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Variability analysis in genotypes of black pepper (*Piper nigrum* L.) for yield and yield related traits

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Abstract

Black pepper (*Piper nigrum* L.) is the world's major spice crop. India faces tough competition from other black pepper-producing countries in both production volume and productivity. There is a pressing need to enhance production per unit area by developing improved varieties with superior quality attributes. Ten genotypes of black pepper developed by different centers of the All India Co-ordinated Research Project on Spices were evaluated. The relationships between dry berry yield and yield-related traits in black pepper were analyzed. Data were collected on 5 quantitative traits, namely spike length (cm), number of berries per spike, fresh berry yield per plant (kg), dry berry yield per plant (kg) and dry recovery (%) during 2022-23. Analysis of variance revealed highly significant differences for all characters. Highest genotypic coefficient of variation and phenotypic coefficient of variation were observed for the number of berries per spike, spike length and dry berry yield per plant. Lowest values of genotypic coefficient of variation and phenotypic co-efficient of variation were noted for dry recovery. Genotypes exhibited high heritability and genetic improvement over the mean for the number of berries per spike and spike length. This suggests that additive gene effects influence the expression of these traits. Yield of dry berries per plant showed a very strong correlation with fresh berry yield, dry recovery and the number of berries per spike, both at the phenotypic and genotypic levels. In the path analysis, yield of fresh berries, dry recovery percentage and the number of berries per spike exhibited strong positive direct and indirect effects on the yield of dry berries. Genotype PRS 161 exhibited superior performance in terms of morphological traits, yield and yield-related characteristics, followed by SV 11 among the various genotypes analyzed. High yielding genotypes identified in this study can be considered for developing new varieties and can also be utilized in future breeding programs.

Keywords

black pepper; correlation; field evaluation; heritability; path analysis

Introduction

Indian pepper is favored worldwide for its inherent qualities. The price of one metric ton of black pepper is around 6470 US Dollars, hence farmers have a strong interest in its cultivation. Global production of black pepper is 621,000 tons from an area of 609,000 hectares (1). India accounted for the largest area under black pepper (42.55 %) with a production share of only 16.76 %. Global production is led by Vietnam with a share of 40.44 %, followed by India (16.76 %), Indonesia (12.56 %) and Brazil (12.56 %) (2). Productivity of black pepper is highest in Brazil (2,801 kg per hectare), followed by Vietnam (2,210 kg/ha) and Malaysia (1,376 kg/ha). India's productivity of black pepper is significantly low (402 kg/ ha) (3). There is a pressing need to enhance production per unit area by developing improved varieties with superior quality traits, coupled with adoption of appropriate practices such as biochar and biostimulants.

There is a great diversity of cultivars in black pepper. Wild types of black pepper (*Piper nigrum*) were cross-pollinated but cultivated varieties are self-pollinated. Selection from wild types over the years has led to the development of cultivars with differences in morphology and yield. Primary gene pool of black pepper consists of landraces, natural mutants, improved cultivars and true seedlings (4). Different breeding techniques, such as clonal selection, open pollination and hybridization, are used to develop black pepper varieties. Success of a crop improvement program relies on the extent of genetic variation within the crop and the degree to which this variation can be inherited from parent to offspring. Variability in morphological as well as qualitative characters has been observed between cultivars and among varieties of black pepper. Ability of black pepper to reproduce sexually, combined with its capacity for vegetative propagation, has played a crucial role in preserving its genetic diversity (5). The polyploid nature of black pepper is also a contributing factor to the population diversity in this crop.

Grasping the relationship between yield, its contributing traits and vegetative characteristics is crucial for creating high-yielding crop varieties. For any successful breeding strategy, it is essential to analyze the relationships among yield-contributing traits. The correlation between the characters reflects only the extent of their interrelationships regarding traits and does not suggest any cause-and-effect relationships. The path coefficient separates correlation coefficients into direct and indirect effects within a network of related traits. In crop improvement programs, direct selection is ineffective for complex traits like yield. It is crucial to assess how much each component trait contributes to the observed correlation and this must be divided into components of direct and indirect effects (6). Only a limited number of studies have been carried out in black pepper regarding the relationship between traits and the direct and indirect effects of various traits on yield. The present study was undertaken to assess genetic variability in ten black pepper genotypes developed by various centers of All India Coordinated Research Project on Spices, identify superior genotypes, analyze the relationships between dry berry yield and related yield traits and distinguish between direct and indirect effects using path analysis.

Materials and Methods

The current study was carried out at the Pepper Research Station Panniyur, Kerala Agricultural University (12.081136 °N and 75.399096 °E). The study materials consisted of 10 genotypes. Two genotypes were developed by Horticultural Research Station, Sirsi, Karnataka (SV 11 and SV 17) and 2 genotypes by Pepper Research Station, Panniyur, Kerala Agricultural University (PRS 160 and PRS 161). The study also included 4 released varieties, namely Panniyur 1 and Panniyur 5 (Pepper Research Station, Panniyur, Kerala Agricultural University), Vijay (College of Agriculture, Vellanikkara, Kerala Agricultural University), Thevam (Indian Institute of Spices Research, Kozhikode), Arka Coorg Excel (Central Horticultural Experiment Station, Chettalli, Karnataka) and a local cultivar of Kerala (Karimunda). In 2016, the experimental materials were planted in a Randomized Block Design with three replications, each containing 6 plants. The plants were managed following the package of practices guidelines recommended by Kerala Agricultural University. Data on 5 quantitative traits including spike length, number of berries per spike, fresh berry yield per plant (kg), dry recovery percentage and dry berry yield per plant (kg) were recorded during 2022-23.

After harvest, the spike length (cm) of each plant was measured and the total number of berries per spike was counted. The fresh berry yield per plant (kg) was recorded by weighing the berries after threshing. Fresh berries were then sun-dried for 4–5 days until their moisture content was reduced to 10-12 % and the dry berry yield per plant (kg) was determined. The dry recovery percentage was calculated using the formula: (Dry berry yield/Fresh berry yield) × 100.

Statistical analysis

Yield data and yield-contributing traits were analyzed using analysis of variance (ANOVA) with *GRAPES* software, developed by Kerala Agricultural University. Additionally, correlation and path analysis were performed with *OPSTAT* software from Haryana Agricultural University, Hisar, India.

Results and Discussion

All the black pepper genotypes exhibited substantial variation in the traits examined (Table 1). The significant differences observed among the genotypes for these traits indicate the presence of ample, usable variation. The success of a crop improvement program relies on the level of genetic diversity available within the crop.

Table 2 presents the economically significant traits of the genotypes studied. The black pepper genotypes exhibited considerable variation in spike length, berry count per spike,

Table 1. ANOVA for yield and characters related to yield in black pepper genotypes

Sources of variation	DF	Mean squares for each character				
		Spike length (cm)	No. of berries/spike	Fresh berry yield (kg)	Dry recovery (%)	Dry berry yield (kg)
Treatment	9	54.715*	693.053*	0.152*	5.590*	0.027*
Replication	2	2.378	24.861	0.011	0.611	0.001
Error	18	1.386	14.431	0.052	0.204	0.007

*Significant at 5 % level

DF - Degrees of Freedom

fresh yield, dry recovery and dry yield. Longest spike length was observed in PRS 161 (21.67 cm) and PRS 160 (20.78 cm) followed by Vijay (18.05 cm). PRS 161 also had the highest number of berries per spike (68.02), followed by Panniyur 5 (33.11), Vijay (28.32), SV 11 (27.39), and SV 17 (27.00), which were on par with each other. Arka Coorg Excel (15.36) and Thevam (11.33) had the lowest number of berries per spike. PRS 161 (1.92 kg) achieved the highest fresh berry yield per plant, which was on par with SV 11 (1.57 kg). All the other genotypes were on par with each other in fresh berry yield per plant. Highest dry recovery of black pepper was observed in PRS 161 (36.65 %) followed by Panniyur 1 (35.32 %), Karimunda (35.11 %), SV 11 (34.99 %) and Panniyur 5 (34.93 %). Maximum dry berry yield per plant was recorded for PRS 161 (0.70 kg) followed by SV 11 (0.55 kg), Karimunda (0.53 kg), SV 17 (0.48 kg), Panniyur 1 (0.47 kg), Panniyur 5 (0.47 kg) and PRS 160 (0.42 kg) which were statistically comparable to each other. Arka Coorg Excel registered lowest dry berry yield per plant (0.39 kg).

Genotype PRS 161 was identified as outstanding among all the genotypes studied for all the economically significant traits, followed by SV 11. PRS 161 recorded highest spike length (21.67 cm), more number of berries per spike (68.02), fresh berry yield (1.92 kg), dry recovery (36.65%) and dry berry yield (0.70 kg). SV 11 registered fresh berry yield of 1.57 kg, dry recovery of 34.99 % and dry berry yield of 0.55 kg. Arka Coorg Excel recorded lowest yield parameters.

Spike lengths varied between 8.95 cm (Thevam) and 21.67 cm (PRS 161), number of berries per spike ranged from 11.33 (Thevam) to 68.02 (PRS 161), fresh berry yields were between 1.19 kg (Arka Coorg Excel and Vijay) and 1.92 kg (PRS 161), dry recovery percentages ranged from 32.74 (Arka Coorg Excel) to 36.65 (PRS 161) and dry berry yields varied from 0.39 kg (Arka Coorg Excel) to 0.70 kg (PRS 161) (Table 3). Highest range was noted for the number of berries per spike (11.33 to 68.02), followed by spike length (8.95 to 21.67). Genotypic variance ranged from 0.007 - 226.21, while phenotypic variance ranged from 0.014 - 240.64. The phenotypic and genotypic variations differed in all traits, indicating a significant impact of environment on yield-related characteristics. PCV (Phenotypic Coefficient of Variation) was consistently higher than GCV (Genotypic Coefficient of Variation) for all the observed traits, indicating that environmental factors significantly influence morphological traits, yield and yield-related characteristics. However, values of GCV and PCV were close to each other for spike length (27.40 and 28.45), number of berries per spike (52.28 and 53.92) and dry recovery (3.92 and 4.14). This suggests that the environment has a minimal impact on the phenotypic expression of spike length, number of berries per spike and dry recovery. Number of berries per spike exhibited highest GCV (52.28) followed by spike length (27.40) and dry yield of berry per vine (17.32). The number of berries per spike exhibited highest PCV (53.92) followed by spike length (28.45) and dry yield of berry per vine (24.12). Lowest values recorded for GCV and PCV were found in dry recovery, which were 3.92 and 4.14, respectively. Several researchers have observed considerable differences in the per-plant yield of black pepper (6, 7).

All the characters analysed showed high heritability. The estimates of broad sense heritability varied between 38.88

Table 2. Comparison of genotypes of black pepper for yield characters

Sl No	Treatment	Spike length (cm)	No. of berries per spike	Fresh berry yield per plant (kg)	Dry recovery %	Dry berry yield per plant (kg)
1	PRS 161 (T1)	21.67^{a}	68.02^{a}	1.92^{a}	36.65^{a}	0.70^{a}
2	PRS 160 (T2)	20.78^{a}	26.50^{c}	1.26^{b}	33.16^{c}	0.42^{bcd}
3	SV 17 (T3)	14.89^{d}	27.00^{bc}	1.45^{b}	32.80^{c}	0.48^{bcd}
4	SV 11 (T4)	14.50^{d}	27.39^{bc}	1.57^{ab}	34.99^{b}	0.55^{b}
5	Panniyur 1 (T5)	16.00^{cd}	26.33^{c}	1.34^{b}	35.32^{b}	0.47^{bcd}
6	Panniyur 5 (T6)	17.17^{bc}	33.11^{b}	1.34^{b}	34.93^{b}	0.47^{bcd}
7	Karimunda (T7)	12.17^{e}	24.33^{c}	1.49^{b}	35.11^{b}	0.53^{bc}
8	Arka Coorg Excel (T8)	9.71^{f}	15.36^{d}	1.19^{b}	32.74^{c}	0.39^{d}
9	Vijay (T9)	18.05^{b}	28.32^{bc}	1.20^{b}	33.20^{c}	0.40^{cd}
10	Thevam (T10)	8.95^{f}	11.33^{d}	1.23^{b}	33.05^{c}	0.41^{cd}
	CD (0.05)	2.02	6.52	0.39	0.77	0.14
	CV %	7.65	13.20	16.33	1.32	16.79

Table 3. Range, mean, genotypic, phenotypic and environmental variance components, heritability and genetic advance for yield traits in black pepper genotypes

Character	Range	Grand mean	Genotypic variance	Phenotypic variance	Environmental variance	Coefficient of		Heritability % (H)	Genetic advance	
						GCV	PCV		GA	GAM (%)
Spike length (cm)	8.95 - 21.67	15.39	17.78	19.16	1.39	27.40	28.45	92.77	8.37	54.36
No. of berries per spike	11.33 - 68.02	28.77	226.21	240.64	14.43	52.28	53.92	94.00	30.04	104.41
Fresh berry yield per vine (kg)	1.19 - 1.92	1.40	0.03	0.09	0.05	13.03	20.89	38.88	0.23	16.73
Dry recovery (%)	32.74 - 36.65	34.20	1.80	2.00	0.20	3.92	4.14	89.82	2.62	7.65
Dry berry yield per vine (kg)	0.39 - 0.70	0.48	0.007	0.014	0.007	17.32	24.12	51.57	0.12	25.62

(fresh yield of berry per vine) to 94.00 % (number of berries spike^{-1}). Heritability estimates combined along with genetic advance over mean will enhance the reliability of a trait for selection. (8). When comparing the 2 estimates, the number of berries per spike (94.00 and 104.41) and spike length (92.77 and 54.36) showed high heritability and significant genetic advancement over the mean. This suggests additive effect of gene on the expression of the traits, which can be seen as a beneficial characteristic. When additive genes are less affected by environmental factors, the phenotypic selection of traits will be more effective. In black pepper, yield of dry berries, fresh berries and weight of the rachis per vine showed high heritability along with high genetic advance (5). It has been reported that black pepper exhibits both high heritability and significant genetic improvement for leaf width, spike length and vine column height (7).

Understanding the relationships between different characters is crucial for effectively initiating crop improvement programs through indirect selection (9). Correlation coefficients indicated that dry berry yield was highly correlated (P<0.001) with fresh berry yield, dry recovery and the number of berries per spike at both phenotypic and genotypic levels (Table 4). Many researchers have found a positive and significant correlation between fresh yield and dry yield in black pepper (5-7,9). Actual yield of black pepper showed a positive correlation with its yield components (10). In this study, dry recovery showed a strong positive correlation with fresh berry yield, dry berry yield and the number of berries per spike at both the phenotypic and genotypic levels. The yield of fresh berries showed a positive and significant correlation with spike length, number of berries per spike, dry recovery and dry berry yield at both phenotypic and genotypic levels.

Yield of dry berries was considered as a dependable trait for conducting path coefficient analysis (Table 5). The correlation coefficients were divided into direct and indirect effects. Fresh berry yield had a strong positive direct effect (0.774) on dry berry yield, indicating a true relationship between the 2 traits. Dry recovery and the number of berries per spike also demonstrated a strong positive direct effect on dry berry yield, with values of 0.202 and 0.042, respectively. The yield of fresh berries has high indirect effect on dry yield through the number of berries per spike (0.794) and dry recovery (0.761). Therefore, a direct selection based on fresh berry weight, dry recovery and the number of berries per spike may be more beneficial. A positive correlation coefficient accompanied by a negative or negligible direct effect suggests that the cause of the association may be attributed to indirect effects (11). Spike length has minimal direct impact on dry yield, suggesting that using spike length as a criterion for enhancing dry berry yield is not suitable.

The high yielding genotypes identified in this study could be used for developing new cultivars and for future breeding programs after analysing quality attributes and resistance to biotic and abiotic stresses. High yielding black pepper varieties with superior quality and resistance to both biotic and abiotic stresses can enhance production, boost productivity and thereby improve export earnings.

Conclusion

A considerable amount of variation in yield traits was observed among the ten genotypes, which included four genotypes tested in a coordinated varietal trial, five released varieties and one local check. The highest GCV and PCV were observed for the number of berries per spike, spike length and dry yield per berry vine. High heritability and significant genetic improvement over the mean were observed for the number of berries per spike and spike length. The yield of dry berries showed a strong correlation with the yield of fresh berries, dry recovery and the number of berries per spike at both phenotypic and genotypic levels. The current study identified several key traits, such as fresh berry weight, dry recovery percentage and the number of berries per spike, which have a direct positive effect on dry berry weight. These characteristics can be taken into account for selection in

Table 4. Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients among yield traits in black pepper genotypes

Character	Spike length (cm)	No. of berries per spike	Fresh berry yield per plant (kg)	Dry recovery (%)	Dry berry yield per plant (kg)
Spike length (cm)	1.00	0.75**	0.37*	0.39*	0.40*
No. of berries per spike	0.77**	1.00	0.66**	0.70**	0.71**
Fresh berry yield per plant (kg)	0.48**	1.03**	1.00	0.60**	0.99**
Dry recovery (%)	0.43*	0.75**	0.98**	1.00	0.71**
Dry berry yield per plant (kg)	0.46**	0.96**	1.00**	0.98**	1.00

**Significant at 1 % level

Table 5. Direct (bold- diagonal values) and indirect effects of yield related traits on dry yield in black pepper genotypes

Character	Spike length (cm)	No. of berries per spike	Fresh berry yield per plant (kg)	Dry recovery (%)
Spike length (cm)	**-0.028**	0.032	0.373	0.086
No. of berries per spike	-0.022	**0.042**	0.794	0.150
Fresh berry yield per plant (kg)	-0.014	0.043	**0.774**	0.198
Dry recovery (%)	-0.012	0.032	0.761	**0.202**

Residual effect = -0.00067

programs aimed at improving the yield of black pepper. PRS 161 was found to be superior among all other genotypes studied, including five released varieties, in all the economically significant traits, followed by SV 11. The present study helped to identify high yielding genotypes of black pepper. Information on the relationships between dry berry yield and related yield traits and their direct and indirect effects is crucial for effectively initiating crop improvement programs through indirect selection in black pepper.

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Authors' contributions

RP carried out experimentation, data analysis and manuscript preparation. DKK was involved in resources acquisition. All authors have read and approved the final manuscript.

Compliance with ethical standards

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