www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(11): 1055-1062

www.thepharmajournal.com
Received: 27-07-2022
Accepted: 23-09-2022

Reshma P
Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Sreekala GS
Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Nainu Joseph
Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Deepa S Nair
Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Roy Stephen
Department of Plant Physiology, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Thomas George
AINP on Pesticide Residues PRRAL, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Corresponding Author:
Reshma P
Department of Plantation Crops and Spices, College of Agriculture, Kerala Agricultural University, Thiruvananthapuram, Kerala, India

Principal component analysis for yield and yield attributes in black pepper (*Piper nigrum* L.)

Reshma P, Sreekala GS, Nainu Joseph, Deepa S Nair, Roy Stephen and Thomas George

Abstract
Genetic variability is a pre-requisite for the selection of superior genotypes in any crop. Knowledge of variability and its contributing traits helps in the selection of an appropriate strategy for a breeding programme for evolving superior varieties. Therefore, the present investigation was conducted to assess the variability present in black pepper for yield and yield contributing traits. Twenty one black pepper cultivars were studied for 22 quantitative traits and summarized using principal component analysis. The first six principal components (PC1, PC2, PC3, PC4, PC5 and PC6) having eigen values greater than one accounted for 83.93% of total variability and individual variability of 28.92, 22.05, 10.86, 9.38, 6.74 and 5.99% for the respective principal components. The strongest positive correlations are obtained between lateral branch length and number of nodes lateral branch^{-1}, juvenile leaf length and leaf length, juvenile leaf length and leaf width, leaf petiole length and spike length, spike length and number of well-developed berries spike^{-1}, number of spikes 30 cm^{-2} and number of spikes vine^{-1}, fresh berry yield and dry yield, and fresh spike yield and dry yield. In black pepper, lateral branch length, leaf petiole length, leaf width, number of spikes lateral branch^{-1}, number of spikes vine^{-1}, fresh spike yield, fresh berry yield, hundred fresh berry weight, hundred fresh berry volume and dry recovery can be considered for selecting genotypes with high yield.

Keywords: Black pepper, selection, genetic variability, principal components, minimum data set

Introduction
Piper nigrum L., known as the king of spices due to its impeccable pungent principles, belongs to the family Piperaceae, is one of the most popular spices used worldwide and is native to southern India. Although there are more than 1000 species in the genus *Piper*, *P. nigrum*, *P. longum* and *P. betle* are the most well-known; 100 cultivars of *P. nigrum* have been identified from tropical and subtropical areas of India (Krishnamoorthy and Parthasarathy, 2010) [7]. The whole peppercorn of *Piper nigrum* or its active components are used in a variety of food items. In addition to being used as a spice in food, black pepper can also be utilised as a biocontrol agent and a medicine. Due to the presence of piperine and its various isomers, *P. nigrum* fruits are also used to generate white pepper and green pepper, and they are highly appreciated. Black pepper is a predominantly self-pollinated perennial vine but propagated vegetatively (Sasikumar *et al.*, 1992) [15] due to considerable heterozygosity. Morphological analysis of 50 landraces of *Piper nigrum* L. occurring in the Western Ghats of Indian Peninsula revealed intraspecific variability in black pepper (Mathew *et al.*, 2005) [9]. India is one of the leading countries in terms of black pepper production, consumption and exports. The key factors that affect the final yield include the variety, the age of the vine, soil fertility and weather (Menon, 1949) [10]. Depending on the cultivation technique and intensity of cultivation, the yield varies greatly between countries. In India, the average commercial yield of black pepper is 237.2 kg ha^{-1}, which is low when compared to other countries such as Brazil (2634.0 kg ha^{-1}), Thailand (2555.6 kg ha^{-1}), Malaysia (1641.8 kg ha^{-1}), Vietnam (1410.5 kg ha^{-1}), Indonesia (798.8 kg ha^{-1}) and Sri Lanka (578.9 kgha^{-1}) (Kandiannan *et al.*, 2007) [5]. Karl (1901) [6] developed principal component analysis (PCA) as an exploratory tool to identify unknown trends in a multidimensional data set. In a study by Ravindran *et al.* (1997) [13], 44 cultivars and 7 wild collections of black pepper were classified on the basis of various characters using PCA and there was identified a relative contribution of each character in cultivar differentiation. Principal component analysis of cultivated black pepper in Malaysia identified parameters such as fruit size and seed diameter as the important key characteristics that determine the yield (Chen *et al.*, 2018) [2].

The present study was conducted to analyse yield variability in order to produce a classificatory analysis on the yield components of *Piper nigrum* L. cultivars from various locations in Kerala, India. This can be used as an aid to arrange the various morphotypes according to their genetic diversity.

Materials and methods

The study was carried out at the College of Agriculture, Kerala Agricultural University, Thiruvananthapuram during 2019–21. The major black pepper growing districts of Kerala such as Idukki, Wayanad, Kollam, Thiruvananthapuram and Alappuzha were surveyed and twenty one black pepper cultivars selected were studied for yield variability. The analyses on yield variability and components contributing to yield were based on 22 traits. Quantitative characters such as vine column height, vine column diameter, lateral branch length, number of nodes per lateral branch, juvenile leaf length, leaf petiole length, leaf length, leaf width, spike peduncle length, spike length, number of well-developed berries per spike, number of spikes per lateral branch, number of spikes per 30 cm^2, number of spikes per vine, fresh spike yield per vine, fresh berry yield per vine, hundred fresh berry weight, hundred fresh berry volume, bulk density, berry diameter, dry berry yield and dry recovery were statistically analysed using PCA.

Results and discussion

The present study was carried out to find the relative contribution of various factors in the yield of black pepper. Six principal components (eigenvalue >1) contributed to 83.93% of the variance as demonstrated by PCA (Table1). The first six principal component axes explained 83.93 per cent of the variability in yield among the black pepper cultivars under study. The remaining 11 axes contributed 16.07 per cent of the variability. PC1 accounted for the highest variance (28.92%), followed by PC2 (22.05%), while PC3, PC4, PC5 and PC6 accounted for 10.86%, 9.38%, 6.74% and 5.99% variance, respectively. The yield-related contribution was greater in PC1. Component features that contribute to the greatest variability in yield have been derived from loading values (Table 2). The percentage contribution of variables on principal components is given in Table3. Variables such as juvenile leaf length (cm) (12.90%), leaf length (cm) (11.29%), leaf width (cm) (10.64%), fresh spike yield per vine (kg) (8.49%) and fresh berry yield per vine (kg) (8.10%) contributed to high variability for yield in PC1. The four yield related traits in PC2 were number of spikes 30 cm^{-2} (12.24%), number of spikes lateral $branch^{-1}$ (11.44%), number of spikes $vine^{-1}$ (9.83%), berry diameter (mm) (8%) and dry berry yield per vine (kg) (8.87%). The overall contribution of number of spikes lateral $branch^{-1}$ (13% in PC3), dry recovery per cent (15.53% in PC3), lateral branch length (cm) (16.55% in PC4), number of nodes lateral $branch^{-1}$ (14.18% in PC4), number of well-developed berries $spike^{-1}$ (17.42% in PC4), hundred fresh berry weight (g) (15.70% in PC4), hundred fresh berry volume (ml)(16.97% in PC4), vine column height (m) (38.94% in PC5), vine column diameter (cm) (17.53% in PC5), leaf petiole length (cm) (11.54% in PC6), spike peduncle length (cm) (23.48% in PC6), spike length (cm) (8.62% in PC6) and bulk density (g) (7.81% in PC6) was high on yield variability. Ravindran *et al.* (1997) [13] investigated the relative contributions of various characters in cultivar differentiation and identified eight PCs as the most important, accounting for 75% of the variation. PC1 had leaf size index, leaf length and leaf breadth as high loading variables and leaf thickness, lower epidermal thickness and upper epidermal thickness with high loadings in PC2. A study conducted by Chen *et al.* (2018) [2] recognized seven PCs using 27 characteristics, explaining 95.79% of the total variance.

To illustrate the relationship between PC1 and PC2, a loading plot (Fig. 1) was generated using the variability of all 22 variables under investigation. The traits observed away from the origin had a higher loading and a great influence on yield variability. The first quadrant had seven yield related variables such as fresh berry yield, fresh spike yield, dry yield, spike length, number of well-developed berries per spike, leaf petiole length and number of spikes per vine. Among these, fresh berry yield and fresh spike yield were strongly correlated with each other. Variables such as fresh berry yield, fresh spike yield and dry yield contribute to high yield variability in the first quadrant. The second quadrant consisted of eight yield related traits such as number of spikes $30cm^{-2}$, number of spikes lateral $branch^{-1}$, number of nodes lateral $branch^{-1}$, lateral branch length, dry recovery, bulk density, vine column height and spike peduncle length. Lateral branch length on which spikes are produced was strongly correlated with the number of nodes lateral $branch^{-1}$, number of spikes lateral $branch^{-1}$ and number of spikes $30cm^{-2}$, indicating that it is one of the important traits for yield improvement. Variables like vine column height and spike peduncle length had a smaller impact on yield variability. The third quadrant lacked a yield-related trait, whereas the fourth quadrant had seven: leaf length, leaf width, juvenile leaf length, hundred berry weight, hundred berry volume, vine column diameter, and berry diameter. Variables such as juvenile leaf length, leaf length and leaf width had a high influence on yield variability. Also, leaf length and leaf width were strongly correlated with each other. As earlier reported by Preethi *et al*. (2018) [12], there was a positive association between leaf length and leaf width. Vine column height and spike peduncle length had smaller loading effects and less influence on yield variability. Plotting the cultivars against the PCs, taking two of each at a time, is important in order to assess the relative positioning of different cultivars with regard to the PCs. Such a PC plot provides a visual representation of the role played by each PC in identifying the various cultivars.

A score plot showing the distribution of selected twenty one black pepper cultivars based on PC1 and PC2 is given in Figure 2. The studied cultivars were assembled into fifteen clusters based on the score plot. The listing of the constituent members of the fifteen quantitative clusters is given in Table 4. The distribution of 21 cultivars into 15 clusters was at random, with the maximum number of cultivars in cluster III and cluster IX (3 cultivars each). Cluster VI and cluster VII were found to be the second largest, with 2 cultivars each. All the other clusters had one cultivar each. The key factor used to distinguish cultivars 9, 11 and 12 (cluster IX) from others is PC1 because of variances with regard to the X coordinate. Cultivars 7 and 13 had large differences with regard to both X and Y coordinates, thereby showing that these cultivars are differentiated from others mainly due to both PCs. Cultivar 17 showed considerable negative deviation from the X coordinate, indicating the significance of the first PC in distinguishing this cultivar from others, whereas cultivar 21 had a positive difference from the X coordinate. This PC is therefore important for distinguishing these two cultivars. Cultivars 10 and 14 had a large negative difference in the Y coordinate representing the second PC, while cultivar 15 had a large positive difference from the Y coordinate.

A biplot was plotted for the visualisation of the results of PCA (Fig. 3), which optimally represented the distance between the observed quantitative characters and also the relationship between the studied cultivars and observed quantitative characters. In the present study, the biplot between PC1 and PC2 was plotted by using the variability of all 22 yield and yield related variables. The biplot showed the distribution of cultivars based on both PCs. The variables with higher values were located away from the origin. As per the biplot, the variability of yield among the black pepper cultivars was mainly influenced by the variables such as juvenile leaf length, leaf length, leaf width, fresh berry yield, fresh spike yield and dry berry yield. This demonstrates that larger leaf areas are associated with greater cultivar yields. The bulk density was strongly negatively correlated to berry diameter, indicated by the vectors of these two variables pointing in opposite directions. High variation in yield has been reported in black pepper (Ibrahim *et al*., 1985a; Pradeepkumar *et al*., 2003; Preethi *et al*., 2018) [3, 11, 12]. In this study, the biplot showed maximum variability for cultivars 1, 4, 5, 15 and 21 in positive quadrants and were identified as cultivars with good yield. In cultivar 1, the most important characteristics that contributed to yield variability were hundred fresh berry weight and hundred fresh berry volume. Yield variability in cultivar 4 was contributed by berry diameter. High yield in cultivar 5 was due to yield related traits such as spike length, number of well-developed berries spike^{-1} and leaf petiole length. Cultivar 15 was influenced by the number of spikes per vine. The most important characteristics contributed to yield variability in cultivar 21 were leaf size. Since leaf lamina is the major photosynthetic organ of the plant to intercept sunlight, the productivity of a plant depends on its leaf surface area (Wahid *et al*., 1997) [19]. Cultivars 10, 14 and 17 exhibited maximum variability in negative quadrants and were the low yielding ones among the studied black pepper cultivars.

Types of correlations between the different yield parameters and the yield of black pepper cultivars are presented in Table 5. Some parameters were either positively or negatively correlated with others. Some correlations are significant, while others are not. The strongest positive correlations are obtained between lateral branch length and number of nodes lateral branch^{-1}, juvenile leaf length and leaf length, juvenile leaf length and leaf width, leaf length and leaf width, leaf petiole length and spike length, spike length and number of well-developed berries spike^{-1}, number of spikes 30cm^{-2} and number of spikes vine^{-1}, no. of spikes per lateral branch and no. of spikes per 30 cm^{2}, fresh berry yield and dry yield, and fresh spike yield and dry yield. This implies that the value increase of one of these parameters leads to the increase of the parameter to which it is significantly correlated. A negative significant correlation is observed between the number of spikes 30cm^{-2} and berry diameter and berry diameter and dry recovery, indicating that if the value of one of these parameters increases, the other decreases. The parameters such as vine column length and spike peduncle length did not show significant correlation to any other parameters studied, indicating that these two parameters are less important in cultivar selection. Lateral branch length is correlated with the number of nodes lateral branch^{-1} (0.001), number of spikes per lateral branch, and dry recovery (0.05). Lateral branch length and yield showed a positive correlation, as reported earlier by Shivakumar *et al.* (2020) [17]. Juvenile leaf length showed highly significant correlation with leaf length and width (0.001). Juvenile leaf length, leaf length, leaf width, spike length, number of well-developed berries per spike, fresh berry yield, fresh spike yield, bulk density, hundred berry weight, hundred berry weight and dry yield significantly correlated with each other. However, this does not corroborate with the findings of Preethi *et al*. (2018) [12], in which dry weight of berries showed a negative significant genotypic correlation with 100 berry weight and 100 berry volume. Moreover, findings by Shango *et al.* (2021) [16] partly contradicted the present findings on the relationship between yield and yield components. Their study showed that yield of fresh pepper berries was significantly negatively correlated with the number of spikes and there was no significant relationship between yield and the number of well-developed berries spike^{-1}. On the contrary, number of berries spike^{-1} has been reported as the most important morphological character that has direct and positive effect on pepper yield (Bermawie *et al*., 2019) [1]. In the present study, number of spikes per lateral branch was positively correlated with number of spikes 30cm^{-2}, number of spikes vine^{-1} and fresh spike yield, which in turn was correlated with fresh berry yield and dry yield. According to Kurian *et al.* (2002) [8], there was a significant and positive correlation between the fresh and dried yields of black pepper. The present correlation study revealed that, fresh and dry yields of black pepper were positively and significantly correlated with the number of spikes and berries. Therefore, a selection programme based on the number of spikes and the number of berries per spike would lead to a significant improvement in fresh and dry yield of black pepper. Spike length and the number of well-developed berries per spike were found to be highly correlated, indicating that the longer the spikes, the more berries they produce. Sujatha and Namboothiri (1995) [18] reported a positive and significant influence on yield with spike length. The number of berries spike-1 is positively correlated to the fresh yield (Sainamole *et al*., 2002) [14]. Berry weight and volume were negatively correlated with bulk density. Berry diameter was negatively correlated with bulk density and dry recovery. Jayashree *et al.* (2009) found increased bulk density with an increase in size. However, bulk density decreased when the berry size was >4.8 mm.

From the 22 yield and yield related characters of studied black pepper cultivars, characters with higher percentage contribution in first six principal components were selected for generating minimum data set (MDS) for black pepper. The characters such as juvenile leaf length, leaf length, leaf width, fresh spike yield, fresh berry yield, number of spikes 30 cm$^{-2,}$ number of spikes vine^{-1}, number of spikes lateral branch^{-1}, dry yield, dry recovery, lateral branch length, number of nodes lateral branch^{-1}, number of well-developed berries spike^{-1}, hundred fresh berry weight, hundred fresh berry volume, vine column height, vine column diameter, leaf petiole length and spike peduncle length had high contribution on yield variability. A Pearson correlation analysis was performed on yield and yield attributing variables (Table 5). The correlation between the variables was worked out and when the

correlation of selected variables was <0.6, both the variables were selected whereas when correlation was >0.6, highly weighed variables were selected. Only ten characters were found finally, after rejecting the remaining variables based on the correlation values. Lateral branch length, leaf petiole length, leaf width, number of spikes lateral branch^{-1}, number of spikes vine^{-1}, fresh spike yield, fresh berry yield, hundred fresh berry weight, hundred fresh berry volume and dry recovery. This MDS including 10 characters are simple, quantifiable and recognisable to farmers, and it can be used for identifying high yielding black pepper genotypes.
It is a simple key
involving characters which are measurable and
recognizable at the farmer level, which can serve
as a preliminary tool for identification of an elite
nutmeg tr

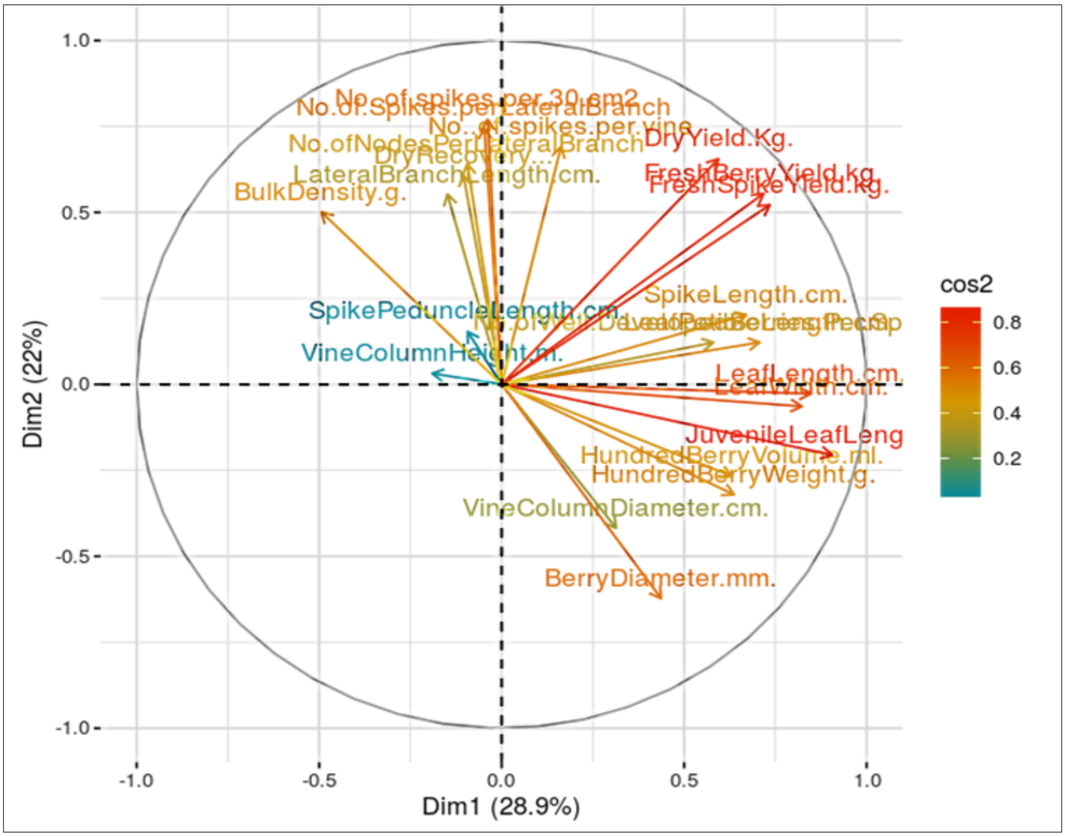

Fig 1: Loading plot showing distribution of 22 variables in PC1 and PC2

Table 1: Principal component analysis for yield and yield related traits

Principal components	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	6.36	28.92	28.92
PC2	4.85	22.05	50.97
PC3	2.39	10.86	61.83
PC4	2.06	9.38	71.21
PC5	1.48	6.74	77.94
PC6	1.32	5.99	83.93
PC7	0.92	4.19	88.12
PC8	0.74	3.38	91.51
PC9	0.45	2.06	93.56
PC10	0.37	1.66	95.23
PC11	0.29	1.31	96.53
PC12	0.25	1.15	97.68
PC13	0.15	0.70	98.38
PC14	0.14	0.64	99.02
PC15	0.13	0.59	99.60
PC16	0.05	0.21	99.82
PC17	0.02	0.11	99.92
PC18	0.01	0.05	99.98
PC19	0.01	0.02	100
PC20	0	0	100

Table 2: Component loadings of each variable on PCs

Sl. No.	variables	PC1	PC2	PC3	PC4	PC5	PC6
1	Vine column height (m)	-0.08	0.01	0.25	-0.01	0.62	0.24
2	Vine column diameter (cm)	0.12	-0.19	-0.22	0.01	0.42	-0.17
3	Lateral branch length	-0.06	0.25	0.07	0.41	-0.34	-0.11
4	Number of nodes per lateral branch	-0.04	0.29	0.23	0.38	0.06	-0.08
5	Juvenile leaf length (cm)	0.36	-0.09	0.12	-0.10	-0.03	-0.11
6	Leaf petiole length (cm)	0.28	0.06	0.13	0.14	0.20	0.34
7	Leaf length (cm)	0.34	-0.01	0.11	0.03	-0.06	-0.32
8	Leaf width (cm)	0.33	-0.03	-0.03	-0.23	-0.01	-0.05
9	Spike peduncle length (cm)	-0.04	0.07	-0.36	-0.22	-0.27	0.48
10	Spike length (cm)	0.27	0.09	0.28	-0.11	-0.13	0.29
11	No. of well developed berries per spike	0.23	0.06	0.16	-0.42	-0.24	0.08
12	No. of spikes per lateral branch	-0.02	0.34	-0.36	0.12	-0.03	0.14
13	No. of spikes per 30 cm2	-0.02	0.35	-0.30	-0.10	0.15	0.06
14	No. of spikes per vine	0.06	0.31	-0.26	-0.01	0.14	-0.31
15	Fresh spike yield per vine (kg)	0.29	0.24	-0.13	-0.05	0.11	-0.01
16	Fresh berry yield per vine (kg)	0.29	0.25	-0.11	-0.03	0.11	-0.03
17	Hundred fresh berry weight (g)	0.25	-0.15	-0.08	0.40	-0.05	0.25
18	Hundred fresh berry volume (ml)	0.25	-0.12	-0.10	0.41	-0.05	0.26
19	Bulk density (g)	-0.20	0.23	0.23	-0.11	0.20	0.28
20	Berry diameter (mm)	0.17	-0.28	-0.08	0.09	0.07	0.01
21	Dry yield (kg)	0.24	0.30	0.08	-0.02	0.06	-0.12
22	Dry recovery (%)	-0.04	0.28	0.39	-0.02	-0.11	-0.02

Table 3: Percentage contribution of variables on PCs

Sl. No.	Variables	PC1	PC2	PC3	PC4	PC5	PC6
1	Vine column height (m)	0.57	0.02	6.09	0.01	38.94	5.62
2	Vine column diameter (cm)	1.54	3.60	5.00	0	17.53	2.75
3	Lateral branch length	0.35	6.30	0.54	16.55	11.21	1.30
4	Number of nodes per lateral branch	0.14	8.48	5.08	14.18	0.38	0.68
5	Juvenile leaf length (cm)	12.90	0.87	1.52	0.94	0.10	1.12
6	Leaf petiole length (cm)	7.86	0.31	1.79	2.04	3.84	11.54
7	Leaf length (cm)	11.28	0.02	1.30	0.10	0.40	9.95
8	Leaf width (cm)	10.64	0.09	0.11	5.31	0.01	0.27
9	Spike peduncle length (cm)	0.14	0.48	13.15	4.71	7.07	23.46
10	Spike length (cm)	7.07	0.84	7.56	1.16	1.78	8.62
11	No. of well developed berries per spike	5.29	0.31	2.64	17.42	5.65	0.71
12	No. of spikes per lateral branch	0.04	11.44	12.99	1.38	0.08	1.90
13	No. of spikes per 30 cm2	0.02	12.24	8.93	1.07	2.32	0.40
14	No. of spikes per vine	0.42	9.83	6.70	0.01	1.90	9.28
15	Fresh spike yield per vine (kg)	8.49	5.61	1.75	0.24	1.22	0.04
16	Fresh berry yield per vine (kg)	8.10	6.35	1.14	0.07	1.20	0.06
17	Hundred fresh berry weight (g)	6.37	2.12	0.68	15.70	0.21	6.27
18	Hundred fresh berry volume (ml)	6.26	1.47	0.88	16.97	0.29	6.77
19	Bulk density (g)	3.83	5.17	5.31	1.29	3.93	7.81
20	Berry diameter (mm)	2.99	7.99	0.62	0.77	0.54	0.01
21	Dry yield (kg)	5.54	8.86	0.69	0.04	0.31	1.43
22	Dry recovery (%)	0.17	7.61	15.53	0.03	1.12	0.05

Table 4: Clustering of cultivars based on yield and yield attributing traits

Cluster number	Number of cultivars
I	1
II	1
III	3
IV	1
V	1
VI	2
VII	2
VIII	1
IX	3
X	1
XI	1
XII	1
XIII	1
XIV	1
XV	1

Table 5: Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1	0.03	-0.27	0.21	-0.13	0.16	-0.18	-0.22	-0.21	-0.04	-0.18	-0.200	0.02	-0.12	-0.08	-0.07	-0.12	-0.14	0.4	-0.17	-0.05	0.15
2	0.03	1	-0.39	-0.36	0.22	0.29	0.22	0.38	-0.16	-0.09	-0.03	-0.15	-0.08	0.15	0.02	-0.01	0.28	0.25	-0.39	0.40	-0.14	-0.42
3	-0.27	-0.39	1	0.68***	-0.32	0.07	0.03	-0.36	-0.05	0.01	-0.17	0.45*	0.22	0.31	0.01	0.06	-0.02	0.02	0.18	-0.30	0.24	0.46*
4	0.21	-0.36	0.68***	1	-0.17	0.16	0.01	-0.22	-0.31	0.07	-0.19	0.34	0.31	0.37	0.17	0.16	-0.01	0.01	0.39	-0.40	0.29	0.56**
5	-0.13	0.22	-0.32	-0.17	1	0.51*	0.88***	0.84***	-0.23	0.58**	0.68**	-0.35	-0.25	-0.07	0.56**	0.52*	0.53*	0.50*	-0.41	0.42	0.40	-0.13
6	0.16	0.29	0.07	0.16	0.51*	1	0.46*	0.44*	-0.07	0.77***	0.34	0.07	-0.01	0.06	0.50*	0.51*	0.51*	0.52*	-0.05	0.42	0.47*	0.13
7	-0.18	0.22	0.03	0.01	0.88***	0.46*	1	0.69***	-0.32	0.45*	0.50*	-0.21	-0.14	0.12	0.57**	0.56**	0.46*	0.44*	-0.31	0.34	0.52*	0.01
8	-0.22	0.38	-0.36	-0.22	0.84***	0.44*	0.69***	1	-0.01	0.59**	0.65**	-0.11	0.05	0.19	0.53*	0.47*	0.39	0.38	-0.37	0.26	0.33	-0.12
9	-0.207	-0.161	-0.054	-0.313	-0.228	-0.067	-0.32	-0.005	1	-0.05	0.18	0.42	0.37	0.15	0.08	0.06	-0.04	-0.02	0.03	-0.08	-0.13	-0.12
10	-0.04	-0.09	0.01	0.07	0.58**	0.68***	0.45*	0.59**	-0.05	1	0.67***	-0.03	-0.07	-0.01	0.46*	0.45*	0.30	0.31	-0.01	0.09	0.51*	0.33
11	-0.18	-0.03	-0.17	-0.19	0.62**	0.38	0.50*	0.65**	0.18	0.67***	1	-0.16	0.05	0.04	0.39	0.36	0.01	-0.02	-0.10	0.04	0.38	0.21
12	-0.20	-0.15	0.45*	0.34	-0.35	0.07	-0.21	-0.12	0.42	-0.03	-0.16	1	0.83***	0.63**	0.44*	0.43	-0.08	-0.02	0.20	-0.42	0.33	0.11
13	0.02	-0.08	0.23	0.31	-0.25	-0.01	-0.14	0.05	0.37	-0.07	0.05	0.83***	1	0.68***	0.48*	0.43	-0.26	-0.22	0.36	-0.40	0.37	0.15
14	-0.12	0.15	0.31	0.37	-0.07	0.06	0.12	0.19	0.15	-0.01	0.04	0.63**	0.68***	1	0.49*	0.53*	-0.19	-0.15	0.02	-0.23	0.52*	0.25
15	-0.08	0.02	0.01	0.17	0.56**	0.50*	0.57**	0.53*	0.08	0.46*	0.39	0.44*	0.48*	0.49*	1	0.46**	0.27	0.30	-0.15	-0.01	0.50**	0.01
16	-0.07	-0.01	0.06	0.16	0.52*	0.51*	0.56**	0.47*	0.06	0.45*	0.36	0.43	0.43	0.53*	0.56**	1	0.26	0.28	-0.11	0.01	0.50**	0.09
17	-0.12	0.28	-0.02	-0.01	0.53*	0.51*	0.46*	0.40	-0.04	0.30	0.01	-0.08	-0.26	-0.19	0.27	0.26	1	0.60**	-0.33	0.35	0.08	-0.34
18	-0.14	0.25	0.02	0.01	0.50*	0.52*	0.44*	0.38	-0.02	0.31	-0.02	-0.02	-0.22	-0.15	0.30	0.28	0.50**	1	-0.32	0.42	0.12	-0.30
19	0.4	-0.39	0.18	0.39	-0.51*	-0.05	-0.51*	-0.37	0.03	-0.01	-0.10	0.20	0.36	0.02	-0.15	-0.11	-0.53*	-0.52*	1	-0.40	0.08	0.49*
20	-0.17	0.40	-0.30	-0.46*	0.42	0.42	0.34	0.26	-0.08	0.09	0.04	-0.42	-0.48*	-0.23	-0.01	0.01	0.45*	0.42	-0.40	1	-0.07	-0.47*
21	-0.05	-0.14	0.24	0.29	0.40	0.47*	0.52*	0.33	-0.13	0.51*	0.38	0.33	0.37	0.52*	0.80***	0.90***	0.08	0.12	0.08	-0.07	1	0.41
22	0.15	-0.42	0.49*	0.56**	-0.13	0.13	0.01	-0.12	-0.12	0.33	0.21	0.11	0.15	0.25	0.01	0.09	-0.34	-0.30	0.39	-0.37	0.41	1

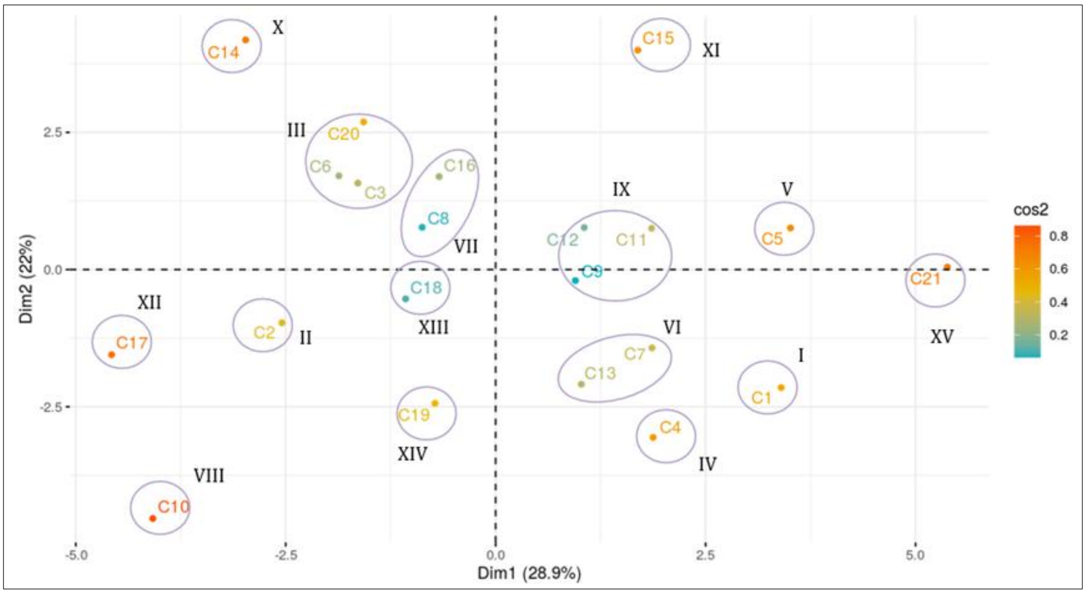

Fig 2: Score plot showing clusters

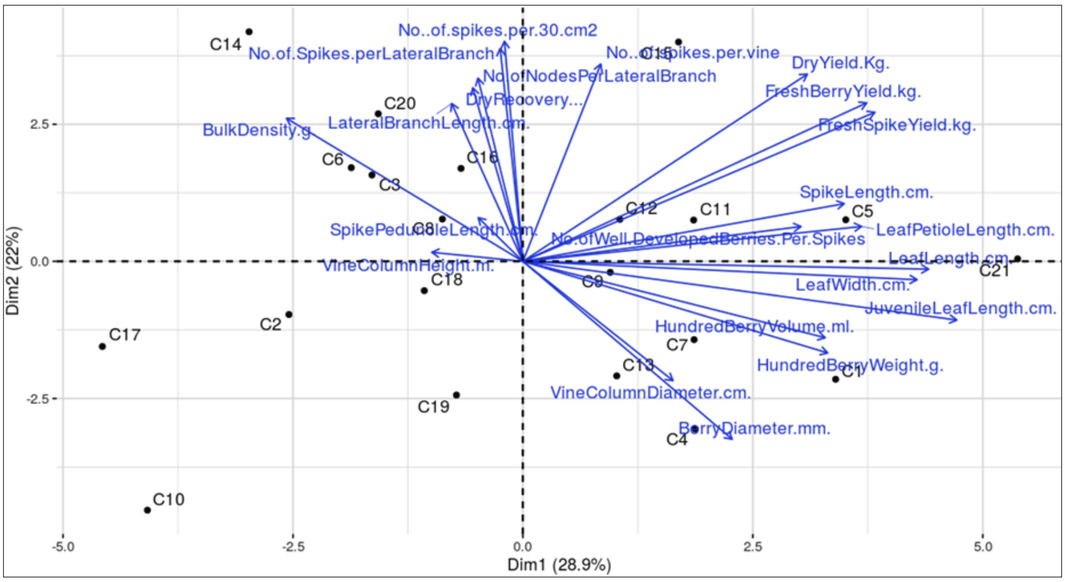

Fig 3: Biplot of 21 black pepper cultivars across PC 1 and PC2 of yield and yield related traits

Conclusion

Black pepper productivity is affected by elevation, soil fertility, cultural techniques, temperature, rainfall, crop age and climatic conditions during flowering, fruit set and development. However, some morphological characteristics have significant effect on black pepper yield. This study highlighted the significance of these traits when choosing high-yielding black pepper cultivars. Significant intercorrelation between the yield-contributing characteristics was seen, which highlights the significance of taking these relationships into account when making character selection decisions for the crop development work on black pepper. Principal component analysis has been carried out, discerning some interrelationships within the morphological characteristics between cultivars. This information is crucial for the future of the plant varietal improvement programme.

References

1. Bermawie N, Wahyuni S, Heryanto R, Darwati I. Morphological characteristics, yield and quality of black pepper Ciinten variety in three agro ecological conditions. IOP Conference Series Earth Environ Sci. 2019;292:1-9.
2. Chen YS, Dayod M, Tawan, CS. Phenetic analysis of cultivated black pepper (*Piper nigrum* L.) in Malaysia. International Journal of Agronomy. 2018, 1-11
3. Ibrahim KK, Pillay VS, Sasikumaran S. Variability, heritability and genetic advance for certain quantitative characters in black pepper. Agricultural Research Journal of Kerala. 1985;23:45-48.
4. Jayashree E, Zachariah TJ, Gobinath, P. Physico-chemical properties of black pepper from selected varieties in relation to market grades. Journal of Food Science and Technology. 2009;46(3):263-265.
5. Kandiannan K, Krishnamurthy KS, Thankamani CK, Mathew PA. Pattern and variability of black pepper yields in tropical humid climatic conditions. Indian Journal of Horticulture. 2007;64(3):314-319.
6. Karl P. On lines and planes of closest fi t to systems of points in space. Philosophical Magazine. 1901;2(11):559-572. Available at: http://pbil.univ-lyon1.fr/R/pearson 1901.pd
7. Krishnamoorthy B, Parthasarathy VA. Improvement of black pepper. CABI Reviews. 2010, 1-12.
8. Kurian PS, Backiyarani S, Josephrajkumar A, Murugan, M. Varietal evaluation of black pepper (*Piper nigrum*) for yield, quality and anthracnose disease resistance in Idukki District, Kerala. Journal of Spices and Aromatic Crops. 2002;11(2):122-124.
9. Mathew PJ, Jose JC, Nair GM, Mathew PM, Kumar V. Assessment and conservation of intraspecific variability in *Piper nigrum* (“black pepper”) occurring in the Western Ghats of Indian Peninsula. Acta Horticulturae. 2005;676):119-126.
10. Menon KK. Survey of “pollu” (hollow berry disease) and root disease of pepper. Indian Journal of Agricultural Science. 1949;19:89-136
11. Pradeepkumar T, Sajith Babu D, Aipe KC, Mathew S. Clonal variability in black pepper hybrid panniyur-1. Journal of Spices and Aromatic Crops. 2003;12(2):154-157.
12. Preethi TT, Aswathy TS, Sathyan T, Dhanya MK, Murugan M. Performance, diversity analysis and character association of black pepper (*Piper nigrum* L.) accessions in the high altitude of Idukki district, Kerala. Journal Spices and Aromatic Crops. 2018;27(1):17- 21.
13. Ravindran PN, Balakrishnan R, Nirmal Babu K. Morphometrical studies on black pepper (*Piper nigrum* L.). II. Principal component analysis of black pepper cultivars. Journal of Spices and Aromatic Crops. 1997;6(1):21-29.
14. Sainamole KP, Backiyarani S, Josephrajkumar A, Murugan M. Varietal evaluation of black pepper for yield, quality and anthracnose disease resistance in Idukki District, Kerala. Journal of Spices and Aromatic Crops. 2002;11(2):122–124.
15. Sasikumar B, George JK, Ravindran PN. Breeding behaviour of black pepper (*Piper nigrum* L.). Indian Journal of Genetics. 1992;52:17- 21.
16. Shango Jafari A, Majubwa RO, Maerere AP. Morphological characterization and yield of pepper (*Piper nigrum* L.) types grown in Morogoro District, Tanzania. CABI Agriculture and Bioscience. 2021;2(1):1-13.
17. Shivakumar MS, Saji KV, Sasikumar B. Genetic variability and correlation for yield and yield attributes in promising black pepper genotypes. Electronic Journal of Plant Breeding, 2020;11(01):65-69.
18. Sujatha R, Namboothiri KMN. Influence of plant characters on yield of black pepper (*Piper nigrum* L.). Journal Tropical Agriculture. 1995;33:11-15.
19. Wahid A, Rasul E, Rao AR, Iqbal RM. Photosynthesis in leaf, stem, flower and fruit. Handbook of Photosynthesis (ed. Pessarakli M.), Marcel Dekker Inc., New York, p.632. Wright, S. 1921. Correlation and causation. Journal of agricultural Research. 1997;20:557-585