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EVALUATION OF BLACK PEPPER (*PIPER NIGRUM* L.) GENOTYPES FOR GROWTH YIELD AND QUALITY TRAITS

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ABSTRACT

A comprehensive investigation was conducted to evaluate the performance of twenty quantitative traits in a diverse collection of 25 black pepper (*Piper nigrum* L.) genotypes. The field experiment, executed in a well-established six-year-old orchard, was arranged in a randomized block design with three replications. The analysis of variance revealed highly significant differences among all genotypes for all characters, confirming the presence of substantial genetic variability. Mean performance analysis identified superior genotypes, with Panniyur-1 recording the highest dry berry yield per vine (11.46 kg), followed by Vellanamban (9.08 kg). The nearly ten-fold variation observed in dry yield underscores the immense potential for genetic improvement. The genotype V-2 was particularly outstanding for architectural traits, exhibiting the highest number of laterals per m² (27.33) and number of spikes per m² (65.00). For quality parameters, Vijay was identified as superior for essential oil content (3.90%), while Nateshan kudi excelled in oleoresin content (13.67%). This study successfully identified elite genotypes with superior phenotypic performance for key economic traits, providing valuable genetic material for direct cultivation and for strategic utilization in future black pepper breeding programs.

***Keywords*:** Black pepper, Genotypes, Performance evaluation, *Piper nigrum*, Quality traits, Yield components.

Introduction

Black pepper (*Piper nigrum* L.) is a globally significant spice crop cultivated for its berries, which are valued for their pungency and aroma. Its economic importance necessitates continuous efforts toward developing high-yielding varieties with improved quality and resilience to biotic and abiotic stresses (Thomas *et al.*, 2024). However, productivity in many pepper-growing regions has stagnated, partly due to a narrow genetic base and reliance on a few traditional cultivars (Nair and George, 2023; Hegde, 2023). The success of any crop improvement program is fundamentally dependent on the magnitude of genetic variability present in the base population, as this variation serves as the raw material for selection (Allard, 1960; Singh *et al.*, 2025). The systematic evaluation of diverse germplasm collections is, therefore, a critical and foundational stage in modern plant breeding, offering an unparalleled opportunity to select superior existing genotypes or identify parents for hybridization (Reddy *et al.*, 2023; Kumar and Meena, 2024; Joseph *et al.*, 2024).

The overall phenotypic performance of a genotype is an expression of its genetic potential interacting with the environment. To devise an effective selection strategy, it is imperative to systematically evaluate and quantify the performance of genotypes for a wide range of agro-morphological traits. This allows breeders to identify not only the highest-yielding individuals but also those possessing desirable component traits, such as an optimal plant architecture, high spike density, or superior berry quality, which contribute to overall value and farmer acceptance (Patel and Rao, 2025). The final yield in black pepper is a complex quantitative trait governed by the interplay of several component traits, including vegetative vigor, the number of fruit-bearing laterals, spike characteristics, and berry development (Ahmad *et al.*, 2023; Misra and Pandey, 2022). Simultaneously, quality traits, primarily essential oil (aroma) and oleoresin (pungency), are critical for determining the commercial value and end-use suitability for the food and oleoresin extraction industries (Verma and Singh, 2022). Therefore, this study was designed to systematically evaluate a diverse collection of 25 black pepper genotypes to (1) assess their mean performance for various agro-morphological, yield, and quality traits and (2) identify superior genotypes for direct cultivation or for use in future breeding programs.

Material and Methods

The experimental material consisted of 25 diverse black pepper genotypes, including released varieties, hybrids, and local selections. The trial was established in a randomized block design (RBD) with three replications at an experimental farm in the Malenadu region of Karnataka, India. All genotypes were maintained under the recommended package of practices, including uniform fertilizer application and need-based plant protection measures, to ensure that observed differences were primarily attributable to genotypic effects.

Data were meticulously recorded for twenty quantitative characters: No. of leaves/m², an indicator of canopy density; Leaf length (cm) and Leaf width (cm), which relate to photosynthetic capacity; Vine length (m), a measure of overall vigor; No. of laterals/m² and Length of plagiotropic shoot (cm), key architectural traits determining yield framework; No. of runner shoots/vine; No. of spikes/plagiotropic shoot and No. of spikes/m², primary yield components; Spike length (cm); Fresh spike weight (g); No. of berries per spike, an indicator of pollination success; 100-fresh berry weight (g) and 100-dry berry weight (g), measures of berry size; Fresh berry yield per vine (kg) and Dry berry yield per vine (kg), the final economic output; Dry recovery (%); Essential oil (%); Oleoresin (%); and Bulk density (kg/m ³). In addition, qualitative morphological traits were recorded as per standard evaluation methodologies (Utpala and Das, 2021). The collected data were subjected to statistical analysis, and mean performance, range, and critical difference (CD) were computed to compare the genotypes.

Results and Discussion

The comprehensive evaluation of 25 diverse black pepper genotypes revealed highly significant ($p<0.05$) differences for all twenty quantitative traits studied, confirming the existence of a substantial reservoir of phenotypic and underlying genetic diversity within the germplasm collection. This variability is the foundational raw material essential for plant breeders to make effective selections and achieve tangible genetic improvement in black pepper (*Piper nigrum* L.), a conclusion supported by numerous germplasm evaluation studies (Bhoi *et al.*, 2024; Rao and Patel, 2022; Zachariah, 2017). The wide range observed for key economic traits underscores the immense potential for crop improvement through both direct selection of superior genotypes and their strategic use in future hybridization programs.

Table 1: Qualitative morphological traits of black pepper genotypes

Genotypes		Shoot tip colour	Leaf lamina	Leaf base
G_1	Arakulamundi	Purple	Ovate	Acute
G_2	Cholamundi	Purple	Ovate-elliptic	Acute
G_3	Neelamundi	Purple	Ovate-lanceolate	Round
G_4	Zion mundi	Purple	Ovate	Round
G_5	Kurimale	Purple	Ovate-lanceolate	Round
G_6	Nateshan kudi	Purple	Ovate-lanceolate	Round
G_7	Vellanamban	Purple	Ovate	Round
G_8	Vijay	Green	Ovate-lanceolate	Cordate
G_9	Karimunda	Green	Ovate-lanceolate	Acute

G_{10}	Sigandini	Purple	Cordate	Cordate
G_{11}	Arka Coorg Excel	Purple	Ovate-lanceolate	Round
G_{12}	IISR Thevam	Green	Ovate-lanceolate	Round
G_{13}	Panchami	Green	Cordate	Round
G_{14}	Punjarmundi	Purple	Ovate	Round
G_{15}	Panniyur-1	Green	Cordate	Round
G_{16}	Panniyur-2	Purple	Ovate	Round
G_{17}	Panniyur-3	Green	Cordate	Cordate
G_{18}	Panniyur-5	Green	Ovate-elliptic	Cordate
G_{19}	V-1	Purple	Ovate-lanceolate	Acute
G_{20}	V-2	Green	Ovate-elliptic	Round
G_{21}	V-3	Green	Ovate-lanceolate	Acute
G_{22}	V-4	Green	Ovate-elliptic	Acute
G_{23}	V-5	Green	Ovate-lanceolate	Acute
G_{24}	V-7	Green	Ovate-lanceolate	Acute
G_{25}	V-8	Green	Ovate-elliptic	Round

Table 2: Branching and spike characters in black pepper genotypes

Genotypes		Branching pattern of bearing shoot	Spike setting pattern	Spike shape	Spike twisting
G_1	Arakulamundi	Semi erect	Loose	Filiform	Present
G_2	Cholamundi	Hanging	Loose	Filiform	Present
G_3	Neelamundi	Semi erect	Compact	Cylindrical	Present
G_4	Zion mundi	Semi erect	Compact	Cylindrical	Present
G_5	Kurimale	Drooping	Loose	Cylindrical	Absent
G_6	Nateshan kudi	Horizontal	Loose	Filiform	Absent
G_7	Vellanamban	Horizontal	Loose	Cylindrical	Present
G_8	Vijay	Semi erect	Loose	Cylindrical	Absent
G_9	Karimunda	Horizontal	Compact	Filiform	Absent
G_{10}	Sigandini	Semi erect	Loose	Cylindrical	Present
G_{11}	Arka Coorg Excel	Horizontal	Loose	Cylindrical	Present
G_{12}	IISR Thevam	Horizontal	Compact	Cylindrical	Absent
G_{13}	Panchami	Horizontal	Compact	Filiform	Present
G_{14}	Punjarmundi	Horizontal	Compact	Filiform	Present
G_{15}	Panniyur-1	Horizontal	Compact	Filiform	Absent
G_{16}	Panniyur-2	Semi erect	Compact	Filiform	Present
G_{17}	Panniyur-3	Horizontal	Compact	Cylindrical	Present
G_{18}	Panniyur-5	Horizontal	Loose	Cylindrical	Absent
G_{19}	V-1	Horizontal	Loose	Filiform	Present
G_{20}	V-2	Semi erect	Loose	Filiform	Present
G_{21}	V-3	Hanging	Loose	Filiform	Present
G_{22}	V-4	Horizontal	Compact	Filiform	Present
G_{23}	V-5	Horizontal	Compact	Filiform	Present
G_{24}	V-7	Horizontal	Loose	Filiform	Present
G_{25}	V-8	Horizontal	Loose	Filiform	Present

Qualitative morphological diversity and its implications

The genotypes exhibited considerable diversity in their qualitative morphological characteristics (Table 1, Table 2), which are crucial as stable markers for varietal identification (DUS testing), maintaining genetic purity during propagation, and preventing misidentification in commercial nurseries (Anu and Saji, 2025). For instance, shoot tip colour was a clear dimorphic marker, being either purple (e.g., Arakulamundi, Neelamundi) or green (e.g., Vijay, Panniyur-1). Similarly, leaf lamina shapes ranged from ovate and cordate to ovate-elliptic and ovate-lanceolate. Such easily observable traits are the first step in characterization and are invaluable for creating distinct varietal profiles (Parthasarathy & Zachariah, 2018).

Furthermore, architectural traits such as branching pattern (semi-erect, hanging, horizontal, drooping) and spike setting (loose vs. compact) differed significantly among the genotypes. The horizontal branching habit of genotypes like Panniyur-1 and Nateshan kudi is often preferred for efficient space utilization and ease of cultural operations. Conversely, compact spike setting, observed in Neelamundi and Karimunda, is a desirable trait as it can lead to higher berry density and reduced physical damage (Krishnamurthy *et al.*, 2021). This variation suggests that distinct ideotypes can be selected for different cultivation systems (e.g., high-density planting vs. traditional intercropping), a key objective in modern breeding programs aiming for climate resilience and enhanced productivity (Ghosh, 2023).

Performance for vegetative and growth parameters

The mean performance for quantitative vegetative traits showed a wide and significant range of variation (Table 3). In terms of canopy density, Neelamundi (G3) was exceptional, recording the highest number of leaves/m² (102.00). A dense canopy is a vital trait that influences light interception, microclimate, and overall photosynthetic efficiency, which are primary drivers of biomass production and yield (George and Jacob, 2023). However, an overly dense canopy can sometimes promote disease incidence due to reduced air circulation; thus, an optimal leaf density is often sought (Ravindran, 2019). At the other end of the spectrum, Arakulamundi (G1) recorded the maximum vine length (7.01 m), indicating superior vegetative vigor. Strong vigor is often correlated with better field establishment, longevity, and resilience to abiotic stresses, making such genotypes valuable rootstock candidates or parents for improving adaptability (Sasikumar *et al.*, 2022).

Table 3: Mean performance of black pepper genotypes for vine and leaf parameters

Genotypes		No. of leaves/m²	Leaf length (cm)	Leaf width (cm)	Vine length (m)
G_1	Arakulamundi	56.67	15.00	9.33	7.01
G_2	Cholamundi	53.67	15.67	8.00	3.65
G_3	Neelamundi	102.00	8.63	14.33	4.77
G_4	Zion mundi	49.67	16.33	9.83	3.86
G_5	Kurimale	72.67	15.33	10.67	4.43
G_6	Nateshan kudi	62.33	15.40	9.67	4.97
G_7	Vellanamban	52.67	14.67	9.00	6.09
G_8	Vijay	64.00	15.17	11.17	4.36
G_9	Karimunda	56.00	12.67	5.67	5.89
G_{10}	Sigandini	60.00	13.83	9.67	3.45
G_{11}	Arka Coorg Excel	59.00	15.67	8.83	3.86
G_{12}	IISR Thevam	52.67	14.67	9.67	3.55
G_{13}	Panchami	51.00	15.67	11.33	4.06
G_{14}	Punjarmundi	31.33	17.17	11.50	3.88
G_{15}	Panniyur-1	61.00	17.00	11.33	4.74
G_{16}	Panniyur-2	47.33	12.23	8.30	3.95
G_{17}	Panniyur-3	71.67	12.83	10.37	4.22
G_{18}	Panniyur-5	95.67	17.00	8.87	5.05
G_{19}	V-1	45.00	8.67	5.77	4.43
G_{20}	V-2	93.33	14.83	9.00	4.88
G_{21}	V-3	49.33	14.33	8.17	3.28
G_{22}	V-4	55.00	13.33	7.50	4.35
G_{23}	V-5	50.67	11.00	5.67	4.28
G_{24}	V-7	48.33	14.00	6.67	4.73
G_{25}	V-8	47.33	18.33	9.33	5.09
Mean		**59.53**	**14.38**	**9.19**	**4.51**
SEm±		**3.06**	**0.64**	**0.42**	**0.15**
CD @5%		**8.68**	**1.82**	**1.21**	**0.42**

Table 4: Mean performance of black pepper genotypes for shoot parameters

Genotypes		No. of laterals/m^2	Length of plagiotropic shoot (cm)	No. of runner shoots/ vine	No. of spikes/ plagiotropic shoot
G_1	Arakulamundi	11.00	60.00	5.00	6.33
G_2	Cholamundi	10.00	58.67	8.00	8.67
G_3	Neelamundi	18.33	66.33	6.33	6.33
G_4	Zion mundi	6.33	60.67	2.67	10.00
G_5	Kurimale	8.67	71.00	6.67	3.67
G_6	Nateshan kudi	11.67	81.00	7.33	4.67
G_7	Vellanamban	6.67	50.00	3.33	4.67
G_8	Vijay	12.33	49.17	5.00	14.00
G_9	Karimunda	8.33	54.00	2.00	17.33
G_{10}	Sigandini	11.00	66.33	3.67	9.67
G_{11}	Arka Coorg Excel	8.00	57.67	3.67	15.67
G_{12}	IISR Thevam	7.33	53.33	7.00	8.67
G_{13}	Panchami	6.33	35.00	5.33	6.00
G_{14}	Punjarmundi	4.67	62.67	2.33	2.67
G_{15}	Panniyur-1	7.47	69.33	8.67	5.00
G_{16}	Panniyur-2	7.67	52.67	4.33	9.00
G_{17}	Panniyur-3	11.67	79.33	6.00	16.33
G_{18}	Panniyur-5	12.33	79.00	4.67	10.67
G_{19}	V-1	12.67	61.67	4.00	12.33
G_{20}	V-2	27.33	62.67	8.33	10.33
G_{21}	V-3	11.67	65.33	6.00	13.00
G_{22}	V-4	7.33	88.33	3.00	10.00
G_{23}	V-5	7.00	39.00	2.67	5.33
G_{24}	V-7	9.33	56.67	3.33	7.33
G_{25}	V-8	5.33	45.00	4.67	4.00
Mean		**10.02**	**60.99**	**4.96**	**8.87**
SEm±		**0.40**	**1.75**	**0.22**	**0.42**
CD @5%		**1.13**	**4.98**	**0.63**	**1.19**

Table 5: Mean performance of black pepper genotypes for spike parameters

Genotypes		No. of spikes/m^2	Spike length (cm)	Fresh spike weight (g)	Number of berries per spike
G_1	Arakulamundi	39.33	13.75	10.00	68.33
G_2	Cholamundi	41.33	8.83	7.83	58.67
G_3	Neelamundi	48.67	13.17	11.83	80.33
G_4	Zion mundi	34.00	9.58	9.83	60.83
G_5	Kurimale	40.33	20.1	20.92	106.17
G_6	Nateshan kudi	38.00	13.83	7.35	62.17
G_7	Vellanamban	38.33	10.33	9.50	71.67
G_8	Vijay	36.33	14.83	8.00	60.67
G_9	Karimunda	44.00	9.83	5.50	46.50
G_{10}	Sigandini	29.67	13.33	10.33	65.83
G_{11}	Arka Coorg Excel	46.67	15.67	13.50	80.50
G_{12}	IISR Thevam	49.00	11.08	11.25	59.67
G_{13}	Panchami	46.67	15.42	13.55	118.33
G_{14}	Punjarmundi	6.3	15.67	19.33	90.50
G_{15}	Panniyur-1	45.67	21.5	21.33	105.33
G_{16}	Panniyur-2	40.67	11.67	10.50	78.67
G_{17}	Panniyur-3	55.67	10.50	12.17	69.83
G_{18}	Panniyur-5	56.33	15.50	10.33	64.00
G_{19}	V-1	36.00	12.50	8.50	72.67

G_{20}	V-2	65.0	11.33	6.83	65.67
G_{21}	V-3	44.33	11.83	8.67	62.17
G_{22}	V-4	41.67	12.50	10.67	70.0
G_{23}	V-5	28.33	7.83	5.83	63.33
G_{24}	V-7	40.67	10.50	8.83	66.17
G_{25}	V-8	36.00	14.67	11.17	66.67
Mean		**41.16**	**13.03**	**10.94**	**72.59**
SEm±		**1.79**	**0.64**	**0.49**	**2.13**
CD @5%		**5.09**	**1.81**	**1.40**	**6.07**

Table 6: Mean performance of black pepper genotypes for berry parameters

Genotypes		**100-fresh berry weight**	**100-dry berry weight**	**Fresh berry yield per vine (kg)**	**Dry recovery (%)**	**Dry berry yield per vine (kg)**
G_1	Arakulamundi	12.67	4.78	22.07	39.89	8.80
G_2	Cholamundi	13.60	4.54	5.17	36.07	1.86
G_3	Neelamundi	13.73	4.85	10.14	35.14	3.56
G_4	Zion mundi	15.20	4.31	5.84	31.2	1.82
G_5	Kurimale	18.47	6.3	5.52	33.56	1.85
G_6	Nateshan kudi	10.37	4.30	6.28	34	2.14
G_7	Vellanamban	11.33	5.16	24.70	36.75	9.08
G_8	Vijay	12.00	5.52	5.58	35.66	1.99
G_9	Karimunda	12.23	4.32	5.20	34.72	1.80
G_{10}	Sigandini	13.33	5.41	3.52	35	1.23
G_{11}	Arka Coorg Excel	14.40	4.63	6.71	33.05	2.22
G_{12}	IISR Thevam	16.63	4.86	5.25	32.3	1.69
G_{13}	Panchami	12.57	4.18	5.23	33.2	1.74
G_{14}	Punjarmundi	17.00	5.59	5.16	33.72	1.74
G_{15}	Panniyur-1	14.37	5.10	32.77	34.96	11.46
G_{16}	Panniyur-2	12.00	4.59	19.67	34.92	6.87
G_{17}	Panniyur-3	16.67	4.66	5.82	29.44	1.71
G_{18}	Panniyur-5	12.40	4.46	5.61	36.03	2.02
G_{19}	V-1	11.40	3.87	10.79	30.22	3.26
G_{20}	V-2	8.67	3.91	8.50	35.98	3.06
G_{21}	V-3	13.67	5.03	6.22	38.75	2.41
G_{22}	V-4	14.33	3.96	6.00	30.14	1.81
G_{23}	V-5	10.47	3.55	4.41	34.29	1.51
G_{24}	V-7	12.63	3.76	11.23	33.59	3.77
G_{25}	V-8	16.87	5.78	7.63	34.97	2.67
Mean		**13.48**	**4.70**	**9.40**	**34.30**	**3.28**
SEm±		**0.46**	**0.22**	**0.56**	**1.33**	**0.17**
CD @5%		**1.32**	**0.64**	**1.59**	**3.78**	**0.49**

Table 7: Mean performance of black pepper genotypes quality parameters

Genotypes		**Essential oil (%)**	**Oleoresin (%)**	**Bulk density (g/l)**
G_1	Arakulamundi	1.37	10.70	549.32
G_2	Cholamundi	2.29	6.00	568.68
G_3	Neelamundi	2.68	2.60	539.56
G_4	Zion mundi	1.63	12.00	575.32
G_5	Kurimale	2.00	7.93	555.40
G_6	Nateshan kudi	1.38	13.67	585.80
G_7	Vellanamban	0.88	4.00	571.96

G_8	Vijay	3.90	10.10	591.20
G_9	Karimunda	3.17	10.93	577.36
G_{10}	Sigandini	2.12	8.12	572.28
G_{11}	Arka Coorg Excel	3.10	5.97	523.52
G_{12}	IISR Thevam	2.27	7.65	639.80
G_{13}	Panchami	0.75	11.73	527.80
G_{14}	Punjarmundi	3.00	6.0	543.24
G_{15}	Panniyur-1	3.50	11.50	565.10
G_{16}	Panniyur-2	3.67	12.37	537.16
G_{17}	Panniyur-3	3.38	10.42	515.68
G_{18}	Panniyur-5	3.67	10.71	524.80
G_{19}	V-1	3.12	13.18	494.36
G_{20}	V-2	2.89	12.33	569.08
G_{21}	V-3	3.19	10.47	657.60
G_{22}	V-4	3.21	9.39	567.48
G_{23}	V-5	2.99	10.43	600.12
G_{24}	V-7	2.56	13.00	574.68
G_{25}	V-8	3.27	13.33	588.96
Mean		**2.64**	**10.25**	**564.65**
SEm±		**0.14**	**0.51**	**23.62**
CD @5%		**0.39**	**1.44**	**67.16**

The significant variation in leaf dimensions, with Panniyur-1 and Punjarmundi exhibiting large leaves, further points to differences in photosynthetic capacity among the genotypes.

Plant architecture and primary yield components

The architecture of the vine, particularly the framework of fruit-bearing lateral branches (plagiotropes), is a primary determinant of yield potential. In this study, the genotype V-2 (G20) proved to be exceptionally promising for plant architecture (Table 4), excelling in key yield framework traits by recording the highest number of laterals/m² (27.33). This trait is fundamentally important as it directly determines the number of potential nodes for spike development and is a major focus in breeding for higher productivity (Choudhary and Kumar, 2024). A high density of laterals per unit area is a cornerstone of developing compact and highly productive "bush pepper" varieties as well (Hamza *et al.*, 2020).

The number of spikes per unit area, a direct consequence of lateral density, followed a similar trend, with V-2 (G20) again recording the highest value (65.00 spikes/m²) (Table 5). This demonstrates a clear yield-building strategy based on producing a very high number of inflorescences. Other genotypes like Panniyur-5 (56.33) and Panniyur-3 (55.67) also showed high spike density. In contrast, genotypes like Karimunda (G9) and Panniyur-3 (G17) excelled in the number of spikes per plagiotropic shoot (17.33 and 16.33, respectively) (Table 4), indicating a different architectural efficiency where individual laterals are highly productive. This highlights that multiple genetic pathways to achieving a high sink capacity exist within this germplasm, offering breeders flexibility in their selection strategies (Srinivasan *et al.*, 2021).

Yield performance and its contributing traits

For the ultimate economic trait, dry berry yield per vine, the performance range was remarkable, varying from 1.23 kg (Sigandini, G10) to 11.46 kg (Panniyur-1, G15) (Table 6). This nearly ten-fold difference is a powerful indicator of the immense scope for achieving rapid genetic gain through simple selection of these superior genotypes. The genotype Panniyur-1 was the highest yielder, followed by Vellanamban (G7) (9.08 kg) and Arakulamundi (G1) (8.80 kg). The consistent high performance of Panniyur-1, a well-established released hybrid, across different studies and locations validates its superior and stable genetic makeup (Thankamani and Kandiannan, 2024; Lissy *et al.*, 2019).

An analysis of the components contributing to this high yield reveals diverse strategies. Panniyur-1's high yield is attributable to its exceptionally long spikes (21.5 cm) combined with a high number of berries per spike (105.33) (Table 5), ensuring each spike contributes significantly to the total yield. In contrast, V-2, while having a modest dry yield (3.06 kg), achieved its yield potential through an exceptionally high number of spikes per unit area (65.00), as previously discussed. This suggests that a powerful breeding strategy would be to hybridize genotypes like Panniyur-1 (with large sinks per spike) with genotypes like V-2 (with high sink density) to potentially pyramid these complementary traits for a new yield plateau (Manju & Sreelathakumary, 2002; Mathew *et al.*, 2022).

Genotype Panchami (G13) was notable for producing the highest number of berries per spike (118.33), suggesting superior efficiency in pollination and fruit set. This trait is highly influenced by climatic factors during the flowering period, and genotypes that consistently exhibit high fruit set are invaluable for ensuring yield stability in the face of climate variability (Menon and Pillai, 2023; John *et al.*, 2020). Furthermore, berry size and weight, reflected by 100-berry weight, also varied significantly. Kurimale (G5) recorded the highest 100-fresh berry weight (18.47 g), indicating large berries, a trait often preferred in markets for table-grade pepper (Bhatt *et al.*, 2023).

Quality parameters and commercial value

In addition to yield, quality parameters are critical for determining market acceptance, price, and end-use suitability. The two primary quality components in black pepper are essential oil, which contributes to the characteristic aroma, and oleoresin, which is responsible for pungency (piperine content). For these traits (Table 7), Vijay (G8) recorded the highest essential oil content (3.90%), making it a valuable genotype for markets where aroma is a primary consideration, such as the gourmet food industry. High essential oil content is a key selection criterion for varieties intended for direct culinary use (Singh *et al.*, 2025; Peter & Shylaja, 2018).

Conversely, Nateshan kudi (G6) was superior in oleoresin content (13.67%), followed by V-8 (13.33%), V-1 (13.18%) and V-7 (13.00%). Oleoresin is the primary product for the value-added extraction industry, which supplies food processing, pharmaceutical, and nutraceutical sectors. The identification of genotypes with high oleoresin content is therefore critical for this industry, a point highlighted in recent market analyses (Kumar and Singh, 2025; Sivaraman and Bhat, 2022). The existence of genotypes with high essential oil but moderate oleoresin (e.g., Vijay) and others with high oleoresin but moderate essential oil (e.g., Nateshan kudi) suggests that the genetic control of these pathways may be largely independent, allowing for targeted breeding for specific end-uses (Gorgani *et al.*, 2017).

In conclusion, this study successfully identified elite genotypes with superior phenotypic performance for key economic traits. Panniyur-1 stands out for its exceptional yield, V-2 for its ideal plant architecture with high spike density, Vijay for its high aroma content, and Nateshan kudi for its high pungency. These genotypes represent valuable genetic material for direct cultivation in similar agro-climatic zones and, more importantly, serve as a strategic genetic resource for future black pepper breeding programs aimed at developing varieties with higher yield, improved quality, and resilient plant architecture. Future work should focus on multi-location trials to assess the stability of these genotypes and employ molecular markers to facilitate the pyramiding of these desirable traits.

Conclusion

The present investigation revealed substantial and exploitable genetic variability among the twenty-five black pepper (Piper nigrum L.) genotypes evaluated for growth, yield, and quality attributes. Panniyur-1 consistently outperformed all other genotypes in terms of dry berry yield, reaffirming its suitability for high-productivity cultivation. Genotype V-2, characterized by its superior plant architectural traits such as higher lateral density and spike production, emerged as a promising ideotype for enhancing yield efficiency. In relation to quality parameters, Vijay exhibited the highest essential oil content, while Nateshan kudi recorded maximum oleoresin content, indicating their potential for value-added and industrial applications.The identification of these elite and trait-specific genotypes underscores the importance of systematic germplasm evaluation in strengthening black pepper improvement programmes. The promising lines identified in this study merit inclusion in future breeding efforts aimed at developing high-yielding, quality-rich cultivars. Further multilocational evaluation and molecular characterization are recommended to confirm their stability, adaptability, and utility in long-term genetic enhancement strategies.

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