerable variation for yield, biochemical composition and mineral nutrient content, providing opportunities for the identification of genotypes with contrasting agronomic and nutritional attributes. The present investigation was undertaken to evaluate nineteen brinjal genotypes for three yield traits, six biochemical traits and eight mineral nutrient traits and to characterize their multivariate variation through principal component analysis. The experiment was conducted during Kharif 2025–26 at the Vegetable Science Block, College of Horticulture, Dr. YSR Horticultural University, Anantharajupeta, Andhra Pradesh, India, using a Randomized Block Design with three replications. Significant differences were observed among the genotypes for all the traits studied. Pusa Purple Long recorded the earliest harvest and the highest fruit yield per plant, whereas Siddarth Local recorded the highest fruit weight. Moisture content ranged from 90.41 to 94.56%, while dry matter varied from 5.44 to 9.59 g 100 g⁻¹. Protein content ranged from 0.19 to 1.98 g 100 g⁻¹, total sugars from 1.84 to 6.48 g 100 g⁻¹ and phenols from 0.39 to 1.92 mg 100 g⁻¹. Considerable variation was also observed for biochemical traits, including moisture, dry matter, protein, total sugars, total phenols and carbohydrates, as well as for phosphorus, potassium, calcium, magnesium, sodium, iron, zinc and copper. Principal component analysis retained five components with eigenvalues greater than one, collectively explaining 77.23% of the total variation. The first two principal components accounted for 45.14% of the variation and revealed distinct multivariate trait profiles among the genotypes. Erode Local, Polur Local, Vellore Local, Siddipet Local and Raydurgam Local showed relatively distinctive positions in the multivariate space, whereas some genotypes exhibited comparatively intermediate trait profiles. The results demonstrate substantial variation in the evaluated material under the present experimental conditions and highlight the usefulness of combining per se performance with multivariate analysis for identifying genotypes with contrasting combinations of yield and nutritional traits. Further multi-environment evaluation would be useful to confirm the consistency of the observed trait expression.

Key words : Brinjal, Landraces, Yield, Biochemical traits, Mineral composition, Principal component analysis, Multivariate variation.

Introduction

Brinjal or eggplant (*Solanum melongena* L.) is one of the most important solanaceous vegetable crops cultivated extensively in tropical and subtropical regions of the world. India is considered a primary centre of origin

and diversity for brinjal and possesses enormous variability in fruit shape, size, colour, plant architecture and nutritional quality (Medina *et al.*, 2014). The crop occupies a prominent place in Indian vegetable cultivation owing to its adaptability, affordability and culinary importance. India

is the second largest producer of brinjal after China, with an annual production of about 12.99 million tonnes cultivated over approximately 0.68 million hectares (Department of Agriculture and Farmers Welfare, 2026). According to the National Horticulture Board (2023), Andhra Pradesh contributes nearly 252.09 thousand tonnes of brinjal production, representing about 1.94 per cent of the national output. The crop is widely cultivated in the state due to its high economic value, adaptability and consumer demand. However, the productivity of brinjal still remains below its attainable potential, thereby necessitating genetic improvement programmes aimed at enhancing yield as well as nutritional quality.

Brinjal fruits are rich in carbohydrates, dietary fiber, vitamins and mineral nutrients. The crop is also recognized for its antioxidant compounds such as phenols and anthocyanins, which contribute to several health benefits including anti-diabetic, anti-inflammatory and cardio-protective effects (Tripathi *et al.*, 2014 and Ojiewo *et al.*, 2007). Considerable variability exists among indigenous landraces for biochemical and mineral composition, making them valuable genetic resources for nutritional improvement and biofortification programmes.

Landraces adapted to local agro-climatic conditions often possess unique nutritional characteristics and tolerance to biotic and abiotic stresses. Therefore, systematic evaluation of local germplasm for nutritional traits is essential to identify superior genotypes that can be directly utilized in breeding programmes. Biochemical traits such as protein, sugars and phenols along with mineral nutrients including calcium, potassium, iron and zinc are important indicators of fruit quality and nutritional value. Although several studies have reported variability in morphological and yield traits of brinjal, information regarding biochemical and mineral variability in regional landraces remains limited. Hence, the present investigation was undertaken to evaluate diverse brinjal genotypes for biochemical and mineral traits and to identify promising genotypes suitable for nutritional improvement and hybrid development programmes.

Multivariate statistical approaches are particularly useful when several traits contribute simultaneously to genotype differentiation. Principal component analysis (PCA) reduces complex multidimensional data into a smaller number of components while retaining a substantial proportion of the original variation. It can therefore provide an integrated representation of genotype distribution, trait contributions and associations among yield, biochemical and mineral characteristics (Lyu *et al.*, 2025).

Although, several studies have evaluated individual yield or nutritional traits in brinjal, an integrated assessment combining productivity with biochemical and mineral composition can provide a more comprehensive view of genotype variation. Therefore, the present investigation was undertaken to evaluate nineteen brinjal genotypes for yield, biochemical and mineral nutrient traits and to characterize their multivariate variation using principal component analysis. The objective was to identify genotypes with desirable and contrasting trait profiles that may be useful in future brinjal improvement programmes.

Materials and Methods

The experiment was conducted during Kharif 2025–26 at the Vegetable Science Block, College of Horticulture, Dr. YSR Horticultural University, Anantharajupeta, Andhra Pradesh, India. The experimental site is situated at 13.98° N latitude and 79.40° E longitude at an altitude of 162 m above mean sea level. The region falls under a tropical climatic zone and receives an average annual rainfall of approximately 700 mm.

The experimental soil was neutral in reaction, with a pH of 7.47 and non-saline, with an electrical conductivity of 0.242 dS m⁻¹. Available nitrogen was low, whereas available phosphorus and potassium were high. Exchangeable calcium was within the optimum range, while magnesium and sulphur were high. Available iron was low, whereas zinc and copper were comparatively higher than the optimum range. The soil fertility status of the experimental field is presented in Table 1.

Nineteen brinjal genotypes comprising 14 local landraces collected from Karnataka, Telangana, Andhra Pradesh, Tamil Nadu and Maharashtra, two varieties from ICAR-IIHR, two varieties from ICAR-IARI and one variety from MPKV Rahuri (Table 2) were evaluated in a Randomized Block Design (RBD) with three replications. Each replication consisted of 20 plants maintained at the recommended spacing. Five healthy and competitive plants were randomly selected from each replication for recording observations. The variation in fruit characteristics among the genotypes is illustrated in Fig. 1. Recommended agronomic practices and plant protection measures as per the package of practices of Dr. YSRHU were uniformly followed throughout the crop growth period.

Days to first harvest was recorded as the number of days from transplanting to the first marketable harvest. Fruit weight was calculated from representative marketable fruits and expressed in grams. Total fruit yield per plant was recorded as the cumulative weight of

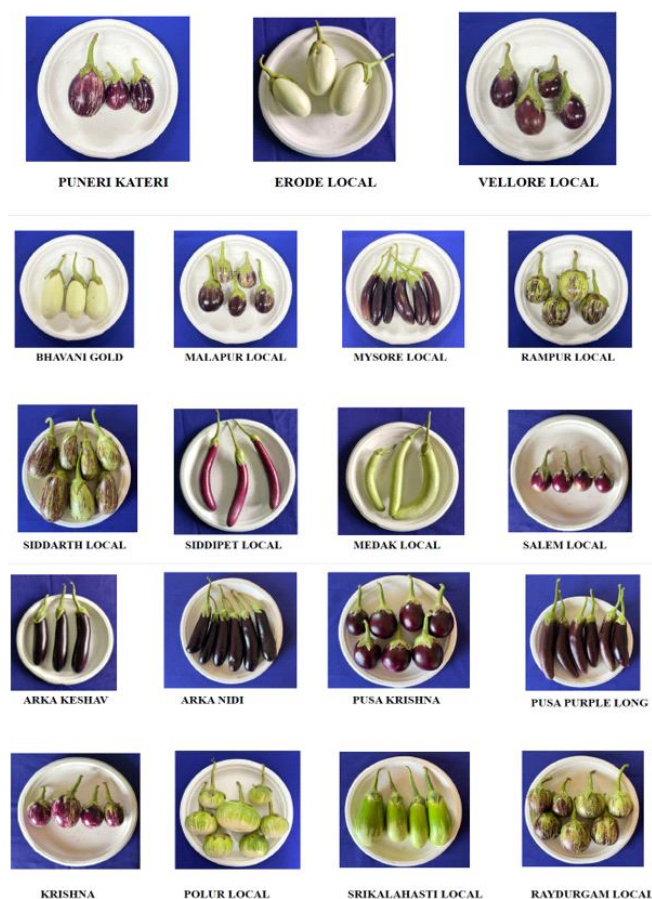


Fig. 1 : Fruits of brinjal genotypes used in the investigation.

Table 1 : Soil Fertility Status of experimental field.

Parameter	Unit	Observed Value	Optimum Range	Interpretation
pH	—	7.47	6.50–7.50	Normal
EC	dS m ⁻¹	0.242	<1.00	Non-saline
Available Nitrogen	Kg	86.34	250-360	Very low
Available Phosphorus	Kg	86.32	10-20	High
Available Potassium	Kg	404.5	124-250	High
Exchangeable Calcium	ppm	1274.50	800–1500	Optimum
Exchangeable Magnesium	ppm	360.45	150–250	Very high
Available Sulphur	ppm	27.70	10–15	High
Available Iron	ppm	3.85	5–10	Low
Available Zinc	ppm	1.403	0.75–1.00	Slightly high
Available Copper	ppm	2.17	0.50–1.00	High

marketable fruits harvested from the selected plants and expressed in kilograms per plant.

Biochemical parameters included moisture content, dry matter, protein, total sugars, total carbohydrates and total phenols. Moisture content and dry matter were determined by the oven-drying method described by

Table 2 : List of Brinjal Genotypes evaluated in the study.

S. no.	Genotype	Source/Region
1	Mysore local, Malapur local, Rampur local	Karnataka
2	Raydurgam local, Srikalahasti local, Polur local, Siddarth local	Andhra Pradesh
3	Puneri Kateri local, Krishna	Maharashtra
4	Bhavani Gold, Erode local, Salem local, Vellore local	Tamil Nadu
5	Medak local, Siddipet local	Telangana
6	Arka Nidhi, Arka Keshav	ICAR-IIHR, Bangalore
7	Pusa Krishna, Pusa Purple Long	ICAR-IARI New Delhi

AOAC (2005). Protein content was estimated using the Kjeldahl method (Kjeldahl, 1883; AOAC, 2005). Total sugars were estimated by the standard colorimetric procedure described by Dubois *et al.* (1956). Total carbohydrates were estimated using the anthrone method described by Hedge and Hofreiter (1962). Total phenols were determined using the Folin–Ciocalteu method described by Singleton and Rossi (1965).

Mineral nutrients analyzed included phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), zinc (Zn) and copper (Cu). Phosphorus was estimated by the vanadomolybdate yellow colour method described by Jackson (1973). Potassium and sodium were determined using a flame photometer following Jackson (1973). Calcium and magnesium were estimated by EDTA titration as described by Jackson (1973) and Cheng and Bray (1951). Iron, zinc and copper were determined using an Atomic Absorption Spectrophotometer following Lindsay and Norvell (1978).

The experimental data were subjected to analysis of variance appropriate for a Randomized Block Design as described by Panse and Sukhatme (1985). The significance of treatment differences was tested at the 5 and 1 per cent probability levels. Principal component analysis was performed using the mean values of the nineteen genotypes for all seventeen traits comprising three yield traits, six biochemical traits and eight mineral nutrient traits. Prior to PCA, the trait values were standardized to eliminate the effect of differences

in measurement scales. Principal components with eigenvalues greater than one were retained for interpretation. Trait loadings were used to identify the variables contributing to each component, while the PCA biplot based on the first two principal components was used to visualize the distribution of genotypes and their relationships with the studied traits.

Results and Discussion

Analysis of variance revealed significant differences among the nineteen brinjal genotypes for all the three yield traits, six biochemical traits and eight mineral nutrient traits studied, indicating the presence of substantial variation among the evaluated genotypes (Table 3). The mean performance of the genotypes for the yield and biochemical traits is presented in the Table 4 and for mineral traits in Table 5.

Table 3 : Analysis of variance (mean sum of squares) for various yield, biochemical and mineral traits in brinjal.

S. no.	Source of variation/ characters	Replications	Treatments	Error
1.	Days to first harvest	1.18	147.05**	0.48
2.	Fruit weight (g)	50.11	3,937.44**	13.76
3.	Fruit yield per plant (kg)	0.71	0.29**	0.03
4.	Moisture (%)	2.21	3.45**	0.54
5.	Dry weight (g 100 g ⁻¹)	2.35	3.51**	0.52
6.	Total Phenols (mg 100 g ⁻¹)	0.14	0.57**	0.01
7.	Protein (g 100 g ⁻¹)	0.05	0.82**	0.04
8.	Carbohydrates (g 100 g ⁻¹)	0.41	2.07**	0.01
9.	Total Sugars (%)	1.64	5.70**	0.02
10.	P (mg 100 g ⁻¹)	13,775.44	1,895.71**	171.74
11.	K (mg 100 g ⁻¹)	113,733.33	106,008.77**	4,200
12.	Ca (mg 100 g ⁻¹)	59.28	6,887.82**	502.74
13.	Mg (mg 100 g ⁻¹)	229.63	5,438.40**	346.47
14.	Na (mg 100 g ⁻¹)	30.75	48**	7.25
15.	Fe (mg 100 g ⁻¹)	0.28	14.86**	2.18
16.	Zn (mg 100 g ⁻¹)	0.45	0.48**	0.04
17.	Cu (mg 100 g ⁻¹)	0.21	0.31**	0.02

The analysis of variance revealed highly significant differences among genotypes for dry matter, moisture, protein, total sugars, phenols and carbohydrates, indicating substantial genetic variability for these biochemical traits. The significant treatment effects suggest that the observed

differences among genotypes were mainly associated with their genetic constitution, providing scope for selection of superior genotypes for improvement of fruit nutritional and quality attributes.

Significant variation was observed among the genotypes for days to first harvest, fruit weight and fruit yield per plant. Pusa Purple Long recorded the earliest first harvest (55.20 days after transplanting), followed by Siddarth Local (57.40 days) and Srikalahasti Local (59.60 days), whereas Malapur Local recorded the latest first harvest (83.87 days), followed by Vellore Local (74.27 days) and Krishna (72.07 days). The overall mean was 65.87 days.

Fruit weight ranged from 45.41 g in Mysore Local to 166.12 g in Siddarth Local. Rampur Local (161.51 g) and Raydurgam Local (159.85 g) also recorded comparatively higher fruit weight, whereas Medak Local (62.82 g) and Siddipet Local (83.29 g) exhibited lower values. The overall mean fruit weight was 117.92 g.

For fruit yield per plant, Pusa Purple Long recorded the highest yield (2.88 kg plant⁻¹), followed by Srikalahasti Local (2.70 kg plant⁻¹) and Raydurgam Local (2.60 kg plant⁻¹). Rampur Local, Medak Local and Krishna recorded the lowest fruit yield (1.90 kg plant⁻¹), with an overall mean of 2.26 kg plant⁻¹.

The significant variation observed for days to first harvest, fruit weight and fruit yield per plant demonstrated the presence of contrasting agronomic performance among the evaluated brinjal genotypes. Pusa Purple Long combined early harvesting with the highest fruit yield per plant, whereas Siddarth Local and Rampur Local were distinguished by their higher fruit weight. This indicates that larger fruit size did not necessarily correspond with higher total yield, highlighting the importance of considering multiple yield attributes during genotype evaluation.

The contrasting performance of the genotypes provides useful material for selecting parents according to specific breeding objectives such as earliness, fruit size or productivity. Similar variability for maturity and yield-related traits among brinjal germplasm has been reported by Koundinya *et al.* (2019), Kousalya *et al.* (2024), Tripathy *et al.* (2025) and Kumar *et al.* (2026). Under the present experimental conditions, the identified variation indicates the availability of genotypes with complementary yield attributes that may be useful in future breeding programmes.

Moisture content ranged from 90.41% in Srikalahasti local to 94.56% in Erode local, whereas dry matter content

Table 4 : Mean performance of brinjal genotypes for yield and biochemical traits.

S. no.	Genotype	Days to first harvest (days)	Fruit weight (g)	Fruit yield per plant (kg)	Moisture (%)	Dry matter (g 100 g ⁻¹)	Total phenols (mg 100 g ⁻¹)	Protein (g 100 g ⁻¹)	Carbohydrates (g 100 g ⁻¹)	Total sugars (%)
1	Mysore Local	61.13	45.41	1.95	92.19	7.96	1.21	1.56	2.82	4.62
2	Rampur Local	71.80	161.51	1.90	92.87	7.13	0.39	0.64	0.71	3.93
3	Malapur Local	83.87	116.24	1.93	92.03	7.97	1.02	0.94	1.08	2.63
4	Raydurgam Local	64.60	159.85	2.60	93.52	6.48	0.56	0.93	1.46	2.65
5	Srikalahasti Local	59.60	107.31	2.70	90.41	9.59	0.40	0.44	1.54	4.46
6	Poltur Local	62.80	139.29	2.05	93.37	6.63	0.63	0.54	3.37	2.78
7	Siddarth Local	57.40	166.12	2.33	92.81	7.19	1.61	1.02	3.35	3.22
8	Puneri Kateri	66.87	157.99	2.51	93.31	6.69	0.59	0.99	3.26	4.80
9	Bhavani Gold	61.53	119.65	2.43	94.51	5.49	0.54	1.58	1.69	6.29
10	Erode Local	61.13	158.44	2.20	94.56	5.44	1.57	0.74	1.56	3.79
11	Salem Local	69.13	91.32	2.18	91.03	8.97	1.07	1.20	1.01	4.48
12	Medak Local	69.27	62.82	1.90	94.04	5.96	0.95	0.76	1.47	6.48
13	Siddipet Local	68.67	83.29	2.41	93.81	6.19	1.92	1.98	2.42	6.45
14	Vellore Local	74.27	144.45	2.05	91.94	8.06	0.55	0.19	1.95	3.79
15	Arka Nidhi	60.20	88.99	2.56	92.53	7.47	0.94	0.41	1.27	3.30
16	Arka Keshav	60.40	94.57	2.31	93.29	6.71	1.14	1.14	1.70	2.81
17	Pusa Krishna	70.53	137.43	2.21	93.23	6.77	0.62	0.80	2.00	2.57
18	Pusa Purple Long	55.20	95.95	2.88	93.36	6.64	0.59	1.93	3.04	1.84
19	Krishna	72.07	145.03	1.90	93.16	6.84	1.02	0.22	1.73	4.89
C.D. (5%)			1.16	6.16	0.29	1.22	1.20	0.07	0.32	0.16 0.25
SE(m)			0.40	2.14	0.10	0.43	0.42	0.02	0.11	0.05 0.09
SE(d)			0.57	3.03	0.14	0.60	0.59	0.03	0.16	0.08 0.12
C.V.(%)			1.06	3.10	7.82	0.79	10.25	4.34	20.17	4.81 3.75

ranged from 5.44 g 100 g⁻¹ in Erode local to 9.58 g 100 g⁻¹ in Srikalahasti local. Moisture content is an important quality attribute in brinjal as it contributes to fruit succulence, tenderness, freshness and fresh-market acceptability. The observed variation indicates differences among genotypes in water accumulation and retention, cell expansion and assimilate partitioning during fruit development. Dry matter is an important quality attribute representing the solid fraction of the fruit and is associated with nutritional density, firmness and processing quality. The considerable variation observed among the genotypes indicates differences in dry matter accumulation and assimilate partitioning during fruit development. The inverse relationship observed between moisture and dry matter content indicates differential accumulation of solids among the brinjal genotypes. Similar findings were reported by Moghaddas *et al.* (2025), Rahim *et al.* (2024), Dutta *et al.* (2022), Kandoliya *et al.* (2020) and Quamruzzaman *et al.* (2020) in brinjal.

Phenolic content ranged from 0.39 to 1.92 mg 100 g⁻¹, with Siddipet local recording the highest value followed by Siddarth local and Erode local. Total phenol content is an important biochemical quality trait in brinjal because phenolic compounds contribute to antioxidant capacity, functional nutritional quality and plant defence. The considerable variation observed among the genotypes indicates differences in the synthesis and accumulation of phenolic compounds, which may be influenced by genetic background and the activity of phenolic biosynthetic pathways during fruit development. Similar results were

Table 5 : Mean performance of Brinjal Genotypes for mineral traits.

S. no.	Genotypes	Total P %	Total K %	Total Ca %	Total Mg %	Total Na%	Total Feppm	Total Cuppm	Total Znppm
1	Mysore Local	0.42	1.72	0.19	0.18	0.02	87.36	23.26	27.71
2	Rampur Local	0.47	1.74	0.18	0.16	0.02	88.90	14.86	27.97
3	Malapur Local	0.47	1.76	0.16	0.15	0.02	58.65	14.52	32.19
4	Raydurgam Local	0.49	2.18	0.19	0.18	0.03	79.65	16.37	35.67
5	Srikalahasti Local	0.46	2.14	0.24	0.22	0.02	58.95	16.70	26.21
6	Polur Local	0.52	2.13	0.23	0.21	0.03	115.46	16.34	34.57
7	Siddarth Local	0.49	1.85	0.22	0.20	0.03	74.25	15.40	28.42
8	Puneri Kateri Local	0.47	1.77	0.17	0.16	0.02	51.75	13.36	25.75
9	Bhavani Gold	0.49	2.12	0.27	0.24	0.02	44.25	14.34	25.70
10	Erode Local	0.52	2.27	0.25	0.24	0.02	82.20	22.18	38.16
11	Salem Local	0.47	1.73	0.31	0.27	0.02	65.45	13.98	26.02
12	Medak Local	0.47	1.85	0.28	0.26	0.02	128.95	15.37	27.94
13	Siddipet Local	0.47	1.87	0.28	0.24	0.02	74.75	16.32	24.52
14	Vellore Local	0.48	1.80	0.16	0.13	0.02	44.55	8.98	24.71
15	Arka Nidi	0.44	1.68	0.18	0.17	0.01	58.40	13.07	23.28
16	Arka Keshav	0.47	2.05	0.27	0.27	0.02	78.30	12.95	25.96
17	Pusa Krishna	0.49	1.73	0.18	0.17	0.02	69.95	12.75	28.34
18	Pusa purple long	0.48	1.75	0.18	0.18	0.01	50.05	12.96	25.90
19	Krishna	0.44	1.91	0.17	0.14	0.02	65.40	13.70	26.46
	C.D. (0.05)	0.04	0.19	0.07	0.06	0.01	44.13	4.48	5.80
	SE(m) ±	0.01	0.07	0.02	0.02	0.00	14.74	1.50	1.94
	SE(d)	0.02	0.09	0.03	0.03	0.00	20.85	2.12	2.74
	C.V.(%)	3.68	4.83	14.50	13.17	19.32	28.76	13.98	9.71

P- Phosphorous, K – Potassium, Ca- Calcium, Mg- Magnesium, Na- Sodium, Fe- Iron, Zn-Zinc, Cu-Copper

reported by Rahim *et al.* (2024), Praneetha and Jayakashmi (2018), Reshmika *et al.* (2016).

Total sugars varied from 1.84 g 100 g⁻¹ in PPL to 6.48 g 100 g⁻¹ in Medak local. Carbohydrate content ranged from 0.71 g 100 g⁻¹ in Rampur local to 3.37 g 100 g⁻¹ in Polur local. Total sugars content is an important biochemical quality trait in brinjal, as soluble sugars contribute directly to sweetness, palatability and consumer acceptability, while also contributing to the energy value of the fruit. The considerable variation observed among the genotypes indicates differences in photosynthate production, translocation and sugar accumulation during fruit development. The higher sugar accumulation in Medak Local, Siddipet Local and Bhavani Gold indicates their potential as genetic resources for improving sensory quality. Carbohydrates constitute an important component

of the nutritional quality of brinjal and contribute to its energy value and sensory attributes, particularly through soluble carbohydrate fractions. The considerable variation observed among the genotypes indicates differences in photosynthate production, translocation and partitioning during fruit development. These results are in close agreement with the findings of earlier studies by Moghaddas *et al.* (2025), Rahim *et al.* (2024), Bidaramali *et al.* (2020) and Quamruzzaman *et al.* (2020).

Protein content exhibited wide variation ranging from 0.19 g 100 g⁻¹ in Vellore local to 1.98 g 100 g⁻¹ in Siddipet local, followed by PPL (1.93 g 100 g⁻¹) and Bhavani Gold (1.58 g 100 g⁻¹). Protein content is an important nutritional quality trait in brinjal, contributing to the dietary value of the fruit and serving as a component of enzymes and other functional proteins involved in cellular metabolism.

The considerable variation observed among the genotypes indicates differences in protein accumulation associated with their genetic background and assimilate partitioning during fruit development. Similar variability in protein content was reported by Moghaddas *et al.* (2025), Dutta *et al.* (2022), Quamruzzaman *et al.* (2020) and Kandoliya *et al.* (2015).

Phosphorus content ranged from 0.42% in Mysore local to 0.52% in Polur local and Erode local. Potassium content varied from 1.68% in Arka Nidhi to 2.27% in Erode local. Calcium content ranged from 0.16% in Vellore local to 0.31% in Salem local. Similarly, magnesium content varied from 0.13% in Vellore local to 0.27% in Salem local. Similar variability was reported by Moghaddas *et al.* (2025) and Quamruzzaman *et al.* (2020).

Iron content showed substantial variability ranging from 44.25 ppm in Bhavani Gold to 128.95 ppm in Medak local. Copper content ranged from 8.98 ppm in Vellore local to 23.26 ppm in Mysore local. Zinc content varied from 23.28 ppm in Arka Nidhi to 38.16 ppm in Erode local. The observed variability for macro and micronutrients indicates the possibility of identifying nutritionally superior genotypes suitable for biofortification programmes. Similar findings were previously reported by Moghaddas *et al.* (2025), Rahim *et al.* (2024), Sharma *et al.* (2021), Bidaramali *et al.* (2020) and Quamruzzaman *et al.* (2020). Sodium content ranged from 0.01% in Arka Nidhi and Pusa Purple Long to 0.03% in Polur local.

The higher accumulation of mineral nutrients such as potassium, calcium, magnesium, iron and zinc in certain genotypes may be attributed to their superior nutrient absorption efficiency, root architecture and internal nutrient translocation mechanisms. Genotypes possessing efficient uptake systems are capable of absorbing nutrients more effectively from the soil solution and subsequently accumulating them in edible plant parts.

The experimental soil contained high levels of phosphorus, potassium, magnesium and sulphur, which might have enhanced nutrient availability and facilitated greater accumulation of these nutrients in fruits. However, the low availability of nitrogen and iron in the soil indicated that genotypes exhibiting higher iron content under such conditions may possess better nutrient acquisition efficiency and adaptive mechanisms for micronutrient uptake. Medak local recorded exceptionally high iron content despite low available iron status in the soil, suggesting its superior iron uptake and mobilization efficiency. Similarly, Erode local exhibited higher

potassium and zinc accumulation, indicating efficient nutrient absorption and partitioning capacity. Salem local showed higher calcium and magnesium content, which may be associated with efficient cation uptake and translocation mechanisms.

The observed variability among genotypes for mineral accumulation indicates the existence of genetic differences controlling nutrient uptake efficiency, ion transport, storage and remobilization within plant tissues (Sharma *et al.*, 2021; Quamruzzaman *et al.*, 2020). Such genotypes can serve as valuable donor parents in breeding programmes aimed at mineral biofortification. Biofortification through genetic improvement is considered a sustainable and cost-effective strategy to address micronutrient malnutrition (Sharma *et al.*, 2021). Identification of nutrient-dense brinjal genotypes possessing superior nutrient uptake efficiency can facilitate the development of biofortified cultivars with enhanced mineral composition and improved nutritional security. Furthermore, the integrated evaluation of mineral accumulation along with biochemical traits provides a comprehensive understanding of nutritional variability among brinjal landraces and supports their utilization in functional food and nutritional breeding programs (Rahim *et al.*, 2024; Moghaddas *et al.*, 2025).

The analysis of variance revealed significant differences among the genotypes for all the mineral nutrients studied. Phosphorus, potassium, calcium, magnesium, copper and zinc showed highly significant differences, while sodium and iron showed significant differences among genotypes. This indicates the presence of considerable genetic variability for mineral accumulation and suggests that the genotypes differed in their nutrient uptake, transport and accumulation capacity. The observed variability provides scope for selection of superior genotypes with desirable mineral profiles for nutritional improvement and biofortification of brinjal.

Principal component analysis was performed using the mean values of the nineteen genotypes for all seventeen traits comprising three yield traits, six biochemical traits and eight mineral nutrients. Of the seventeen principal components generated, five components with eigenvalues greater than unity were retained, together accounting for 77.23% of the total variation. The first and second principal components explained 24.59% and 20.55% of the total variation, respectively, and together accounted for 45.14%. PCA component loadings and eigen values are presented in Tables 6 and 7, respectively.

PC1 was mainly associated with positive loadings

Table 6 : Principal component loadings of yield and quality traits in brinjal genotypes.

	PC1	PC2	PC3	PC4	PC5
NDFH	-0.18	0.16	-0.43	0.19	-0.19
FW	0.06	0.46	0.09	-0.02	-0.10
TY	0.01	-0.10	0.58	-0.21	-0.09
M	0.35	0.08	0.08	0.44	-0.17
DM	-0.35	-0.08	-0.08	-0.44	0.18
TPH	0.18	-0.24	-0.12	0.20	0.23
PR	0.14	-0.31	0.26	0.24	0.06
CARB	0.10	0.01	0.35	0.27	0.36
TS	0.08	-0.27	-0.23	0.20	-0.33
P	0.31	0.27	0.11	-0.11	-0.18
K	0.35	0.12	0.06	-0.36	-0.12
Ca	0.28	-0.33	-0.10	-0.24	-0.28
Mg	0.30	-0.33	-0.06	-0.28	-0.20
Na	0.22	0.34	-0.05	0.01	-0.08
Fe	0.26	-0.02	-0.36	0.02	0.23
Zn	0.30	0.28	-0.14	-0.18	0.31
Cu	0.26	-0.13	-0.14	-0.10	0.52

NDFH- Number of days to first harvest, FW- Fruit weight, TY- Total yield per plant, M-Moisture, DM-Dry matter, TPH-Total phenols, PR-Protein, CARB-Carbohydrates, TS-Total sugars, P- Phosphorous, K – Potassium, Ca- Calcium, Mg- Magnesium, Na- Sodium, Fe- Iron, Zn-Zinc, Cu-Copper

for moisture, potassium, phosphorus, magnesium and zinc, while dry matter showed a comparatively high negative loading. PC2 was characterized primarily by fruit weight and sodium with positive loadings, whereas calcium, magnesium and protein showed higher negative loadings. PC3 was mainly associated with total yield per plant and carbohydrates, while days to first harvest and iron showed negative loadings. PC4 mainly represented variation related to moisture, dry matter and potassium, whereas PC5 was characterized predominantly by copper, carbohydrates, zinc and total sugars.

The PCA biplot revealed wide dispersion of the genotypes across the four quadrants, indicating substantial multivariate variation. Pusa Purple Long, Siddarth Local, Puneri Kateri Local and Pusa Krishna were located comparatively close to the origin, indicating relatively intermediate trait profiles in relation to PC1 and PC2. In contrast, Erode Local, Polur Local, Vellore Local, Siddipet Local and Raydurgam Local were positioned farther from the origin, indicating more distinctive combinations of yield, biochemical and mineral traits. PCA Biplot of brinjal genotypes are represented in Fig. 2.

The biplot further revealed important relationships among traits. Calcium and magnesium showed a strong

Table 7 : The eigenvalues, proportion of variation explained and total variation across the principal components.

Principal Component	Eigen Value	Variance (%)	Cumulative (%)
PC1	4.41	24.59	24.59
PC2	3.69	20.55	45.14
PC3	2.44	13.6	58.75
PC4	1.76	9.81	68.56
PC5	1.56	8.67	77.23

positive association, while positive relationships were also observed between phosphorus and zinc, potassium and zinc, and fruit weight and sodium. In contrast, moisture and dry matter showed a strong negative association. Days to first harvest and total yield were negatively associated, while fruit weight showed negative relationships with calcium and magnesium.

The PCA provided additional insight into the relationships among mineral traits. The close association between calcium and magnesium suggests potential for their simultaneous improvement, whereas the positive relationships of phosphorus with zinc and potassium with zinc indicate that some mineral attributes tended to vary together. Conversely, the weak associations observed among certain other traits suggest the possibility of improving one nutritional attribute with comparatively limited influence on another.

The PCA demonstrated that the overall variation among the nineteen genotypes was determined by the combined contribution of yield, biochemical and mineral traits. Five principal components accounted for 77.23% of the total variation, confirming that the complex variation present among the genotypes could be summarized effectively through a smaller number of multivariate components.

The first two components explained 45.14% of the total variation and revealed clear differences in genotype distribution. The distinctive positioning of Erode Local, Polur Local, Vellore Local, Siddipet Local and Raydurgam Local indicated that these genotypes possessed more contrasting multivariate trait combinations, whereas genotypes positioned closer to the origin exhibited relatively intermediate profiles for the traits represented by PC1 and PC2. Importantly, distance from the origin should not be interpreted as superiority; rather, it reflects the degree of multivariate differentiation from the overall genotype centroid.

The present findings are comparable with the observations of Lyu *et al.* (2025), who demonstrated the effectiveness of PCA in distinguishing eggplant germplasm

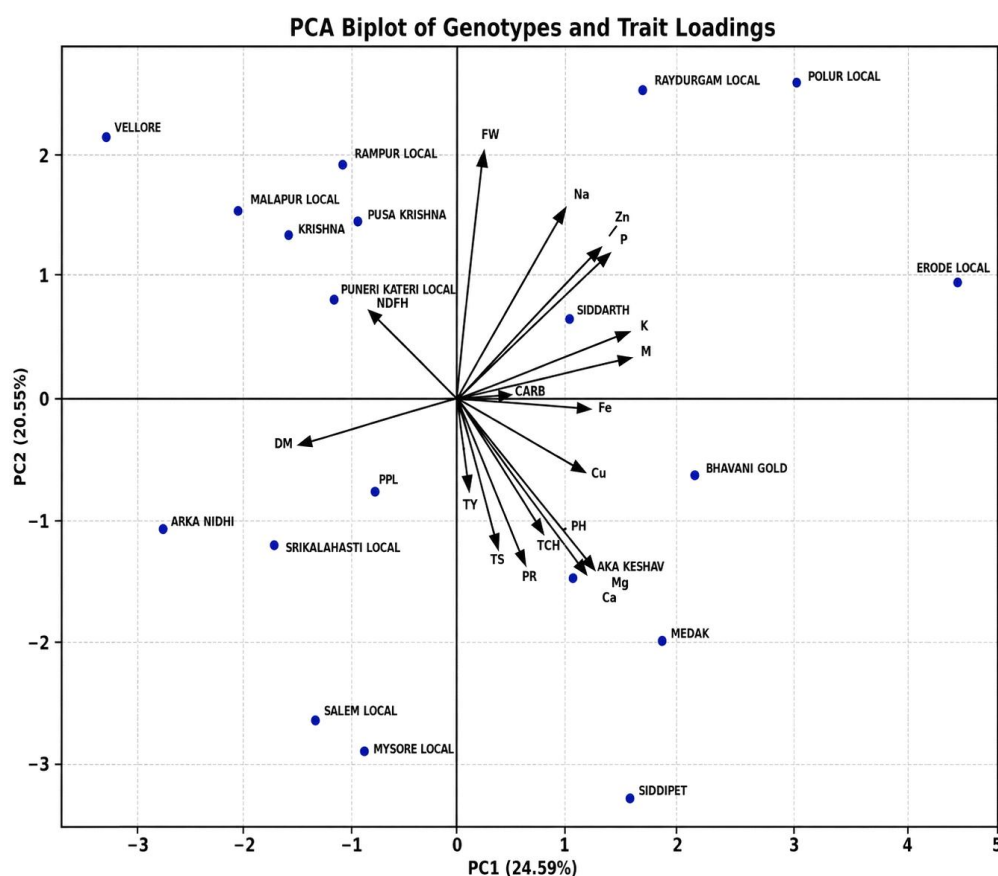


Fig. 2 : PCA Biplot of brinjal genotypes and trait loadings.

Table 8 : Nutritionally Superior Brinjal genotypes identified in the study.

Genotype	Superior Traits	Breeding Utility
Pusa Purple long	Earliness and higher yield	Yield improvement
Siddipet local	Protein, phenols, sugars	Nutritional enhancement
Medak local	Iron, sugars	Iron biofortification
Erode local	Potassium, zinc	Mineral enrichment
Salem local	Calcium, magnesium	Mineral donor parent
Polur local	Carbohydrates, phosphorus	Biofortification breeding

based on contrasting combinations of agronomic and nutritional traits. Similar usefulness of PCA for summarizing multivariate variation and identifying traits contributing to genotype differentiation has also been reported by Barik *et al.* (2021), Chaudhary *et al.* (2023) and Singh *et al.* (2024). Rosa-Martínez *et al.* (2022) further demonstrated substantial variation in fruit composition and nutritional characteristics among eggplant materials, supporting the use of multivariate approaches for interpreting complex compositional variation.

Overall, the PCA results showed that variation among the brinjal genotypes was not governed by a single group of traits. Instead, the observed differentiation resulted from the combined contribution of yield, biochemical and mineral characteristics. This integrated approach

therefore provides a more comprehensive basis for identifying contrasting trait profiles than evaluation of individual traits alone. However, since the present observations were obtained under a single set of experimental conditions, the identified trait combinations should be further evaluated across seasons and environments before making conclusions regarding their stability or wider adaptation.

Conclusion

The present investigation revealed substantial genetic variability among the evaluated brinjal genotypes for yield, biochemical and mineral traits. Significant differences among genotypes for protein, sugars, phenols, carbohydrates and mineral nutrients indicate ample scope for selection and nutritional improvement. Among the

evaluated genotypes, Siddipet local, Medak local, Erode local, Polur local and Salem local were identified as promising genotypes owing to their superior nutritional composition (Table 8). These landraces can be effectively utilized as donor parents in breeding programmes aimed at enhancing nutritional quality and developing biofortified brinjal hybrids. Furthermore, the identified nutrient-rich landraces possess local adaptability and consumer acceptance, which increases their potential utility in future hybridization programmes and sustainable vegetable production systems.

The principal component analysis further demonstrated that genotype differentiation was governed by the combined contribution of yield, biochemical and mineral characteristics rather than by any single group of traits. The wide distribution of genotypes in the PCA biplot and the contrasting associations among traits confirmed the presence of distinct multivariate trait profiles within the evaluated germplasm. The observed diversity provides opportunities for selecting complementary parents and combining desirable agronomic performance with improved nutritional composition.

Overall, the identified high-yielding and nutritionally distinct genotypes represent useful genetic resources for future brinjal improvement programmes. Genotypes with superior productivity may be combined with those possessing favourable biochemical and mineral attributes to develop improved cultivars or hybrids with desirable yield and nutritional quality. However, as the present evaluation was conducted under a single set of environmental conditions, further assessment across seasons and locations would be necessary to determine the stability of the identified trait combinations.

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Author contributions

Conceptualization, methodology, investigation, software, validation and formal analysis-B Hari Vara Prasad, resources- P Syam Sundar Reddy.; writing original draft preparation, writing review and editing- Naresh Y.R. and V Vinay Kumar; funding acquisition- L Mukunda Lakshmi and T Susila. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no competing interests.

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