E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 118-124
Received: 23-09-2025
Accepted: 25-10-2025

Shankarprasad KS
University of Horticultural Sciences, Bagalkote, Karnataka, India

Hegde Laxminarayan
University of Horticultural Sciences, Bagalkote, Karnataka, India

Narayanapur VB
University of Horticultural Sciences, Bagalkote, Karnataka, India

Kulkarni S
University of Horticultural Sciences, Bagalkote, Karnataka, India

Shet RM
University of Horticultural Sciences, Bagalkote, Karnataka, India

Gunnaiah R
University of Horticultural Sciences, Bagalkote, Karnataka, India

Pushpa P
University of Horticultural Sciences, Bagalkote, Karnataka, India

Maniyar AK
University of Horticultural Sciences, Bagalkote, Karnataka, India

Corresponding Author:
Shankarprasad KS
University of Horticultural Sciences, Bagalkote, Karnataka, India

Comparative evaluation of root and shoot development in black pepper (*piper nigrum* L.) hybrids propagated via single-node cuttings

Shankarprasad KS, Hegde Laxminarayan, Narayanapur VB, Kulkarni S, Shet RM, Gunnaiah R, Pushpa P and Maniyar AK

DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i11b.4154

Abstract
Black pepper (*Piper nigrum* L.), one of the world's most traded spices, requires improved and climate-resilient varieties to meet rising demand. The present study evaluated 37 hybrids for vegetative propagation using single-node cuttings in a randomized design at HREC, Sirsi (2022-2023). Substantial genetic variability was detected for early growth, shoot and root parameters among the raised plants. Hybrids SPH-84 and SPH-2 exhibited superior plant height, development of nodes and root attributes. Root diameter was positively correlated with root length (r = 0.514, $P<0.001$), whereas root number per cutting was negatively associated with root diameter. Heterosis analysis identified SPH-84 with the highest positive heterosis for plant height (117.54%). These findings highlighted SPH-84 and SPH-2 as promising candidates for future breeding programmes aimed at enhancing black pepper productivity and resilience.

Keywords: Black pepper (*Piper nigrum* L.), single-node cuttings, vegetative propagation

1. Introduction

Black pepper (*Piper nigrum* L.), also popularly known as the 'King of Spices', is a perennial climber, predominantly propagated through vegetative methods to maintain genetic uniformity and desirable traits. The propagation through single node cutting has emerged as an efficient method for rapid multiplication of elite varieties and hybrids as it increases multiplication rate and reduces unit cost per nursery raised plant. As noted by Krishnamoorthy and Parthasarathy (2010) [9], the success of vegetative propagation in black pepper varies significantly among different genetic materials. With a total production of about 1,25,927 tons in India (Spices Board, 2025) [19], the state of Karnataka (≈70%) is leading in terms of production and area. India's national average is ≈400-450 kg/ha which is significantly low compared to yield of 5-8 tons/ha in well-cultivated gardens (Ranganathan, 2019) [14]. Three-fourths of the world's area under black pepper cultivation is in India, still overall yields are very low. Currently, the black pepper prices are soaring and the demand for quality planting material of superior varieties is also rapidly gaining momentum. The established fact is that the robust growth and strong root system is the key for disease tolerance and better agronomic performance. With this background, the present study was undertaken to evaluate the response of newly developed hybrids to the single-node cutting propagation method. The null hypothesis stated that there were no significant variations among the hybrids, whereas the alternative hypothesis proposed the presence of significant differences among them.

2. Materials and Methods

The present experiment was conducted (2022-2023) at the Horticultural Research and Extension Centre, Sirsi, with 44 treatments (37 hybrids, 4 male parents, 1 female parent, 2 released varieties) were assessed in a completely randomized design with five replications. The hybrids were developed by Bhat (2023) [3] during 2017-2018. The growing stems were cut one meter above ground; tender tips were discarded. Single-node cuttings (≈6.50 cm on lower side and ≈2.00 cm upper side of node) were treated with 1000 ppm IBA (indole-3-butyric acid) for one minute and then cuttings were immersed in Carbendazim 12% + Mancozeb 63% WP (2 g/L) for 15 min, followed by 4% Metalaxyl + 64% Mancozeb WP (2g/l) for 15 min, then planted in solarized potting mixture containing soil: FYM: sand (4:2:1) in 5" x 3" polybags under polythene cover inside greenhouse. Observations on plant height, number of nodes, diameter of cutting, number of roots, root diameter, root length and new shoot diameter were recorded manually. The leaf area was measured using Petiole Pro mobile application (Petiole LTD, 2020) [11]. The specific leaf area (SLA) and specific leaf weight (SLW) were calculated using following formula:

$$\text{a) SLA} = \frac{\text{Leaf area}}{\text{Dry weight of leaf}}$$

$$\text{b) SLW} = \frac{\text{Dry weight of leaf}}{\text{Leaf area}}$$

All statistical analysis was validated using software packages. Analysis of variance, post-hoc analysis and correlation analysis were carried out using WASP 2.0 (Jangam and Thali, 2004) [7], OPSTAT and KAU GRAPES (Gopinath *et al*., 2020) [5] data analysis web platforms. Heterosis was calculated using following formula:

$$\text{a) Relative heterosis (\%)} = \left(\frac{\text{F1 - MP}}{\text{MP}}\right) \times 100$$

$$\text{b) Heterobeltiosis (\%)} = \left(\frac{\text{F1 - BP}}{\text{BP}}\right) \times 100$$

$$\text{c) Standard heterosis (\%)} = \left(\frac{\text{F1 - CC}}{\text{CC}}\right) \times 100$$

Where, F_1 represents the first filial generation, MP is the mid-parent value, BP is the better parent value and CC is the commercial check.

3. Results and discussion

Thirty-seven black pepper hybrids developed at HREC, Sirsi, were evaluated for their response to single node cutting. Growth parameters of both aerial and root parts were assessed five months after planting, testing the hypothesis that significant genetic variability exists among hybrids.

3.1 Growth parameters

Significant variation was observed (Table 1) in plant height. SPH-84 recorded the tallest plants (46.50 cm), followed by SPH-2 (38.33 cm). The check variety Panniyur-1 reached 23.75 cm, while SPH-41 was the shortest (7.00 cm). These results confirm the alternative hypothesis and agree with previous findings (Prajapati *et al*., 2018 [12]; Raja *et al*., 2018 [13]; Ravindran & Sasikumar, 1993). SPH-84 also recorded the highest number of leaves (9 Nos.) and nodes (9 Nos.), compared to 5.50 in the check, with SPH-2 at 8.50 each in nodes and leaves count, highlighting superior photosynthetic and growth potential. As all the nodes produced one leaf each, only number of nodes per cutting was considered here after. Rooting performance showed clear differences. SPH-78 developed the most roots (16.5), followed by SPH-47, SPH-64 and SPH-33, and while Panniyur-1 had only five roots and SPH-70 had three. These findings reflect strong genetic influence on rooting, consistent with Bhai *et al.* (2018) [2] and Bhat *et al.* (2018) [4]. Root morphology revealed SPH-77 with the longest root (38.5 cm), and SPH-71 and SPH-70 following (29.0 cm and 28.0 cm). While Panniyur-1 showed the largest root diameter (2.08 mm), SPH-36 (2.05 mm) and Keregadde Malligesara (1.95 mm) were statistically on par with each other. SPH-74 lagged at 0.85 mm. Root traits directly influence water uptake and anchorage (Secundino *et al*., 2014 [18]; Wu *et al*., 2016) [20].

Diameter of cuttings varied from 6.97 mm in SPH-2 to 3.50 mm in SPH-26, indicating the vigour of mother plants. New shoot diameter was highest in SPH-83 (5.28 mm) and lowest in SPH-53 (3.32 mm), aligning with observations in *Moringa* and *Jatropha* (Santoso and Parwata, 2020 [17]; Kanimozhi *et al*., 2023) [8].

Leaf area, a representing factor for photosynthetic capacity, ranged from 68.90 cm² in SPH-18 to 17.10 cm² in SPH-66, with genetic factors predominantly driving differences under uniform conditions. High SLA was noted in SPH-85 (0.223 cm²/mg) and SPH-47/SPH-84 (0.207 cm²/mg), whereas SPH-71 recorded the lowest (0.132 cm²/mg). SLW values correspondingly ranged, confirming structural variations in leaf traits, paralleling trends observed in rice and black pepper (Banjare *et al*., 2024 [1]; Reshma *et al*., 2024) [16]. The higher SLW is associated with drought resilience characters.

3.2 Correlation analysis

Plant height was strongly correlated with number of nodes (no. of leaves) (r = 0.882, $p<0.001$) and moderately with diameter of cutting, root diameter, root length and new shoot diameter. Root diameter and root length were positively related (r = 0.514, $p<0.001$). Root number negatively correlated with root size traits indicating a balance between the traits (Wu *et al*., 2016 [20]; Liang *et al*., 2011) [10].

3.3 Heterosis Analysis

Mid-parent heterosis revealed significant variability. SPH-84 (117.54%) and SPH-2 (81.46%) exhibited highest positive heterosis for plant height, while SPH-72 (-63.86%) was among the lowest. Similar patterns were seen for number of nodes and roots, whereas SPH-47 and SPH-88 recording high positive heterosis for root number. Root diameter showed mostly negative heterosis, except SPH-77 (4.42%). Better parent heterosis ranged widely, plant height (−70.53% to 95.79%), number of nodes (−48.72% to 54.55%), diameter of cutting (−36.59% to 32.09%) and root number (−53.85% to 155.88%). The root diameter was negatively skewed across hybrids. Whereas, standard heterosis (compared to check var. Panniyur-1) showed SPH-84 with the highest plant height gain (+95.79%) and SPH-78 with the highest root number increase (+230%) and negative heterosis for root diameter was consistent across all the cross combinations and across all hybrids.

Overall, heterosis analysis revealed hybrids like SPH-84 and SPH-2 exhibited strong positive heterosis for plant height and number of nodes. Number of roots also showed significant positive heterosis across hybrids. Conversely, heterosis for root diameter was generally negative. Specific cross combinations, particularly Panniyur-1 × Chomala and Panniyur-1 × Ademane pepper, showed distinct heterotic responses across growth *et al.* (2014) [6].

Table 1: Growth response of different hybrids for propagation by single node cutting

Genotype	Plant height (cm)	Number of leaves	Number of nodes	Number of roots	Root diameter (mm)	Root length (cm)	Cutting diameter (mm)	New shoot diameter (mm)
Ademane pepper	$17.75^{ghijklmnop}$	5.00^{efghi}	5.00^{efghi}	14.50^{abcd}	$1.36^{cdefghij}$	15.80^{fgh}	4.51^{jklm}	3.84^{ghijk}
Chomala	$18.50^{ghijklmnop}$	4.50^{fghi}	4.50^{fghi}	7.00^{hijk}	1.53^{bcdef}	14.67^{gh}	4.46^{klm}	3.76^{ghijk}
K. malligesara	$19.00^{fghijklmno}$	6.50^{cde}	6.50^{cde}	6.50^{hijk}	1.95^{ab}	$21.00^{bcdefgh}$	$5.52^{bcdefghi}$	$4.15^{defghij}$
Kurimale	$19.33^{fghijklmno}$	5.67^{cdefg}	5.67^{cdefg}	5.67^{ijk}	$1.38^{cdefghi}$	24.67^{bcdef}	$5.30^{bcdefghijkl}$	3.98^{fghijk}
Panniyur1 (check)	23.75^{efghi}	5.50^{defg}	5.50^{defg}	5.00^{jk}	2.08^{a}	25.25^{bcde}	$5.28^{bcdefghijkl}$	$4.16^{defghij}$
SPH-100	$20.50^{fghijklm}$	6.00^{cdef}	6.00^{cdef}	8.00^{fghijk}	$1.47^{bcdefghi}$	$21.50^{bcdefgh}$	$5.41^{bcdefghijk}$	3.85^{ghijk}
SPH-99	31.00^{bcde}	7.00^{bcd}	7.00^{bcd}	$11.50^{abcdefgh}$	$1.36^{cdefghij}$	18.25^{defgh}	6.15^{abcd}	4.39^{bcdefg}
SPH-95	$20.00^{fghijklmn}$	6.00^{cdef}	6.00^{cdef}	$9.00^{defghij}$	$1.37^{cdefghi}$	$22.00^{bcdefgh}$	6.20^{abc}	3.55^{ijk}
SPH-89	$21.00^{fghijklm}$	6.00^{cdef}	6.00^{cdef}	7.50^{ghijk}	1.64^{abcd}	25.75^{bcd}	$5.19^{defghijklm}$	$4.09^{defghij}$
SPH-88	13.00^{lmnopq}	4.00^{ghi}	4.00^{ghi}	14.50^{abcd}	$1.17^{defghij}$	18.50^{defgh}	$5.60^{bcdefgh}$	4.04^{efghij}
SPH-86	23.25^{efghi}	7.50^{abc}	7.50^{abc}	$11.50^{abcdefgh}$	$1.43^{cdefghi}$	$20.17^{bcdefgh}$	$5.76^{bcdefgh}$	4.03^{fghij}
SPH-85	12.00^{mnopq}	4.00^{ghi}	4.00^{ghi}	$12.00^{abcdefgh}$	1.05^{fghij}	19.00^{cdefgh}	6.25^{ab}	3.75^{ghijk}
SPH-84	46.50^{a}	9.00^{a}	9.00^{a}	$10.50^{bcdefghij}$	$1.36^{cdefghij}$	$21.50^{bcdefgh}$	$5.14^{efghijklm}$	4.00^{fghijk}
SPH-83	$17.50^{ghijklmnop}$	5.50^{defg}	5.50^{defg}	$8.50^{efghijk}$	$1.38^{cdefghi}$	16.25^{efgh}	$5.20^{defghijklm}$	5.28^{a}
SPH-82	11.00^{nopq}	4.00^{ghi}	4.00^{ghi}	$12.83^{abcdefg}$	$1.46^{bcdefghi}$	18.75^{defgh}	6.00^{bcdef}	4.65^{abcdef}
SPH-81	9.50^{pq}	3.50^{hi}	3.50^{hi}	$11.00^{abcdefghi}$	$1.40^{cdefghi}$	16.25^{efgh}	4.81^{hijklm}	4.99^{ab}
SPH-78	$19.00^{fghijklmno}$	6.00^{cdef}	6.00^{cdef}	16.50^{a}	$1.38^{cdefghi}$	18.00^{defgh}	$5.08^{fghijklm}$	4.36^{bcdefg}
SPH-77	24.33^{efgh}	6.00^{cdef}	6.00^{cdef}	7.50^{ghijk}	1.81^{abc}	38.50^{a}	6.00^{bcdef}	$4.25^{cdefghi}$
SPH-74	11.00^{nopq}	5.00^{efghi}	5.00^{efghi}	8.00^{fghijk}	0.85^{j}	19.00^{cdefgh}	4.31^{lmn}	3.49^{jk}
SPH-72	7.50^{q}	3.50^{hi}	3.50^{hi}	13.50^{abcdef}	1.00^{ghij}	16.25^{efgh}	6.08^{bcde}	3.60^{hijk}
SPH-71	35.00^{bc}	8.50^{ab}	8.50^{ab}	14.50^{abcd}	$1.40^{cdefghi}$	29.00^{b}	$5.66^{bcdefgh}$	4.30^{cdefgh}
SPH-70	23.50^{efghi}	6.50^{cde}	6.50^{cde}	3.00^{k}	1.66^{abcd}	28.00^{bc}	$5.34^{bcdefghijk}$	4.26^{cdefgh}
SPH-66	$14.83^{ijklmnopq}$	4.00^{ghi}	4.00^{ghi}	5.67^{ijk}	$1.46^{bcdefghi}$	$21.00^{bcdefgh}$	4.53^{ijklm}	4.02^{fghij}
SPH-64	$14.00^{jklmnopq}$	5.50^{defg}	5.50^{defg}	15.00^{abc}	0.95^{ij}	17.00^{defgh}	$5.41^{bcdefghijk}$	3.60^{hijk}
SPH-63	$15.25^{hijklmnopq}$	5.50^{defg}	5.50^{defg}	$8.50^{efghijk}$	$1.40^{cdefghi}$	$20.00^{bcdefgh}$	$5.50^{bcdefghij}$	4.34^{bcdefg}
SPH-60	$13.50^{klmnopq}$	3.50^{hi}	3.50^{hi}	$13.00^{abcdefg}$	1.52^{bcdefg}	13.50^{h}	$5.45^{bcdefghijk}$	3.95^{ghijk}
SPH-59	23.00^{efghij}	6.50^{cde}	6.50^{cde}	$9.50^{cdefghij}$	$1.40^{cdefghi}$	23.00^{bcdefg}	$5.16^{defghijklm}$	5.23^{a}
SPH-53	$13.50^{klmnopq}$	4.00^{ghi}	4.00^{ghi}	14.50^{abcd}	$1.18^{defghij}$	23.00^{bcdefg}	$5.07^{fghijklm}$	3.32^{k}
SPH-49	25.00^{defg}	6.50^{cde}	6.50^{cde}	14.00^{abcde}	1.75^{abc}	25.50^{bcd}	4.93^{hijklm}	4.00^{fghijk}
SPH-47	$17.50^{ghijklmnop}$	4.00^{ghi}	4.00^{ghi}	16.00^{ab}	0.97^{hij}	14.00^{gh}	4.57^{ijklm}	3.74^{ghijk}
SPH-46	$22.25^{efghijk}$	5.50^{defg}	5.50^{defg}	14.50^{abcd}	$1.43^{cdefghi}$	18.25^{defgh}	$5.65^{bcdefgh}$	$4.15^{defghij}$
SPH-43	33.00^{bcd}	7.50^{abc}	7.50^{abc}	$10.50^{bcdefghij}$	1.75^{abc}	24.75^{bcdef}	5.95^{bcdefg}	$4.09^{defghij}$
SPH-41	7.00^{q}	3.50^{hi}	3.50^{hi}	15.00^{abc}	1.09^{efghij}	17.00^{defgh}	$4.99^{ghijklm}$	3.83^{ghijk}
SPH-36	27.75^{cdef}	7.00^{bcd}	7.00^{bcd}	7.00^{hijk}	2.05^{a}	22.75^{bcdefg}	5.97^{bcdefg}	4.84^{abc}
SPH-34	$15.25^{hijklmnopq}$	4.00^{ghi}	4.00^{ghi}	$9.50^{cdefghij}$	$1.18^{defghij}$	17.00^{defgh}	4.82^{hijklm}	3.60^{hijk}
SPH-33	24.67^{efg}	6.33^{cdef}	6.33^{cdef}	15.00^{abc}	$1.50^{bcdefgh}$	13.17^{h}	$5.23^{cdefghijkl}$	3.91^{ghijk}
SPH-32	9.50^{pq}	3.50^{hi}	3.50^{hi}	$10.50^{bcdefghij}$	1.10^{efghij}	$20.00^{bcdefgh}$	$5.00^{ghijklm}$	3.90^{ghijk}
SPH-31	10.33^{opq}	3.33^{i}	3.33^{i}	$10.50^{bcdefghij}$	1.59^{abcde}	22.75^{bcdefg}	4.32^{lmn}	$4.10^{defghij}$
SPH-26	$20.25^{fghijklm}$	6.00^{cdef}	6.00^{cdef}	6.50^{hijk}	$1.49^{bcdefgh}$	$21.75^{bcdefgh}$	3.50^{n}	4.74^{abcd}
SPH-18	$21.50^{fghijkl}$	5.50^{defg}	5.50^{defg}	7.50^{ghijk}	1.00^{ghij}	16.00^{fgh}	4.23^{mn}	4.36^{bcdefg}
SPH-12	23.50^{efghi}	6.00^{cdef}	6.00^{cdef}	14.50^{abcd}	1.53^{bcdefg}	$21.25^{bcdefgh}$	$5.44^{bcdefghijk}$	3.74^{ghijk}
SPH-2	38.33^{b}	8.50^{ab}	8.50^{ab}	$11.00^{abcdefghi}$	1.72^{abc}	25.50^{bcd}	6.97^{a}	4.72^{abcde}
IISR Thevam	$20.67^{fghijklm}$	5.33^{defgh}	5.33^{defgh}	8.00^{fghijk}	1.69^{abcd}	25.67^{bcd}	4.59^{ijklm}	3.80^{ghijk}
Vijay	$13.83^{jklmnopq}$	4.00^{ghi}	4.00^{ghi}	$9.67^{cdefghij}$	$1.38^{cdefghi}$	17.00^{defgh}	4.54^{ijklm}	3.95^{ghijk}
Mean	19.73	5.47	5.47	10.55	1.42	20.63	5.25	4.11
SE(m) ±	2.05	0.44	0.44	1.24	0.12	2.00	0.22	0.15
CD (0.01)	7.62	1.63	1.63	4.63	0.43	7.44	0.82	0.57
CV (%)	17.96	13.87	13.87	20.40	14.16	16.76	7.24	6.47

Note: Treatments with the samae letter grouping are not significantly different.

Table 2: Growth response of different hybrids for leaf parameters during propagation through single node cutting

Genotype	Leaf area (cm^2)	Specific leaf area (cm^2/mg)	Specific leaf weight (mg/cm^2)
Ademane pepper	25.00^{nopqr}	0.16^{mno}	6.31^{ghi}
Chomala	22.40^{pqr}	0.14^{s}	7.09^{b}
Karimalligesara	35.00^{hijklm}	0.17^{ij}	5.95^{mn}
Kurimale	$30.60^{jklmnop}$	0.16^{kl}	6.13^{jk}
Panniyur-1	32.70^{ijklmn}	0.18^{e}	5.46^{r}
SPH-100	26.80^{mnopq}	0.14^{s}	7.15^{b}
SPH-99	62.60^{ab}	0.17^{fg}	5.74^{pq}
SPH-95	40.00^{efghij}	0.17^{h}	5.83^{op}
SPH-89	$29.00^{klmnopq}$	0.16^{kl}	6.12^{jk}
SPH-88	33.60^{ijklmn}	0.18^{e}	5.52^{r}
SPH-86	36.60^{ghijkl}	0.20^{c}	5.04^{t}
SPH-85	40.00^{efghij}	0.22^{a}	4.49^{v}
SPH-84	23.00^{opqr}	0.21^{b}	4.83^{u}
SPH-83	57.70^{bc}	0.15^{r}	6.78^{c}
SPH-82	41.40^{efghi}	0.18^{f}	5.66^{q}
SPH-81	48.90^{cde}	0.18^{e}	5.46^{r}
SPH-78	56.30^{bc}	0.16^{no}	6.38^{fg}
SPH-77	50.40^{cd}	0.15^{q}	6.56^{d}

SPH-74	29.50^{klmnop}	0.18^{e}	5.45^{r}
SPH-72	34.60^{ijklm}	0.17^{jk}	6.02^{lm}
SPH-71	20.30^{qr}	0.13^{t}	7.58^{a}
SPH-70	37.80^{ghijk}	0.20^{c}	5.07^{t}
SPH-66	17.10^{r}	0.19^{d}	5.28^{s}
SPH-64	34.40^{ijklm}	0.15^{r}	6.87^{c}
SPH-63	29.60^{klmnop}	0.15^{pq}	6.50^{de}
SPH-60	40.80^{efghi}	0.17^{hi}	5.89^{no}
SPH-59	44.30^{defg}	0.15^{r}	6.79^{c}
SPH-53	28.00^{lmnopq}	0.16^{jk}	6.06^{kl}
SPH-49	44.20^{defgh}	0.15^{pq}	6.49^{de}
SPH-47	47.20^{def}	0.21^{b}	4.84^{u}
SPH-46	37.40^{ghijkl}	0.16^{mno}	6.31^{gh}
SPH-43	65.00^{ab}	0.16^{op}	6.44^{ef}
SPH-41	39.20^{fghij}	0.17^{ij}	5.97^{lmn}
SPH-36	57.70^{bc}	0.16^{lm}	6.21^{ij}
SPH-34	34.80^{ijklm}	0.17^{h}	5.85^{o}
SPH-33	34.50^{ijklm}	0.17^{gh}	5.81^{op}
SPH-32	32.20^{ijklmn}	0.16^{no}	6.35^{fgh}
SPH-31	56.10^{bc}	0.16^{mn}	6.30^{ghi}
SPH-26	40.70^{efghi}	0.16^{mn}	6.29^{ghi}
SPH-18	68.90^{a}	0.16^{mno}	6.31^{ghi}
SPH-12	63.60^{ab}	0.17^{jk}	6.04^{klm}
SPH-2	34.40^{ijklm}	0.15^{q}	6.58^{d}
IISR Thevam	23.00^{opqr}	0.19^{d}	5.26^{s}
Vijay	$31.90^{ijklmno}$	0.16^{mn}	6.25^{hi}
Mean	39.07	0.168	6.029
SE(m) ±	2.135	0.001	0.025
CD (0.01)	7.949	0.003	0.094
CV (%)	9.464	0.769	0.724

Note: Treatments with the same letter grouping are not significantly different.

Table 3: Mid parent heterosis for growth traits utilized in propagation of black pepper

Hybrid	Mid parent heterosis (%)						
	Plant height	Number of nodes	Cutting diameter	Number of roots	Root diameter	Root length	New shoot diameter
SPH-71	68.67	61.90	15.66	48.72	-48.72	41.29	7.50
SPH-72	-63.86	-33.33	24.25	38.46	-63.37	-20.83	-10.00
SPH-78	-8.43	14.29	3.80	69.23	-49.45	-12.30	8.92
SPH-89	1.20	14.29	6.12	-23.08	-40.05	25.46	2.25
SPH-2	81.46	70.00	43.17	83.33	-5.07	27.77	19.16
SPH-12	11.24	20.00	11.74	141.67	-15.58	6.47	-5.60
SPH-18	1.78	10.00	-13.18	25.00	-44.70	-19.83	10.15
SPH-26	-5.26	0.00	-35.16	13.04	-50.85	-5.95	14.00
SPH-31	-51.66	-44.44	-20.02	82.61	-47.44	-1.62	-1.32
SPH-32	-55.56	-41.67	-7.36	82.61	-63.64	-13.51	-6.14
SPH-33	15.40	5.56	-3.17	160.87	-50.52	-43.06	-5.82
SPH-34	-28.65	-33.33	-10.70	65.22	-61.10	-26.49	-13.36
SPH-36	29.82	16.67	10.61	21.74	-32.34	-1.62	16.49
SPH-41	-67.25	-41.67	-7.61	160.87	-63.97	-26.49	-7.82
SPH-43	54.39	25.00	10.24	82.61	-42.15	7.03	-1.64
SPH-46	4.09	-8.33	4.68	152.17	-52.84	-21.08	-0.12
SPH-47	-18.13	-33.33	-15.39	178.26	-68.04	-39.46	-10.07
SPH-49	16.96	8.33	-8.66	143.48	-42.15	10.27	-3.81
SPH-53	-36.84	-33.33	-6.07	152.17	-61.10	-0.54	-20.10
SPH-59	7.60	8.33	-4.46	65.22	-53.72	-0.54	25.79
SPH-60	-36.84	-41.67	0.97	126.09	-49.75	-41.62	-4.93
SPH-63	-28.65	-8.33	1.90	47.83	-53.72	-13.51	4.53
SPH-64	-34.50	-8.33	0.23	160.87	-68.60	-26.49	-13.44
SPH-66	-30.60	-33.33	-16.01	-1.45	-51.63	-9.19	-3.25
SPH-70	9.94	8.33	-1.13	-47.83	-45.12	21.08	2.45
SPH-74	-48.54	-16.67	-20.15	39.13	-71.90	-17.84	-16.00
SPH-84	117.54	50.00	-4.83	82.61	-55.15	-7.03	-3.73
SPH-77	12.96	7.46	13.46	40.63	4.42	54.26	4.38
SPH-81	-55.90	-37.31	-9.05	106.25	-19.23	-34.89	22.55
SPH-82	-48.94	-28.36	13.46	140.63	-15.77	-24.87	14.20
SPH-83	-18.76	-1.49	-1.67	59.38	-20.58	-34.89	29.68
SPH-85	-44.29	-28.36	18.18	125.00	-39.42	-23.87	-7.90
SPH-86	7.93	34.33	8.92	115.63	-17.50	-19.20	-1.02
SPH-88	-39.65	-28.36	5.83	171.88	-32.50	-25.88	-0.78
SPH-95	-7.16	7.46	17.24	68.75	-21.15	-11.85	-12.81
SPH-99	43.91	25.37	16.23	115.63	-21.54	-26.88	7.74
SPH-100	-4.84	7.46	2.24	50.00	-15.38	-13.86	-5.53

Table 4: Better parent heterosis for growth traits utilized in propagation of black pepper

Hybrid	Better parent heterosis (%)						
	Plant height	Number of nodes	Cutting diameter	Number of roots	Root diameter	Root length	New shoot diameter
SPH-71	47.37	54.55	7.20	0.00	-32.80	14.85	3.37
SPH-72	-68.42	-36.36	15.16	-6.90	-52.00	-35.64	-13.46
SPH-78	-20.00	9.09	-3.79	13.79	-33.76	-28.71	4.73
SPH-89	-11.58	9.09	-1.64	-48.28	-21.44	1.98	-1.68
SPH-2	61.40	54.55	32.09	57.14	-17.60	0.99	13.38
SPH-12	-1.05	9.09	3.10	107.14	-26.72	-15.84	-10.18
SPH-18	-9.47	0.00	-19.90	7.14	-52.00	-36.63	4.81
SPH-26	-14.74	-7.69	-36.59	0.00	-28.64	-13.86	13.86
SPH-31	-56.49	-48.72	-21.80	61.54	-23.68	-9.90	-1.44
SPH-32	-60.00	-46.15	-9.42	61.54	-47.20	-20.79	-6.25
SPH-33	3.86	-2.56	-5.31	130.77	-28.16	-47.85	-5.93
SPH-34	-35.79	-38.46	-12.68	46.15	-43.52	-32.67	-13.46
SPH-36	16.84	7.69	8.15	7.69	-1.76	-9.90	16.35
SPH-41	-70.53	-46.15	-9.66	130.77	-47.68	-32.67	-7.93
SPH-43	38.95	15.38	7.79	61.54	-16.00	-1.98	-1.76
SPH-46	-6.32	-15.38	2.36	123.08	-31.52	-27.72	-0.24
SPH-47	-26.32	-38.46	-17.27	146.15	-53.60	-44.55	-10.18
SPH-49	5.26	0.00	-10.69	115.38	-16.00	0.99	-3.93
SPH-53	-43.16	-38.46	-8.15	123.08	-43.52	-8.91	-20.19
SPH-59	-3.16	0.00	-6.58	46.15	-32.80	-8.91	25.64
SPH-60	-43.16	-46.15	-1.27	100.00	-27.04	-46.53	-5.05
SPH-63	-35.79	-15.38	-0.36	30.77	-32.80	-20.79	4.41
SPH-64	-41.05	-15.38	-1.99	130.77	-54.40	-32.67	-13.54
SPH-66	-37.54	-38.46	-17.87	-12.82	-29.76	-16.83	-3.37
SPH-70	-1.05	0.00	-3.32	-53.85	-20.32	10.89	2.32
SPH-74	-53.68	-23.08	-21.92	23.08	-59.20	-24.75	-16.11
SPH-84	95.79	38.46	-6.94	61.54	-34.88	-14.85	-3.85
SPH-77	2.46	5.88	13.21	32.35	-13.12	52.48	2.16
SPH-81	-60.00	-38.24	-9.25	94.12	-32.80	-35.64	19.95
SPH-82	-53.68	-29.41	13.21	126.47	-29.92	-25.74	11.78
SPH-83	-26.32	-2.94	-1.89	50.00	-33.92	-35.64	26.92
SPH-85	-49.47	-29.41	17.92	111.76	-49.60	-24.75	-9.86
SPH-86	-2.11	32.35	8.68	102.94	-31.36	-20.13	-3.13
SPH-88	-45.26	-29.41	5.60	155.88	-43.84	-26.73	-2.88
SPH-95	-15.79	5.88	16.98	58.82	-34.40	-12.87	-14.66
SPH-99	30.53	23.53	15.97	102.94	-34.72	-27.72	5.45
SPH-100	-13.68	5.88	2.01	41.18	-29.60	-14.85	-7.53

Table 5: Standard heterosis for growth traits utilized in propagation of black pepper

Hybrid	Standard heterosis (%)						
	Plant height	Number of nodes	Cutting diameter	Number of roots	Root diameter	Root length	New shoot diameter
SPH-71	47.37	54.55	7.20	190.00	-32.80	14.85	3.37
SPH-72	-68.42	-36.36	15.16	170.00	-52.00	-35.64	-13.46
SPH-78	-20.00	9.09	-3.79	230.00	-33.76	-28.71	4.73
SPH-89	-11.58	9.09	-1.64	50.00	-21.44	1.98	-1.68
SPH-2	61.40	54.55	32.09	120.00	-17.60	0.99	13.38
SPH-12	-1.05	9.09	3.10	190.00	-26.72	-15.84	-10.18
SPH-18	-9.47	0.00	-19.90	50.00	-52.00	-36.63	4.81
SPH-26	-14.74	9.09	-33.67	30.00	-28.64	-13.86	13.86
SPH-31	-56.49	-39.39	-18.19	110.00	-23.68	-9.90	-1.44
SPH-32	-60.00	-36.36	-5.24	110.00	-47.20	-20.79	-6.25
SPH-33	3.86	15.15	-0.95	200.00	-28.16	-47.85	-5.93
SPH-34	-35.79	-27.27	-8.65	90.00	-43.52	-32.67	-13.46
SPH-36	16.84	27.27	13.14	40.00	-1.76	-9.90	16.35
SPH-41	-70.53	-36.36	-5.50	200.00	-47.68	-32.67	-7.93
SPH-43	38.95	36.36	12.76	110.00	-16.00	-1.98	-1.76
SPH-46	-6.32	0.00	7.08	190.00	-31.52	-27.72	-0.24
SPH-47	-26.32	-27.27	-13.46	220.00	-53.60	-44.55	-10.18
SPH-49	5.26	18.18	-6.57	180.00	-16.00	0.99	-3.93
SPH-53	-43.16	-27.27	-3.92	190.00	-43.52	-8.91	-20.19
SPH-59	-3.16	18.18	-2.27	90.00	-32.80	-8.91	25.64
SPH-60	-43.16	-36.36	3.28	160.00	-27.04	-46.53	-5.05
SPH-63	-35.79	0.00	4.23	70.00	-32.80	-20.79	4.41
SPH-64	-41.05	0.00	2.53	200.00	-54.40	-32.67	-13.54

SPH-66	-37.54	-27.27	-14.09	13.33	-29.76	-16.83	-3.37
SPH-70	-1.05	18.18	1.14	-40.00	-20.32	10.89	2.32
SPH-74	-53.68	-9.09	-18.32	60.00	-59.20	-24.75	-16.11
SPH-84	95.79	63.64	-2.65	110.00	-34.88	-14.85	-3.85
SPH-77	2.46	9.09	13.71	50.00	-13.12	52.48	2.16
SPH-81	-60.00	-36.36	-8.84	120.00	-32.80	-35.64	19.95
SPH-82	-53.68	-27.27	13.71	156.67	-29.92	-25.74	11.78
SPH-83	-26.32	0.00	-1.45	70.00	-33.92	-35.64	26.92
SPH-85	-49.47	-27.27	18.45	140.00	-49.60	-24.75	-9.86
SPH-86	-2.11	36.36	9.16	130.00	-31.36	-20.13	-3.13
SPH-88	-45.26	-27.27	6.06	190.00	-43.84	-26.73	-2.88
SPH-95	-15.79	9.09	17.50	80.00	-34.40	-12.87	-14.66
SPH-99	30.53	27.27	16.49	130.00	-34.72	-27.72	5.45
SPH-100	-13.68	9.09	2.46	60.00	-29.60	-14.85	-7.53

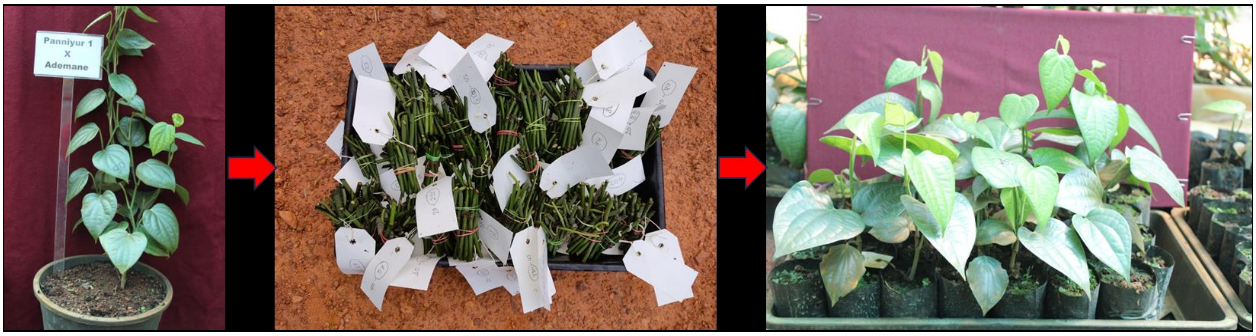

Fig 1: Multiplication of black pepper hybrids

Fig 2: Variability in response of black pepper hybrids for single node propagation

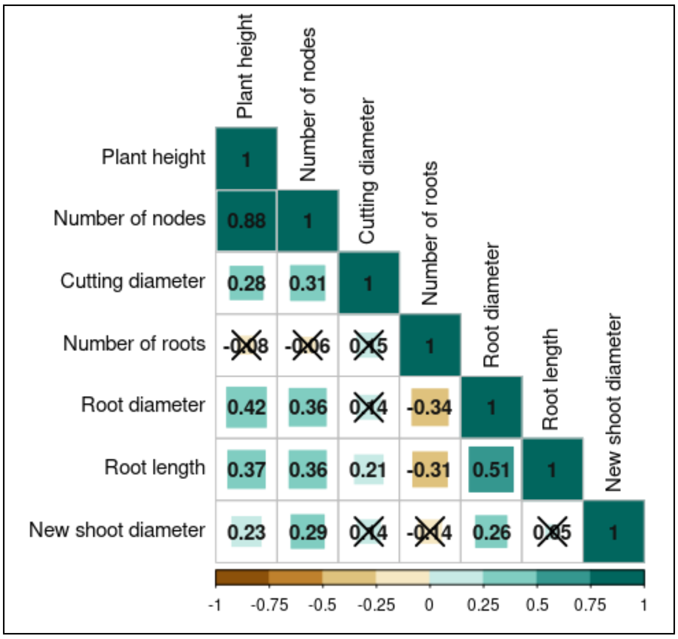

Fig 3: Correlation between growth parameters of propagation study

4. Conclusion

Evaluation of thirty-seven black pepper hybrids through single-node cuttings revealed substantial genetic variability in vegetative growth traits. Hybrids SPH-84 and SPH-2 consistently out-performed the check variety in plant height, nodal development and root attributes, underscoring their strong potential for clonal propagation. Correlation and heterosis analyses further validated their superior vigour, identifying them as promising candidates for future breeding programmes. As this study provides a preliminary assessment of hybrid vigour, future evaluations of yield and related traits are essential to consolidate these findings. Overall, the results establish the presence of significant hybrid variation and highlight elite lines that can accelerate breeding and cultivation efforts in black pepper.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used ChatGPT-4o in order to improve readability and language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

References

1. Banjare B, Katiyar P, Magar AS, Thakur N. Exploring the correlation between morpho-physiological traits and growth attributes associated with yield characteristics in rice (*Oryza sativa* L.). J Exp Agric Int. 2024;46(8):158-164.
2. Bhai RS, Subila KP, Eapen SJ, Reshma A, Pervez R, Bhat AI, *et al*. Effect of biocontrol agents on production of rooted black pepper cutting by serpentine method. J Spices Aromat Crops. 2018;27(1):59-65.
3. Bhat DS. Studies on improvement in black pepper (*Piper nigrum* L.) through selection, hybridization and mutation breeding [PhD thesis]. Bagalkot (India): University of Horticultural Sciences; 2023. 341 p.
4. Bhat DS, Hegde NK, Hegde L, Manju MJ, Shivakumar KM, Mahantesh PS. Effect of fortified nursery media with bioagents in nursery production of black pepper (*Piper nigrum* L.) varieties. Int J Curr Microbiol Appl Sci. 2018;7(8):390-395.
5. Gopinath PP, Parsad R, Joseph B, Adarsh VS. GRAPES: General R Shiny Based Analysis Platform Empowered by Statistics. 2020. https://www.kaugrapes.com/home
6. Groszmann M, Gonzalez-Bayon R, Greaves IK, Wang L, Huen AK, Peacock WJ, *et al*. Intraspecific *Arabidopsis* hybrids show different patterns of heterosis despite the close relatedness of the parental genomes. Plant Physiol. 2014;166(1):265-280.
7. Jangam AK, Thali P. WASP - Web Agri Stat Package 2.0. Ela, Old Goa (India): ICAR Research Complex for Goa; 2004.
8. Kanimozhi C, Silviya RA, Gopu B. Clonal propagation of *Vernonia elaeagnifolia*. Agric Sci Digest. 2023;43(D-5707):1-4. doi:10.18805/ag.D-5707.
9. Krishnamoorthy B, Parthasarathy VA. Improvement of black pepper. CABI Rev. 2010;(2010):1-12.
10. Liang YS, Zhan XD, Gao ZJ, Lin ZC, Shen XH, Cao LY, *et al*. Analysis on phenotypic relationship between roots and important shoot agronomic traits using a RIL and two derived backcross populations of super rice Xieyou 9308. Acta Agron Sin. 2011;37(10):1711-1723.
11. Petiole LTD. Petiole - Petiole Leaf Area Meter (Version 4.0.2) [Mobile application software]. 2020. https://play.google.com/store/apps/details?id=com.petioleap p.petiole
12. Prajapati N, Padhiar BV, Patel U, Patel P. Effect of plant growth regulators on rooting of cutting in black pepper (*Piper nigrum* L.) cv. Panniyar-1 under protected condition. Trends Biosci. 2018;11(11):2133-2136.
13. Raja MB, Parthiban S, Anandhan M, Venkadeswaran E, Pandi K, Suganthi S, *et al*. Rooting and sprouting performance of nodal cutting of cultivated and wild interspecific *Piper* rootstocks. Int J Chem Stud. 2018;6(2):20-24.
14. Ranganathan V. Challenges in sustaining pepper (*Piper nigrum* L.) productivity. Indian J Plant Soil. 2019;6(1):40-47.
15. Ravindran P, Sasikumar B. Variability in open pollinated seedlings of black pepper (*Piper nigrum* L.). J Spices Aromat Crops. 1993;2(1-2):60-65.
16. Reshma P, Sreekala GS, Deepa SN, Stephen R. Genetic diversity assessment of black pepper (*Piper nigrum* L.) cultivars of Western Ghats. Plant Sci Today. 2024;11:4816-4823.
17. Santoso BB, Parwata IA. The growth of *Moringa* seedling originated from various sizes of stem cutting. IOP Conf Ser Earth Environ Sci. 2020;519(1):012010.
18. Secundino W, Alexandre RS, Schmildt ER, Schmildt O, Magevski GC, Martins JPR. Rhizogenic behavior of black pepper cultivars to indole-3-butyric acid. Acta Sci Agron. 2014;36(3):355-364.
19. Spices Board. Major spice/state wise area and production of spices 2023-24. Government of India. 2025. https://indianspices.com/sites/default/files/Major%20spice%20state%20wise%20area%20production%202023-24%20web.pdf
20. Wu Q, Pagès L, Wu J. Relationships between root diameter, root length and root branching along lateral roots in adult, field-grown maize. Ann Bot. 2016;117(3):379-390.