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# Contribution of spike and berry characters for yield in promising genotypes of black pepper (*Piper nigrum* L.)

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## Abstract

Black pepper, the king of spices, is grown for its dry berries. Genetic variation and the relationship between yield and yield-linked characters in nine black pepper genotypes were studied. Highly significant differences for all the characters were found in the variance analysis. Maximum GCV and PCV were noted for spike length, dry berry yield and number of berries spike$^{-1}$. High heritability and genetic advance over the mean exhibited by the genotypes for dry recovery and spike length indicate additive gene effect in the expression of these characters. Dry berry yield plant$^{-1}$ had a very strong correlation with fresh berry yield plant$^{-1}$ and dry recovery at both phenotypic and genotypic levels. During path analysis, fresh berry weight and dry recovery percentage showed a high positive direct and indirect effect on dry berry weight. Genotype PRS 161 was found superior in morphological, yield and yield-related characters, followed by SV11 among the different genotypes studied. Fresh berry yield per plant and dry recovery percentage are the most critical factors for enhancing dry yield in black pepper genotypes, while the number of berries per spike plays a significant indirect role.

**Key words:** black pepper, correlation, field evaluation, heritability, path analysis

## Introduction

Black pepper (*Piper nigrum* L.), 'the king of spices', is the world's major spice. It is a perennial climber grown for its berries. Black pepper originated in the Western Ghats of South India and is now cultivated in more than 25 nations. Wild relatives of black pepper are abundant in the Western Ghats (Joy *et al.*, 2007). Farmers cultivating black pepper face several obstacles, including low yield, labour shortages, inadequate water supplies, biotic stresses like pests and diseases, and drought stress. Consumers look forward for clean and quality spices. The aim of black pepper crop improvement should be for bold, high-quality berries and resistance to biotic and abiotic stresses.

Wild forms of black pepper are cross-pollinated, but cultivated forms are self-pollinated. Selection from wild types over the years has led to the development of cultivars with variation in morphology and yield (Ibrahim *et al.*, 1985a). The main gene pool for black pepper consists of landraces, natural mutants, improved cultivars and true seedlings (Sasikumar *et al.*, 2007). India has a good wealth of genetic resources for pepper. Varieties of black pepper are developed through different breeding techniques like clonal selection, open pollination and progeny selection, hybridisation, polyploidy breeding and biotechnological approaches (Krishnamoorthy and Parthasarathy, 2010.). Variability in morphological and qualitative characters has been observed between cultivars and varieties of black pepper (Ratnambal *et al.,* 1985). The potential of black pepper for sexual reproduction and its capacity for vegetative propagation has significantly contributed to conserving its variability. The polyploid nature of black pepper is also the reason for its population diversity.

Many workers have reported variations within clones of black pepper for growth and yield (Ratanambal *et al.,* 1985; Pradeepkumar *et al.,* 2003a). The high amount of genetic diversity in black pepper accessions using molecular markers was also reported by several researchers (Pradeepkumar *et al.,* 2001; Pradeepkumar *et al.,* 2003b; Joy *et al.*, 2007; Raghavan *et al.,* 2010). Ibrahim *et al*. (1985a) recorded the significance of the interaction between genotype x season in black pepper. De Waard and Zeven (1969) observed that the hermaphrodite nature of black pepper, which is genetically controlled, varies between cultivars, which decides its productivity to a great extent. Studies by Ravindran and Babu (1994) revealed that black pepper cultivars show wide variability in the composition of male, female and bisexual flowers, which would affect the ultimate yield.

Understanding the relationship between yield, yield contributing characteristics, and vegetative characteristics, is essential for developing high-yielding crop varieties. For any effective breeding strategy, inter-trait association of yield contributing traits should also be analysed. Correlation between characters expresses only the degree of interrelationships between traits and does not indicate anything about its cause and effect. Path coefficient divides correlation coefficients into direct and indirect effects within a system of correlated traits. Giriraji and Vijayakumar (1974) stated that in crop improvement programmes for complex traits such as yield, direct selection is not competent and it is essential to measure the contribution of each of the component traits to the observed correlation and correlation has to be partitioned into components of direct and indirect effect. Only few studies have been conducted on black pepper about the association of traits and the direct and indirect effect of various traits on yield (Ibrahim *et al.*, 1985c; Thanuja and Rajendran, 2003). The objectives of the present study were to evaluate nine genotypes of black pepper developed by different centres of AICRP on spices and to interpret information on the nature of the association between dry berry yield and yield-related traits that are divided into direct and indirect effects in path analysis.

## Materials and methods

The present investigation was conducted at Pepper Research Station, Panniyur (12.0764°N and 75.4053°E), Kannur, Kerala, India. Study materials comprised of nine genotypes of black pepper developed by various centres of AICRP on spices *viz.*, Horticultural Research Station, Sirsi, Karnataka (SV 11 and SV 17), Pepper Research Station, Panniyur, Kerala Agricultural University (PRS 160, PRS 161, Panniyur 1 and Panniyur 5), College of Agriculture, Vellanikkara, Kerala Agricultural University (Vijay) and Central Horticultural Experiment Station, Chettalli, Karnataka (Arka Coorg Excel) and a local cultivar Karimunda planted during 2016. Panniyur 1, Panniyur 5, Vijay and Arka Coorg Excel are released varieties of black pepper. SV 11, SV 17, PRS 160 and PRS 161 are the genotypes of black pepper tested under Co-ordinated Varietal Trial under AICRP on spices for its growth and yield performance along with released varieties and local check (Karimunda). Three replications of the experimental material, each with six plants, were planted in a Randomized Block Design. The plants were grown following the package of practice recommendations of Kerala Agricultural University. Data on five quantitative characters *viz.*, number of spikes plant$^{-1}$, number of berries spike$^{-1}$, fresh berry yield plant$^{-1}$ (kg), dry recovery (%) and dry berry yield plant$^{-1}$ (kg) were recorded during 2019-20, 2020-21, 2021-22 and 2022-23. Characters such as spike length, number of spikes plant$^{-1}$, number of berries spike$^{-1}$, fresh berry yield plant$^{-1}$ (kg) and dry recovery (%) are the most important characteristics of black pepper, which contribute to its economic yield, *i.e.* dry berry yield plant$^{-1}$. The pooled data on yield and yield contributing characters for the four years were subjected to analysis of variance (ANOVA) using GRAPES software developed by Kerala Agricultural University and correlation and path analysis using OPSTAT software developed by Haryana Agricultural University, Hisar, India.

## Results and discussion

All the black pepper genotypes differed significantly for the characters investigated (Table 1). The significant difference shows high variability in the genotypes concerning the characters studied, which shows sufficient usable variation. Effectiveness of a crop improvement programme depends upon the amount of genetic variability present in a crop (Prasad *et al.*, 1981).

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

| Sources of variation | DF | Mean squares for each character | | | | |
|---|---|---|---|---|---|---|
| | | Spike length (cm) | No. of berries spike$^{-1}$ | Fresh berry yield (kg) | Dry recovery (%) | Dry berry yield (kg) |
| Replication | 2 | 22.212 | 646.22 | 0.08 | 17.13 | 0.02 |
| Treatment | 8 | 8.475* | 2211.77* | 0.05* | 4.71* | 0.01* |
| Error | 16 | 5.077 | 80.82 | 0.03 | 3.29 | 0.01 |

*Significant at 5 % level

Economically important characteristics of the genotypes studied are shown in Table 2. All the genotypes of black pepper varied significantly in spike length, number of berries per spike, fresh berry yield, dry recovery and dry berry yield. Maximum spike length was recorded in PRS 161 (20.23 cm). All the other genotypes were on par with each other in spike length. PRS 161 recorded the highest number of berries per spike (75.88), followed by Panniyur 1 (52.01), Panniyur 5 (48.52), SV 17 (48.40), SV 11 (48.33) and Vijay (47.60), which were on par with each other. PRS 160 recorded lowest number of berries spike$^{-1}$ (33.31). PRS 161 (1.66 kg) registered the maximum fresh berry yield plant$^{-1,}$ which was on par with Karimunda (1.50 kg) and SV 11 (1.48 kg). Fresh berry yield plant$^{-1}$ was lowest in Arka Coorg Excel (1.23 kg) and Vijay (1.23 kg). Dry recovery of black pepper was highest in PRS 161 (37.30 %) which was on par with Panniyur 1 (35.46 %), SV 11 (35.12 %) and Panniyur 5 (34.72 %). SV 17 registered the lowest dry recovery (30.00 %). PRS 161 (0.62 kg) registered maximum dry berry yield plant$^{-1,}$ which was on par with SV 11 (0.52 kg) followed by Karimunda (0.50 kg), Panniyur 1 (0.49 kg), Panniyur 5 (0.47 kg), PRS 160 (0.43 kg) and Vijay (0.42 kg). The lowest dry berry yield plant$^{-1}$ was recorded by SV 17 (0.41 kg) and Arka Coorg Excel (0.40 kg). Kandiannan *et al*. (2007) reported high yield variability in ten improved lines of black pepper from the first year to the third year of bearing.

Table 2. Comparison of genotypes of black pepper for economically important characters

| Treatment | Spike length (cm) | No. of berries spike$^{-1}$ | Fresh berry yield plant$^{-1}$ (kg) | Dry recovery (%) | Dry berry yield plant$^{-1}$ (kg) |
|---|---|---|---|---|---|
| PRS 161 | 20.23$^{a}$ | 75.88$^{a}$ | 1.66$^{a}$ | 37.30$^{a}$ | 0.62$^{a}$ |
| PRS 160 | 15.25$^{b}$ | 33.31$^{d}$ | 1.30$^{bc}$ | 33.33$^{bc}$ | 0.43$^{bc}$ |
| SV 17 | 15.31$^{b}$ | 48.40$^{bc}$ | 1.33$^{bc}$ | 30.00$^{d}$ | 0.41$^{c}$ |
| SV 11 | 13.32$^{b}$ | 48.33$^{bc}$ | 1.48$^{abc}$ | 35.12$^{ab}$ | 0.52$^{ab}$ |
| Panniyur 1 | 14.93$^{b}$ | 52.01$^{b}$ | 1.38$^{bc}$ | 35.46$^{ab}$ | 0.49$^{bc}$ |
| Panniyur 5 | 14.56$^{b}$ | 48.52$^{bc}$ | 1.35$^{bc}$ | 34.72$^{abc}$ | 0.47$^{bc}$ |
| Karimunda | 13.15$^{b}$ | 35.81$^{cd}$ | 1.50$^{ab}$ | 33.38$^{bc}$ | 0.50$^{bc}$ |
| Arka Coorg Excel | 12.54$^{b}$ | 36.27$^{cd}$ | 1.23$^{c}$ | 32.36$^{cd}$ | 0.40$^{c}$ |
| Vijay | 12.66$^{b}$ | 47.60$^{bc}$ | 1.23$^{c}$ | 33.80$^{bc}$ | 0.42$^{bc}$ |
| CD (0.05) | 3.29 | 13.12 | 0.27 | 2.65 | 0.11 |
| CV % | 15.37 | 18.987 | 13.28 | 5.34 | 15.60 |

Genotype PRS 161 was superior among the different genotypes studied in all the economically important characters, followed by SV 11 (Table 2).

Genotypic variance varied from 0.01 to 188.47 and phenotypic variance from 0.01 to 269.28. The phenotypic and genotypic variations differed from one another in all the characters except dry berry yield, demonstrating the strong influence of the environment on yield-related characters. PCV was generally more than GCV for all the characters observed, suggesting environmental factors' impact on morphological, yield and the yield-related characters (Table 3). Similar observations of higher PCV than GCV in chilli genotypes were reported by Verma *et al.* (2023). However, GCV and PCV values were close to each other for dry recovery (5.15 and 8.53). This indicates very low effect of environment in the phenotypic expression of dry recovery. The spike length had the highest GCV (9.80) followed by dry yield of berry plant$^{-1}$ (8.42) and the number of berries spike$^{-1}$ (5.94). The highest PCV was recorded by the number of berries spike$^{-1}$ (42.74), followed by spike length (18.91) and dry yield of berry plant$^{-1}$ (17.87). Minimum values of GCV were noticed for fresh berry yield plant$^{-1}$ (3.42) and PCV for dry recovery (8.53). Ibrahim *et al*. (1985a), Pradeepkumar *et al*. (2003a), Ravindran *et al*. (1997), Preethy *et al*. (2018), Shivakumar and Saji (2019) and Paul *et al.* (2023b) reported a wide variation in the per plant yield of black pepper. Sasikumar *et al*. (2004) reported variation

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

| Character | Range | Grand mean | Genotypic variance | Phenotypic variance | Environmental variance | Coefficient of variation | | Heritability % (H) | Genetic advance | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | GCV | PCV | | GA | GAM (%) |
| SL | 12.54 - 20.23 | 14.66 | 5.71 | 10.79 | 5.08 | 9.80 | 18.91 | 26.84 | 1.61 | 10.45 |
| NBS | 33.31 - 75.88 | 47.35 | 188.47 | 269.28 | 80.82 | 5.94 | 42.74 | 1.93 | 0.85 | 1.70 |
| FBY | 1.23 - 1.66 | 1.38 | 0.02 | 0.05 | 0.03 | 3.42 | 11.92 | 8.22 | 0.03 | 2.02 |
| DR | 30.00 – 37.30 | 33.94 | 4.61 | 7.90 | 3.29 | 5.15 | 8.53 | 36.43 | 2.19 | 6.40 |
| DBY | 0.40 – 0.62 | 0.47 | 0.01 | 0.01 | 0.01 | 8.42 | 17.87 | 22.18 | 0.04 | 8.16 |

SL=Spike length (cm). NBS=No. of berries spike$^{-1}$. FBY=Fresh berry yield plant$^{-1}$ (kg). DR=Dry recovery (%). DBY=Dry berry yield plant$^{-1}$ (kg)

in yield of black pepper genotypes using regression slope and regression deviation.

All the characters in this study exhibited high heritability. Broad sense heritability estimates ranged from 1.93 (number of berries spike$^{-1}$) to 36.43 per cent (dry recovery %). Heritability estimates combined with genetic advancement over mean will increase the reliability of a character for selection (Johnson and Hanson, 2003). When the two estimates were compared, dry recovery (36.43 and 6.40) and spike length (26.84 and 10.45) recorded high heritability and genetic advance over the mean. This indicates an additive effect of the gene in the characters' expression, which can be viewed as a positive attribute. When the environment less influences additive genes, phenotypic selection of the characters will be effective (Rao and Patil, 1996). Shivakumar *et al*. (2020) observed that dry berry yield vine$^{-1}$, fresh berry yield vine$^{-1}$ and rachis weight vine$^{-1}$ exhibited high heritability accompanied by high genetic advance. Bekele *et al*. (2017) and Paul *et al.* (2023b) also reported a high genetic advance over the mean for economic yield in black pepper. Preethy *et al*. (2018) observed high heritability and genetic advance for black pepper leaf width, spike length and vine column height.

Bhatt and Reddy (1981) stated that knowledge about inter-character association is extremely important in indirect selection for starting any effective crop improvement programmes. Correlation coefficients suggested that dry berry yield had very strong correlation ($P$<0.001) with fresh berry yield and dry recovery at both phenotypic and genotypic levels (Table 4). This is in agreement with reports by Ibrahim *et al*. (1985b), Kurian *et al*. (2002), Bekele *et al*. (2017), Preethy *et al*. (2018), Shivakumar and Saji (2019), Shivakumar *et al*. (2020) and Paul *et al.* (2023a and 2023b). They reported that fresh yield and dry yield had a positive and significant correlation in black pepper. Abhinaya *et al*. (2016) suggested that dry fruit yield had a significant and positive correlation with the number of fruits and fresh fruit yield in chilli. Dry berry yield had very strong correlation ($P$<0.001) with number of berries spike$^{-1}$, only at the genotypic level but not at the phenotypic level. Dry berry yield had a very strong correlation ($P$<0.001) with spike length, only at the phenotypic level but not at the genotypic level. Sujatha and Namboothiri (1995) and Shango *et al*. (2021) recorded a positive correlation between length of spike and yield in black pepper.

Dry recovery was positively and significantly correlated with fresh berry yield at both phenotypic and genotypic levels and with spike length only at the phenotypic level but not at genotypic level. Fresh berry yield was positively and significantly correlated with the number of berries spike$^{-1}$ only at genotypic level but not at the phenotypic level. Several workers have reported that fresh and dry yields were positively and significantly correlated with number of spikes and berries in black pepper (Ibrahim *et al.*, 1985b; Bekele *et al.*, 2017; Kurian *et al.*, 2002).

Table 4. Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients among different characters in genotypes of black pepper

| Character | SL | NBS | FBY | DR | DBY |
|---|---|---|---|---|---|
| SL | 1.00 | 0.30$^{NS}$ | 0.49$^{**}$ | 0.29$^{NS}$ | 0.49$^{**}$ |
| NBS | 3.51$^{**}$ | 1.00 | 0.13$^{NS}$ | 0.07$^{NS}$ | 0.15$^{NS}$ |
| FBY | -0.21$^{NS}$ | 4.86$^{**}$ | 1.00 | 0.53$^{**}$ | 0.94$^{**}$ |
| DR | 0.12$^{NS}$ | 5.00$^{**}$ | 1.10$^{**}$ | 1.00 | 0.79** |
| DBY | 0.05$^{NS}$ | 4.73$^{**}$ | 0.99$^{**}$ | 1.05$^{**}$ | 1.00 |

**Significant at 1 % level. Abbrivations of characters are bellow Table 3

Dry berry yield was taken as a dependable trait for conducting path coefficient analysis (Table 5). Path analysis was done using genotypic correlations. Correlation coefficients were split into direct and indirect effects. Fresh berry yield showed a high positive direct effect (0.630) on dry berry yield, illustrating a true association between the two traits. Dry recovery also showed a high positive direct effect (0.271) on dry berry yield. Fresh berry yield has a high indirect effect on dry yield through number of berries spike$^{-1}$ (3.060) and dry recovery (0.693).

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

| Trait | SL | NBS | FBY | DR |
|---|---|---|---|---|
| SL | **0.086** | 0.055 | -0.129 | 0.033 |
| NBS | 0.303 | **0.016** | 3.060 | 1.355 |
| FBY | -0.017 | 0.077 | **0.630** | 0.298 |
| DR | 0.011 | 0.079 | 0.693 | **0.271** |

Residual effect = 0.013. Abbrivations of characters are bellow Table 3

Accordingly, a direct selection based on fresh berry weight and dry recovery might be more helpful. A similar high direct effect of fresh weight on dry berry weight was previously reported (Ibrahim *et al.*, 1985c; Thanuja and Rajendran, 2003). Singh and Chaudhary (1985) reported that a positive correlation coefficient followed by negative or negligible direct effect indicates that the causal factor of association can be due to indirect effects. Spike length and number of berries spike$^{-1}$ had negligible direct effect on dry yield. This indicates the inappropriateness of selecting spike length and number of berries spike$^{-1}$ for improving the dry berry yield in black pepper.

This study revealed significant variation in yield characteristics among nine black pepper genotypes, including those from the Co-ordinated Varietal trial, released varieties and a local check. The highest GCV and PCV were for spike length, dry berry yield, and berries per spike. High heritability and genetic advance were noted for dry recovery and spike length. Dry berry yield correlated strongly with fresh and dry recovery. Fresh berry yield per plant and dry recovery percentage are key factors in boosting dry yield in black pepper genotypes, with the number of berries per spike playing a notable indirect role. PRS 161 and SV11 outperformed all genotypes in economically important traits. These superior yielders can be considered for new variety release and future breeding programs.

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