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# Genetic variation in phenatic traits of extant varieties of brinjal (*Solanum melongena* L.)

**B. Singh, T. Chaubey#, R.K. Singh#, D.K. Upadhyay, Aastik Jha and S. Pandey***

*ICAR-Indian Institute of Vegetable Research, Varanasi, 221 305, Uttar Pradesh, India. *E-mail: sudhakariivr@gmail.com, rameshiivr@gmail.com #These authors contributed equally to this work.*

## Abstract

This study was conducted using eighty-one extant cultivars of brinjal (*Solanum melongena* L.) with sixteen diverse morphological and yield contributing traits. All the cultivars were evaluated for four years in field conditions to analyze the unpredictability and heritability, genetic variances, correlation and principal component analysis to extract important traits. In results, the highest value of general mean, variances of genotypic and phenotypic ($V_g$ and $V_p$), variation (GCV and PCV), heritability ($h^2$) and genetic advance (GA) were found for AFW and indicated the additive gene action. Due to environmental interaction, the highest variance and variation of environment (Ve and ECV) and GA% were recorded for PH, FDPS, and FL/FD ratio. In case of correlation and path coefficient analysis the yield per plant showed positive correlation for various morphological traits excluding NFI, FT and FL/FD ratio. Those traits established positive correlation with direct and indirect effect from yield can be utilized to improve yield capacity. In principal component analysis, the most important characters were categorized into different PCA group *e.g.,* PCA I (AFW), PCA II (FL), PCA III (FD) and PCA IV (FYPP) and may be extracted for observing the superior recombinants.

**Key words:** *Solanum melongena*; morphological traits; genetic variability; correlation; principal component analysis (PCA)

## Introduction

Brinjal (*S. melongena* L.), is an important vegetable crop cultivated in tropical and sub-tropical parts of the world. Being an indigenous crop, this crop has large diversity and extent of variability in India (Sujin *et al.,* 2017; Singh *et al,* 2023). Besides the diversity in morphological trait, this crop has a great extent of variation in size, shape and colour of fruits (Sunseri *et al.,* 2010). While the variability in morphological traits of inbred are important parameters to measure the extent of hybrid vigour during heterosis breeding. Most of the quantitative traits indicate the narrow difference between the genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) due to genotype and environmental influences (Arivalagan *et al.,* 2013; Madhvi *et al.,* 2015).

The study of heritability is helpful for breeders during the selection of lead genotypes for crop genetic improvement. Heritability is also useful for the determination of phenotypic and genotypic relationships in different environments (Sujin *et al.,* 2017). High heritability is indicating more variances in genotype, which may be a reliable selection for yield-related traits on the basis of genotypic and phenotypic expression (Shekar *et al.,* 2012). The values of heritability along with genetic advance assist in calculating the usual progress during the selection and breeding programme (Shekar *et al.,* 2012).

Correlation and path analysis is carried out the relative significance for yield and contributing traits. The direct and indirect effects represent the association between yield and related morphological traits (Sujin *et al.,* 2017). The similar correlation coefficients of both genotypic and phenotypic were indicated to relationship between morphological and yield traits (Singh *et al.,* 2010). Path coefficient analysis is a way to partition correlation coefficients into the direct and indirect effects of independent and dependent variables. Path coefficient analysis can produce a correlation and relative significance for each factor in these conditions.

The principal component analysis (PCA) helps to extract important variables from massive variables and provides a roadmap for reducing the complex data set (Sunseri *et al.,* 2010). PCA aims to allow the breeders to detect the relationships within data and describe a set of new variables to define the pattern of similarity of observations (Mahendran *et al.,* 2015). Principal component analysis is an expressive way of describing the pattern of character variation and allows for a multi-dimensional relationship (Ullah *et al.*, 2014). Moreover, a large number of extant cultivars had been studied along with huge morphological characters, but the cultivars and specific variables need to be identified for further utilization. Therefore, the present investigation was carried out to study the variability, heritability, genetic advance, correlation coefficient, and principal component analysis to improve the quantitative traits in extant brinjal cultivars.

## Materials and methods

**Experimental materials and design**: Eighty-one extant cultivars of brinjal were collected from diverse climatic zones of state agricultural universities (SAUs), central agriculture universities (CAUs), and research institutes (RIs) of India (Singh *et al., 2023*). The collected seeds were maintained at DUS (Distinctiveness, Uniformity and Stability) test unit of ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi. During the experimentation, one hundred fifty brinjal plants were transplanted in randomized block design in three replications (50 plants in each replication). All the agronomical and cultural practices were followed to grow the healthy crop.

**Data observation:** Data was recorded for 16 phenetic traits of 81 extant cultivars of brinjal from each replication (avoiding the border rows) at specified stages as published in the descriptor of distinctiveness, uniformity and stability (DUS) test guidelines of brinjal (PPV&FRA, 2009). All the observations were taken from the vegetative to maturity stages of plant and fruit for the characters mentioned in Table 3. Fruit length and diameter ratio was calculated by dividing fruit length value from fruit diameter value. Yield/plant (kg) was calculated by multiplying the number of fruits/plant from average fruit weight (g) and divided by 1000.

**Statistical analysis:** All the statistical analyses *viz.* genetic variability, heritability, genetic advances, correlation coefficient, path analysis and principal component analysis (PCA) were done by the software INDOSTAT version 8.5 (www.indistat.com) by using 16 phenetic traits of 81 extant cultivars.

Environmental, genotypical and phenotypical variances, environmental coefficient variation (ECV), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability ($h^2$), genetic advance in percentage of mean (GA andGA%) were calculated based on Singh and Choudhary (1985); Madhavi *et al.* (2015); Sujin *et al.* (2017), respectively.

The correlation coefficient of analysis (for genotypic and phenotypic) and path coefficient of analysis (for direct and indirect effect) were estimated, followed by Singh and Choudhary (1985); Singh *et al.* (2010); Sujin *et al.* (2017).

The principal component analysis was used to determine the variability via the transformation of the initial variables into a limited number of uncorrelated new variables, according to Hair *et al.* (2009); Kumar *et al.* (2016).

## Results and discussion

**Estimates of environmental, genotypic and phenotypic variances and coefficient of variation:** The analysis of variance showed that there were highly significant ($P$<0.01) differences among the genotypes for most of the characters (Table 1). This may be attributed to large variability among the cultivars under the study.

The estimates of minimum and maximum range with general mean, environmental, genotypical and phenotypical variances along with the environmental (ECV), genotypic (GCV), phenotypic coefficient of variation (PCV), broad sense heritability, genetic advance and genetic advance as percent of the mean for sixteen characters of 81 extant cultivars of brinjal were presented in Table 2. A significant variation was recorded in most of the characters. Among the characters, maximum range of mean value was observed for average fruit weight (53.73-490.26g) and the minimum range was recorded with flower size (3.50-5.80cm). The general mean value of characters was observed to be highest and lowest for average fruit weight (123.53g) and fruit yield/plant (1.94kg), respectively. Many studies emphasize the importance of a high range for various morphological traits (Prasad *et al.*, 2010; Madhavi *et al.*, 2015; Sujin *et al.*, 2017). Among these traits, plant height (33.94 cm) and plant spread (12.82 cm) displayed the highest environmental variances, whereas the FL/FD ratio (0.02 cm) and FYPP (0.01 kg) exhibited the lowest environmental variances (Table 2). This suggests that environmental variances are more influenced by

Table 1. Analysis of variance for 16 characters in 81 brinjal genotypes

| Characters | $^{\#}MS_r$ ($2^*$) | $^{\#}MS_g$ ($79^*$) | $^{\#}MS_e$ ($158^*$) |
|---|---|---|---|
| Leaf: Length (cm) | 0.623 | $11.071^{**}$ | 0.387 |
| Leaf: Width (cm) | 0.190 | $4.880^{**}$ | 0.179 |
| Inflorescence: Number of flowers | 0.379 | $2.471^{**}$ | 0.041 |
| Flower size | 0.067 | $0.452^{*}$ | 0.043 |
| Flowering: Time(days after seed sowing) | 46.408 | $237.203^{**}$ | 10.499 |
| Fruit: Length (cm) | 0.322 | $58.120^{**}$ | 0.104 |
| Fruit diameter | 0.032 | $17.785^{**}$ | 0.030 |
| fruit length/diameter ratio | 0.002 | $7.251^{**}$ | 0.022 |
| fruit diameter of pistil scar | 0.165 | $2.823^{**}$ | 0.080 |
| fruit length of pedincle | 0.014 | $4.498^{**}$ | 0.030 |
| No of fruit/plant | 0.004 | $74.091^{**}$ | 0.557 |
| Average fruit weight | 4.816 | $11384.28^{**}$ | 5.073 |
| Plant height | 48.864 | $965.743^{**}$ | 33.948 |
| Plant: Spread (distance between two extremes leaf tips at widest point (cm) | 23.789 | $612.233^{**}$ | 12.820 |
| Time of physiological ripeness (days after fruit set) | 13.735 | $69.213^{**}$ | 7.231 |
| Fruit yield/plant | 0.002 | $0.675^{**}$ | 0.009 |

$^{\#}$Source of variation for $MS_r$ = replication mean squire, $MS_g$= mean squire due to genotype and $MS_e$= error mean squire; $^*$Figures in parenthesis ($^*$) indicatedto degree of freedom, $^{**,*}$Significant at 1% & 5% probability levels, respectively.

plant growth than by fruit morphology (Madhavi *et al.*, 2015). On the other hand, the lowest genotypic and phenotypic variances were reported for flower size (0.14 cm and 0.18 cm, respectively), while the highest values were observed for average fruit weight (379.07 g and 380.14 g, respectively) and plant height (310.60 g and 344.55 g, respectively). These variances may be directly influenced by genotype x environmental interactions (Prasad *et al.*, 2010; Madhavi *et al.*, 2015; Kumar *et al.*, 2016; Sujin *et al.*, 2017). It was also noted that estimates of phenotypic variance were generally higher than those of genotypic variance. However, estimates of environmental variances were lower than both genotypic and phenotypic variances for all traits, indicating that variations were not solely due to genotypes but were also influenced by environmental factors, which could occasionally be misleading (Kumar *et al.*, 2016).

Correspondingly, the values of PCV (phenotypic coefficient of variation) were significantly higher than their corresponding GCV (genotypic coefficient of variation) for all the quantitative traits. However, the values of all ECV (environmental coefficient of variation) characters were lower than both GCV and PCV (Table 2). The lower ECV values were directly influenced by the PCV and GCV values for all traits, indicating a low environmental impact on these traits (Arivalagan *et al.*, 2013; Sujin *et al.*, 2017). It was also observed that most characters showed a small difference between PCV and GCV values. This lesser difference between PCV and GCV for morphometric traits suggested additive gene action and strong genotypic interaction with minimal environmental effects (Arivalagan *et al.*, 2013; Madhavi *et al.*, 2015; Sujin *et al.*, 2017). The lowest and highest ECV recorded were for AFW (1.82 g) and FDPS (10.35 cm), respectively, indicating environmental influences on these characters. This study was conducted by Nayak and Nagre (2013). Meanwhile, the lowest and highest values for GCV and PCV were observed for TPR (6.70 and 7.79 days) and the FL/FD ratio (61.33 and 61.62 cm), respectively, indicating that the observed differences were not solely due to genotypes but were significantly influenced by environmental interactions (Table 2). Similar results were reported by Nayak and Nagre (2013), Arivalagan *et al.* (2013), Madhavi *et al.* (2015), and Sujin *et al.* (2017). The present study also revealed that the narrow expression of variability due to the genetic makeup of the genotypes was influenced more by environmental factors. The selection of desirable traits for highly variable characters, which are less influenced by environmental factors, would be effective in brinjal improvement programs (Nayak and Nagre, 2013; Madhavi *et al.*, 2015; Kumar *et al.*, 2016; Sujin *et al.*, 2017).

**Estimates of heritability in broad sense, genetic advance and genetic advance percent:** The genotypic coefficient of variation, combined with heritability estimates, provides the most accurate basis for phenotypic selection and offers a reliable estimate of genetic advance (Shekar *et al.*, 2012; Madhavi *et al.*, 2015). In this study, the highest heritability percent ($h^2$%) and genetic advance (GA) were observed for average fruit weight (AFW) (1.00 and 162.48), fruit length (FL) (1.00 and 11.58), and fruit diameter (FD) (0.995 and 6.406). Additionally, the highest GA as a percentage of the mean was noted for the FL/FD ratio (161.189), AFW (131.526), and FD (103.579), as shown in Table 2. These traits' high heritability and GA indicate additive gene action, which is highly beneficial for plant breeders in making effective selections during breeding programs (Shekar *et al.*, 2012; Madhavi *et al.*, 2015; Sujin *et al.*, 2017). Conversely, the lowest values for heritability, GA, and GA% of the mean were exhibited by time to first picking (TPR) (0.74%), flower size (FS) (0.85), and TPR (15.23), respectively (Table 2). These low values indicate non-additive (dominant or epistatic) gene action, which may impede brinjal improvement through selection (Madhavi *et al.*, 2015; Sujin *et al.*, 2017). In this study, the lowest values for the standard error difference from the mean (SEDM) were observed in yield per plant (0.053) and the FL/FD ratio (0.085). This indicates low variability and minimal environmental influence on the yield and fruit morphology of the brinjal.

**Correlation coefficient matrix of genotypic and phenotypic traits:** The genotypic and phenotypic correlation coefficient helps to find the relationship between various plant characters, which can be based on generic improvement of yield components. In the present investigation, it was found that the FYPP was positively correlated with all the morphological traits at both genotypic and phenotypic levels (Table 3), excluding FT (-0.49 and -0.48) and FL/FD ratio (-0.031 and -0.028). Previously, it has been studied that the positive correlation of yield per plant with plant growth and fruit morphology are responsible traits for increasing the yield capacity (Singh *et al.*, 2010; Karak *et al.*, 2012; Kumar *et al.*, 2016). In the present investigation, the maximum positive and significant correlation of LW, FS, FD and PS was recorded with LL at both genotypic and phenotypic levels. Similarly, other characters were also found positive and significant correlation with each other at both genotypic and phenotypic levels *e.g.,* FL with FW; FL/FD ratio, FLP and PH with FL; FDPS and AFW with FD; NFPP with FL/FD (Table 3). Earlier, the strong correlation between average fruit weight and related yield traits has been reported by Singh *et al.* (2010) and Kumar *et al.* (2016). However, the TRP was showed negative correlation with all the traits except AFW at both genotypic and phenotypic levels. FW or FS may also be increased or decreased due to the instability in the time of physiological maturity of fruits, but fluctuation in physiological maturity of fruits is due to environmental influences. Similarly, the path coefficient analysis measures the direct and indirect effect of a set of associations between dependent variables on independent variables. In the present study, the characters, FS, FL, FDPS, FLP, NFPP, AFW, PH, PS, TPR and FYPP showed a positive direct (diagonal) effect, while FL/FD ratio exhibited negative direct effect on FYPP at the both genotypic and phenotypic level. The positive and negative direct and indirect effects on FYPP via various yield contributing traits had reported in various studies of Singh *et al.* (2010), Karak *et al.* (2012) and Sujin *et al.* (2017), and also discussed that the residual path effect made a positive relation with the characters which hold important role in determining the FYPP.

Table 2. Estimates of range of mean and general mean, components of variance, coefficients of variations, broad sense heritability, genetic advance and genetic advance percent as per mean for 16 characters in 81 brinjal extant cultivars

| Characters | Range | | GM | $V_e$ | $V_g$ | $V_p$ | ECV% | GCV% | PCV% | $h^2$% | GA | GA% | SEDM | CD% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | | | | | | | | | | | | |
| LL (cm) | 12.133 | 23.733 | 15.327 | 0.387 | 3.562 | 3.949 | 4.059 | 12.313 | 12.965 | 0.902 | 4.732 | 30.872 | 0.357 | 0.931 |
| LW (cm) | 8.267 | 14.633 | 10.388 | 0.179 | 1.567 | 1.746 | 4.077 | 12.050 | 12.721 | 0.897 | 3.130 | 30.135 | 0.243 | 0.634 |
| INF | 1.333 | 4.500 | 3.027 | 0.042 | 0.810 | 0.851 | 6.730 | 29.735 | 30.487 | 0.951 | 2.317 | 76.564 | 0.117 | 0.305 |
| FS (cm) | 3.500 | 5.800 | 4.227 | 0.043 | 0.136 | 0.179 | 4.881 | 8.735 | 10.006 | 0.762 | 0.851 | 20.131 | 0.118 | 0.309 |
| FT (days) | 53.000 | 93.333 | 72.115 | 10.499 | 75.568 | 86.067 | 4.493 | 12.054 | 12.864 | 0.878 | 21.504 | 29.819 | 1.859 | 4.847 |
| FL (cm) | 6.233 | 26.600 | 13.029 | 0.104 | 19.339 | 19.443 | 2.478 | 33.753 | 33.844 | 0.995 | 11.579 | 88.869 | 0.185 | 0.483 |
| FD (cm) | 2.733 | 14.133 | 6.185 | 0.030 | 5.919 | 5.948 | 2.799 | 39.334 | 39.433 | 0.995 | 6.406 | 103.579 | 0.099 | 0.259 |
| FL/FD(ratio) | 0.767 | 6.533 | 2.531 | 0.022 | 2.410 | 2.432 | 5.869 | 61.335 | 61.616 | 0.991 | 4.079 | 161.189 | 0.085 | 0.222 |
| FDPS (cm) | 1.000 | 5.667 | 2.732 | 0.080 | 0.914 | 0.994 | 10.354 | 34.999 | 36.498 | 0.920 | 2.421 | 88.600 | 0.162 | 0.423 |
| FLP (cm) | 3.667 | 9.533 | 6.105 | 0.030 | 1.490 | 1.520 | 2.836 | 19.990 | 20.190 | 0.980 | 3.190 | 52.249 | 0.099 | 0.259 |
| NFPP | 4.667 | 32.000 | 17.442 | 0.557 | 24.511 | 25.068 | 4.279 | 28.385 | 28.706 | 0.978 | 12.924 | 74.101 | 0.428 | 1.116 |
| AFW (g) | 53.733 | 490.267 | 123.537 | 5.073 | 379.070 | 380.143 | 1.823 | 49.854 | 49.887 | 0.999 | 162.483 | 131.526 | 1.292 | 3.369 |
| PH (cm) | 45.267 | 139.200 | 87.791 | 33.948 | 310.598 | 344.547 | 6.637 | 20.075 | 21.143 | 0.902 | 44.175 | 50.319 | 3.343 | 8.716 |
| PS (cm) | 66.100 | 142.033 | 105.493 | 12.820 | 199.805 | 212.624 | 3.394 | 13.399 | 13.822 | 0.940 | 36.175 | 34.291 | 2.054 | 5.356 |
| TPR (days) | 57.667 | 77.333 | 67.801 | 7.231 | 20.661 | 27.892 | 3.966 | 6.704 | 7.789 | 0.741 | 10.328 | 15.233 | 1.543 | 4.023 |
| FYPP (kg) | 1.033 | 3.967 | 1.945 | 0.009 | 0.222 | 0.231 | 4.762 | 24.234 | 24.698 | 0.963 | 1.221 | 62.778 | 0.053 | 0.139 |

GM= general mean; $V_e$= environmental variance; $V_g$= genotypical variance; $V_P$=phenotypical variance; ECV= environmental coefficient of variation; GCV= genotypic coefficient of variation; PCV= phenotypic coefficient of variation; $h^2$= heritability (Broad Sense) (%); GA & GA%= genetic advance at 1%; SEDM= standard error difference from mean; CD= critical difference at 5%; LL=Leaf Length (cm); LW=Leaf Width (cm); INF=Inflorescence Number of flowers; FS=Flower size (cm); FT=Flowering Time (days after seed sowing); FL=Fruit Length (cm); FD=Fruit diameter (cm); FL/FD ratio=fruit length/diameter ratio; FDPS=fruit diameter of pistil scar (cm); FL*P*=fruit length of pedincle (cm); NFPP =No of fruit/plant; AFW=Average fruit weight (g); PH=Plant height (cm); PS=Plant Spread (distance between two extremes leaf tips at widest point (cm); TPR=Time of physiological ripeness (days after fruit set); FYP*P*=Fruit yield/plant(kg).

Table 3. Genotypic (G) and phenotypic (P) coefficient of correlation (M) among different characters ('C' for 1-16) of 81 brinjal cultivars

| C | M | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | G | 1.00 | | | | | | | | | | | | | | |
| | P | 1.00 | | | | | | | | | | | | | | |
| 2 | G | 0.71 | 1.00 | | | | | | | | | | | | | |
| | P | 0.64*** | 1.00 | | | | | | | | | | | | | |
| 3 | G | -0.17 | 0.08 | 1.00 | | | | | | | | | | | | |
| | P | -0.16 | 0.07 | 1.00 | | | | | | | | | | | | |
| 4 | G | 0.32 | 0.17 | 0.05 | 1.00 | | | | | | | | | | | |
| | P | 0.27*** | 0.13* | 0.04 | 1.00 | | | | | | | | | | | |
| 5 | G | 0.03 | 0.02 | -0.21 | 0.04 | 1.00 | | | | | | | | | | |
| | P | 0.02 | 0.01 | -0.18 | 0.05 | 1.00 | | | | | | | | | | |
| 6 | G | 0.23 | 0.30 | 0.05 | 0.20 | 0.18 | 1.00 | | | | | | | | | |
| | P | 0.22*** | 0.28*** | 0.05 | 0.17** | 0.17** | 1.00 | | | | | | | | | |
| 7 | G | 0.45 | 0.29 | -0.15 | 0.21 | -0.03 | -0.28 | 1.00 | | | | | | | | |
| | P | 0.43*** | 0.28*** | -0.15 | 0.18** | -0.03 | -0.28 | 1.00 | | | | | | | | |
| 8 | G | -0.02 | 0.06 | 0.08 | 0.03 | 0.12 | 0.82 | -0.70 | 1.00 | | | | | | | |
| | P | -0.02 | 0.05 | 0.08 | 0.03 | 0.12 | 0.82*** | -0.70 | 1.00 | | | | | | | |
| 9 | G | 0.38 | 0.31 | -0.09 | 0.37 | 0.14 | -0.09 | 0.80 | -0.51 | 1.00 | | | | | | |
| | P | 0.35*** | 0.27*** | -0.09 | 0.31*** | 0.12 | -0.08 | 0.78*** | -0.49 | 1.00 | | | | | | |
| 10 | G | 0.24 | 0.26 | -0.01 | 0.09 | 0.18 | 0.58 | -0.14 | 0.46 | 0.10 | 1.00 | | | | | |
| | P | 0.23*** | 0.25*** | -0.01 | 0.08 | 0.17** | 0.57*** | -0.13 | 0.45*** | 0.09 | 1.00 | | | | | |
| 11 | G | -0.20 | -0.11 | 0.30 | -0.04 | -0.12 | 0.31 | -0.58 | 0.52 | -0.43 | 0.19 | 1.00 | | | | |
| | P | -0.19 | -0.10 | 0.29*** | -0.04 | -0.11 | 0.31*** | -0.57 | 0.52*** | -0.41 | 0.18** | 1.00 | | | | |
| 12 | G | 0.29 | 0.20 | -0.22 | 0.24 | 0.07 | -0.11 | 0.61 | -0.37 | 0.52 | -0.10 | -0.69 | 1.00 | | | |
| | P | 0.27*** | 0.19** | -0.22 | 0.21*** | 0.06 | -0.11 | 0.61*** | -0.37 | 0.50 *** | -0.10 | -0.69 | 1.00 | | | |
| 13 | G | 0.22 | 0.39 | 0.01 | 0.32 | -0.06 | 0.42 | -0.01 | 0.28 | 0.06 | 0.33 | 0.07 | 0.05 | 1.00 | | |
| | P | 0.20** | 0.36*** | 0.01 | 0.24*** | -0.07 | 0.40*** | -0.01 | 0.26*** | 0.06 | 0.31*** | 0.08 | 0.05 | 1.00 | | |
| 14 | G | 0.32 | 0.05 | -0.13 | 0.16 | -0.05 | 0.11 | 0.05 | 0.07 | 0.11 | 0.10 | 0.02 | 0.09 | 0.01 | 1.00 | |
| | P | 0.28*** | 0.04 | -0.12 | 0.13* | -0.04 | 0.10 | 0.05 | 0.07 | 0.10 | 0.09 | 0.02 | 0.09 | 0.02 | 1.00 | |
| 15 | G | -0.32 | -0.40 | -0.02 | -0.04 | -0.14 | -0.15 | -0.05 | -0.10 | -0.08 | -0.22 | -0.03 | 0.04 | -0.23 | -0.06 | 1.00 |
| | P | -0.26 | -0.34 | -0.01 | 0.02 | -0.11 | -0.13 | -0.05 | -0.09 | -0.07 | -0.18 | -0.03 | 0.03 | -0.19 | -0.06 | 1.00 |
| 16 | G | 0.04 | 0.03 | -0.06 | 0.24 | -0.05 | 0.14 | 0.14 | -0.03 | 0.25 | 0.13 | 0.03 | 0.49 | 0.15 | 0.18 | 0.16 |
| | P | 0.04 | 0.03 | -0.06 | 0.22 | -0.05 | 0.14 | 0.13 | -0.03 | 0.24 | 0.12 | 0.05 | 0.48 | 0.15 | 0.18 | 0.14 |

*,**,***Significance Levels at $P$=<0.05, <0.01, <0.005 and <0.001 for phenotypic (if correlation r => 0.1267, >0.166, >0.1806 and >0.2111); **C=** **1**= LL=Leaf Length (cm); **2**= LW=Leaf Width (cm); **3**= INF=Inflorescence Number of flowers; **4**= FS=Flower size (cm); **5**= FT=Flowering Time (days after seed sowing); **6**= FL=Fruit Length (cm); **7**= FD=Fruit diameter (cm); **8**= FL/FD ratio=fruit length/diameter ratio; **9**= FDPS=fruit diameter of pistil scar (cm); **10**= FL*P*=fruit length of pedincle (cm); **11**= NFPP =No of fruit/plant; **12**= AFW=Average fruit weight (g); **13**= PH=Plant height (cm); **14**= PS=Plant Spread (distance between two extremes leaf tips at widest point (cm); **15**= TPR=Time of physiological ripeness (days after fruit set); **16**= FYP*P*=Fruit yield/plant (kg).

**Principal component analysis (PCA):** In this study, principal component analysis (PCA) was conducted on phenotypic traits to describe relationships among different characteristics and to identify significant components. The contribution of the first four components to the total variance and cumulative variance was expressed as a percentage, along with the root mean of the Eigenvalues (Table 4). The first principal component (PCA I) accounted for approximately 61.33% of the total and cumulative variance. The most significant traits of PCA I were average fruit weight (AFW), fruit diameter (FD), time to first picking (TPR), and the FL/FD ratio, with values of 0.89, 0.32, 0.18, and 0.10, respectively (Table 4). The range of values for PCA I varied from -0.00 (PS) to 0.89 (AFW). Variation in AFW and PS depends on the environmental fluctuations or genetically fixed characteristics of the varieties (Solaiman *et al.*, 2014; Mahendran *et al.*, 2015; Kumar *et al.*, 2016). The second principal component (PCA II) accounted for approximately 16.82% of the total variance and 78.15% of the cumulative variance (Table 4). The most important traits for PCA II were fruit length (FL) (0.83), flower length per plant (FLP) (0.28), and AFW (0.24), which depend on the genetic nature of brinjal cultivars and vary due to environmental factors (Ullah *et al.*, 2014; Solaiman *et al.*, 2014; Kumar *et al.*, 2016). The third principal component (PCA III) contributed 8.44% of the total variance and 86.58% of the cumulative variance. The key traits in this component were FD (0.73), FL (0.37), FL/FD ratio (0.35), leaf length (LL) (0.14), and plant height (PH) (0.14). These traits are influenced by fixed genetic characters but are slightly affected by environmental instability (Ullah *et al.*, 2014; Kumar *et al.*, 2016). The fourth component (PCA IV) explained 3.72% of the total variance and 90.30% of the cumulative variance (Table 4). The most significant traits in this group were fruit yield per plant (FYPP), FLP, and FD, with positive PCA values of 0.83740, 0.25415, and 0.20214, respectively (Table 4). The highest negative values for PCA IV were -0.29199 (number of fruits per plant, NFPP) and -0.20176 (FL/FD ratio). The lowest positive and negative values of PCA IV were 0.00322 and -0.00821 for LL and leaf width (LW), respectively. Supporting our findings, Solaiman *et al.* (2014) and Kumar *et al.* (2016) have reported significant traits with both positive and negative values. FYPP depends on fruit number, shape, size, and the genetic architecture of plants, as discussed in various studies (Ullah *et al.*, 2014; Mahendran *et al.*, 2015; Kumar *et al.*, 2016).

In conclusion, the existing brinjal cultivars exhibited a wide range of variability and heritability for phenotypic traits. The highest and lowest heritability with genetic advance for important traits showed both additive and non-additive gene action, which plays a crucial role in governing these traits. The correlation and

Table 4. Rotated components of 16 characters of 81 brinjal cultivars for principal component analysis (PCA)

| Characters | PCA I | PCA II | PCA III | PCA IV | PCA IV |
|---|---|---|---|---|---|
| Leaf: Length (cm) | 0.03 | 0.04 | 0.14 | 0.00 | 0.00 |
| Leaf: Width (cm) | 0.02 | 0.05 | 0.09 | -0.01 | -0.01 |
| Inflorescence: Number of flowers | -0.03 | 0.00 | -0.01 | -0.20 | -0.20 |
| Flower size | 0.01 | 0.03 | 0.03 | -0.03 | -0.03 |
| Flowering :Time(days after seed sowing) | 0.01 | 0.04 | 0.00 | 0.08 | 0.08 |
| Fruit: Length (cm) | -0.07 | 0.83 | 0.37 | 0.01 | 0.01 |
| Fruit diameter | 0.32 | -0.35 | 0.73 | 0.20 | 0.20 |
| fruit length/diameter ratio | 0.11 | **-0.06** | 0.35 | -0.20 | -0.20 |
| fruit diameter of pistil scar | -0.01 | **-0.10** | -0.12 | 0.06 | 0.06 |
| fruit length of pedincle | -0.08 | 0.28 | **0.04** | 0.25 | 0.25 |
| No of fruit/plant | -0.15 | -0.04 | **-0.10** | **-0.29** | **-0.29** |
| Average fruit weight | 0.89 | 0.24 | -0.32 | **0.05** | **0.05** |
| Plant height | -0.05 | 0.09 | 0.14 | 0.09 | 0.09 |
| Plant: Spread (distance between two extremes leaf tips at widest point (cm) | 0.00 | -0.08 | 0.03 | 0.08 | 0.08 |
| Time of physiological ripeness (days after fruit set) | 0.18 | -0.11 | 0.06 | -0.03 | -0.03 |
| Fruit yield/plant | -0.12 | -0.05 | -0.13 | 0.84 | 0.84 |
| Eigene Value (Root) | 24349.17 | 6678.42 | 3349.98 | 1476.19 | 1476.19 |
| Total Variance % Exp. | 61.33 | 16.82 | 8.44 | 3.72 | 3.72 |
| Cumulative Variance % Exp. | 61.33 | 78.15 | 86.58 | 90.30 | 90.30 |

path coefficient analysis established a positive correlation and positive direct and indirect effects on fruit yield for most traits. Thus, traits that showed a positive correlation with yield and exhibited positive direct and indirect effects on yield can be used as selection criteria in brinjal to enhance yield capacity. From the principal component analysis, the limited but significant variables extracted from the data set may be very useful to plant breeders for effective breeding programs and genetic improvement of brinjal.

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