Variability Studies in Maize (Zea Mays L.) inbreds through Morpho Physiological Traits, Principal Component Analysis and their relationship between yield components

Saranprabhakaran K1, Senthil A1*, Sritharan N2 and senthil N2

1Department of Crop physiology, Tamilnadu Agricultural university, Coimbatore -03
2Department of plant Molecular Biology and Bioinformatics, CPMB&B, Tamilnadu Agricultural university, Coimbatore -03

ABSTRACT

The presence of high genetic diversity in physiological traits among maize inbreds had scope for improving the inbreds for better canopy architecture. Eight maize inbreds were characterized by twelve morpho-physiological traits and four yield-related traits. Among the physiological traits, the photosynthetically active radiation (PAR) is evenly distributed in S38, S157, S289, and S322 inbreds at the canopy level. Leaf Dry Matter (LDM) had positive association ($r = 0.734^*$) for 100 kernel weight. In Principal Component Analysis (PCA), the first two PCs were used to construct the biplot where the total number of kernels, cob girth, Average Growth Rate (AGR), and leaf dry matter had a positive association with S157, S322, and D164 inbreds. The inbred S157 recorded high leaf dry matter (47.55 g), more cob length (20.43 cm), more 100-kernel weight (39.32 g) and more average growth rate (6.18 g/day). Hence, S157 is considered as the best ideotype for the developing high yielding maize hybrids based on better canopy architecture.

Keywords: Maize, Morpho-physiological traits, Descriptive statistics, PCA, Genetic diversity.

INTRODUCTION

Maize is one of the major cereal and the third most important crop next to wheat and rice. The overall production of maize in the world was forecast at 1.07 million thousand tonnes in 2020. 28.5 million tonnes of maize produced by India in 2020. It was the sixth position in the world. (Knoema, 2020). The diversity of the genotypes is a key feature of the crop improvement programme. According to Tang et al., (2018) increasing the productivity of maize was possible through high-density planting. Thus, we have to develop the high-density adapted varieties. Thereby, the inbreds having suitable plant architecture with uniform light distribution paves the way to select the inbreds for breeding programs. In maize cultivation, the environmental conditions and the genetic structure plays a dynamic role in yield. The energy from sunlight that was available to photosynthesis is photosynthetically active radiation (PAR). Available PAR to all stratum of crop canopy and utilizing it effectively plays a vital role in improving crop production (Wang et al., 2004). Awal et al., (2006) reported that improving the light use efficiency could improve the crop yield. Crop improvement mainly relies on genetic diversity. In germplasm identification, morphological characters were used earlier and it has an important role in classifying the genotypes (Shrestha, 2014).

Nowadays many inbreds were selected from the restricted number of superior lines, which leads to reduce the diversity of germplasm on the commercially cultivating maize fields (Hallauer et al., 1988).

Basic statistics like Mean, maximum, minimum, standard deviation, coefficient of variation (CV), and variance has been used to identify the variability pattern between inbreds (Sali et al., 2013). Principal component analysis (PCA) is an algorithm that is used to upsurge the variance without affecting the data. It is a data analysis technique that helps in identifying the variance and similarities between inbreds and in categorizing the contribution of variables or traits towards genetic diversity. Many authors used PCA to estimate the genetic divergence and genetic variation for morphological traits in many crops viz., maize, soybean, cowpea, cotton. Pearson’s correlation coefficients between the variables used in the study to found the interrelationships between the variables (Iqbal et al., 2015; Sali et al., 2013). Understanding the genetic variability for morpho-physiological traits helps to develop the perfect ideotype and also utilization in a future breeding programme. The present study was aimed to characterize the maize inbreds with different canopy structures by assessing the morpho-physiological traits and yield-related traits.

*Corresponding author’s
MATERIAL AND METHODS

The inbreds with different canopy structures were selected for the experiment. They were S38, S157, S289, S322, D164, D200, D360, and D435. Seed materials were collected from the Department of Plant Molecular Biology and Bioinformatics, Tamil Nadu Agricultural University, Coimbatore. Selected eight inbred lines were sown during Kharif 2020 in the Department of Farm Management, Tamil Nadu Agricultural University, Coimbatore. They were planted in a randomized complete block design (RCBD) with three replications. The field was maintained at sufficient field capacity by channel irrigation and the total recorded rainfall during the crop growth period was 332 mm, average maximum and minimum temperature was 31.44°C and 23.32°C respectively. Average relative humidity in the morning and afternoon was 83% and 57.2% respectively. The plant population was maintained at the rate of 11,111 plants/ha. NPK was applied at the rate of 135:62.5:50 kg of N: P: K per hectare. Other cultural practices were followed as per the university recommendation package.

In each replication three randomly selected plants were used for observing the morpho-physiological traits viz., Anthesis silking interval (ASI), days to 50% tasselling (DT), days to 50% silking (DS), Shoot dry matter (SDM), leaf dry matter (LDM), leaves below the ear (LBE), leaves above the ear (LAE), cob placement height (CPH), cob length, cob girth, total number of kernels per ear, stover yield and 100 kernel weight.

Table 1. Descriptive statistics of Morpho-physiological traits of studied inbred lines

| Traits | Mean  | Maximum | Minimum | SD   | Variance | CV % |
|--------|-------|---------|---------|------|----------|------|
| LDM    | 31.10 | 50.66   | 19.71   | 7.65 | 58.52    | 24.60|
| SDM    | 100.01| 147.91  | 72.51   | 22.22| 493.54   | 22.22|
| DT     | 55.21 | 63.00   | 51.00   | 3.35 | 11.22    | 6.07 |
| DS     | 56.96 | 66.00   | 51.00   | 4.01 | 16.04    | 7.04 |
| ASI    | 1.71  | 4.00    | 0.00    | 0.95 | 0.91     | 55.56|
| LBE    | 5.88  | 8.00    | 4.00    | 1.12 | 1.25     | 19.05|
| LAE    | 5.71  | 6.00    | 5.00    | 0.46 | 0.22     | 8.06 |
| CPH    | 78.46 | 110.50  | 65.50   | 13.19| 173.85   | 16.81|
| LAD    | 88.92 | 104.72  | 61.01   | 10.44| 108.97   | 11.74|
| AGR    | 4.51  | 7.25    | 1.65    | 1.78 | 3.17     | 39.47|
| Total chl | 1.99 | 2.71    | 1.18    | 0.40 | 0.16     | 20.10|
| Stover yield | 87.19 | 141.50  | 53.97   | 21.72| 471.78   | 24.91|
| Cob length | 17.44 | 21.20   | 14.10   | 1.89 | 3.58     | 10.84|
| Cob girth | 14.89 | 16.60   | 12.90   | 1.15 | 1.31     | 7.72 |
| 100 grain wt | 33.06 | 47.31   | 28.05   | 3.83 | 14.64    | 11.58|
| No of Kernels | 500.13 | 724.00  | 331.00  | 86.46| 7474.81  | 17.29|

Total Chlorophyll content in leaves was estimated by using the DMSO method given by Hiscox et.al, (1979) and expressed in mg g⁻¹ of fresh weight. Leaf area duration (LAD) was calculated as per the formula mentioned in Paul et.al, (2017) and expressed in cm² day. The average growth rate (AGR) was calculated as per the formula mentioned in Paul et.al, (2017) and expressed in g day⁻¹. Photosynthetically active radiation was measured above and below the crop canopy by the LI-190R quantum sensor (Licor, Lincoln, NE, USA) following the method mentioned by (Gao et al., 2010) expressed in µmol of photons m⁻² s⁻¹. A light sensor logger (LI 1500, Licor, Lincoln, NE, USA) was used to record the data.
The data were analysed using descriptive statistics, Principal component analysis (PCA) and Pearson’s correlation coefficient to assess the genetic variance. Mean, maximum, minimum, standard deviation, coefficient of variation (CV), variance and analysis of variance (ANOVA) was carried out in SPSS Statistics version 16.0 (SPSS Inc., Chicago, Ill., USA). Principal component analysis (PCA) was performed by the software R version 3.3.2 and R Studio 1.0.136. Pearson’s correlation coefficients between all traits used in the study were acquired to found the interrelationships between the traits.

RESULTS AND DISCUSSION

The morpho-physiological variations recorded among the inbreds were shown in Table 1. The basic statistics like mean, maximum, minimum, standard deviation (SD), variance, and coefficient of variation (CV) were calculated for all the variables. Higher variability was found in ASI (55.6%) followed by AGR (39.47%), stover yield (24.91%) and LDM (24.6%). The lower variability was found in DT (6.07%) followed by DS (7.04%) cob girth (7.72%) and LAE (8.06%).

Table 2. Per se performance of morpho-physiological parameters.

| Inbred lines | Cob length (cm) | Cob girth (cm) | 100 grain weight (g) | Total no. of kernels | Stover yield (g) | PAR decrease % | LAD (cm² day⁻¹) | AGR (g day⁻¹) |
|--------------|-----------------|----------------|---------------------|---------------------|-----------------|---------------|---------------|--------------|
| S38          | 14.7 ± 0.25d    | 13.1 ± 0.13c   | 32.73 ± 0.65b       | 375.0 ± 33.61b      | 90.18 ± 9.3ab   | 76.3 ± 2.06f  | 67.6 ± 3.6c   | 5.06 ± 0.05b  |
| S157         | 20.4 ± 0.30a    | 15.0 ± 0.23b   | 39.32 ± 0.89a       | 499.6 ± 34.57ab     | 119.18 ± 11.6a  | 86.9 ± 0.96cd | 92.6 ± 3.3ab  | 6.18 ± 0.34a  |
| S289         | 16.2 ± 0.39cd   | 15.8 ± 0.26ab  | 32.48 ± 0.47b       | 519.3 ± 45.08ab     | 76.81 ± 5.7b    | 88 ± 1.06d    | 88.0 ± 1.7b   | 4.28 ± 0.35c  |
| S322         | 17.5 ± 0.45bc   | 15.0 ± 0.28b   | 31.03 ± 0.21b       | 507.7 ± 20.95ab     | 78.79 ± 4.5ab   | 86.1 ± 0.67e  | 100.6 ± 2.6a  | 2.43 ± 0.08e  |
| D164         | 17.9 ± 0.34bc   | 15.6 ± 0.37a   | 32.02 ± 0.67b       | 594.7 ± 65.10a      | 89.33 ± 17.4ab  | 94.6 ± 0.98a  | 95.1 ± 4.4ab  | 3.27 ± 0.04d  |
| D200         | 17.3 ± 0.42bc   | 16.2 ± 0.22a   | 33.61 ± 0.34b       | 527.7 ± 33.20a      | 68.81 ± 6.7b    | 93.3 ± 0.54ab | 89.5 ± 2.0b   | 1.92 ± 0.14e  |
| D360         | 16.8 ± 0.35bcd  | 14.97 ± 0.27b  | 30.98 ± 0.54b       | 482.3 ± 34.28ab     | 90.31 ± 12.5ab  | 91.4 ± 1.1bc  | 93.6 ± 2.9ab  | 6.39 ± 0.20a  |
| D435         | 18.6 ± 0.32ab   | 13.43 ± 0.28c  | 32.31 ± 0.31b       | 494.7 ± 65.42ab     | 84.11 ± 15.4ab  | 92.6 ± 0.89ab | 84.4 ± 3.1b   | 6.59 ± 0.35a  |

* Mean ± SE values (n=3) with different alphabets were significantly different at (P<0.05) level

This variability between the morpho-physiological traits was found similar to the studies of Iqbal et al., (2015); Shrestha, (2014). A significant difference was found among the inbreds for all the variables studied (Table 2 & Table 3). Variability among the inbred lines was mainly due to genetic as well as environmental factors. The photosynthetically active radiation (PAR) decrease percentage, which indicates the amount of PAR reduced while passing through the canopy to reach the soil surface. The amount of reduced percentage was more in D164 followed by D200. S38 recorded with a lower reducing percentage (Table 2). The droopiness of leaves reduces the amount of PAR to reach the surface of the soil. The result of study was in accordance with the findings of Pepper et al., (1977), Liu et al., (2011).

The character’s association between inbreds is presented in Table 4. LDM was positively correlated with stover yield (r = 0.800*), cob length (r = 0.829*) and 100 grain yield (r = 0.734*). Per se performance of LDM and 100 kernel weight were recorded more in S157 (Table 2). The average growth rate (AGR) was indicating the growth of the plant per unit time. Per se performance of the AGR at post silking stage recorded more in D360 followed by D435 (Table 2). Also, LDM was recorded less than the SDM for the two inbreds, respectively. This result is in accordance with Machado et al., (2015).

SDM and ASI were positively correlated (r = 0.778*) which leads to reducing yield. ASI also negatively correlated with yield attributes like cob length (r = -0.204), cob girth (r = -0.488), total number of kernels per cob (r = -0.433) and 100 grain weight (r = -0.213). Similar results accorded by Edmeades and Islam (1987). Anthesis silking interval was counted more in D360 followed by D435. (Table 3). CPH was positively correlated with SDM (r = 0.708*). CPH increased the plant height thereby increasing the SDM which is in accordance with Shrestha (2014), in this study, the per se performance of D360 and S38 recorded the high and low CPH respectively (Table 2). LAE was positively correlated to the cob length (r = 0.309), cob girth (r = 0.829*), total number of kernels (r = 0.633) 100 grain weight (r = 0.108). Where, LBE was negatively correlated to the cob girth (r = -0.318), total number of kernels (r = -0.488) and 100 grain weight (r = -0.318). Per se performance of the LBE was more and less in D435 and S38 respectively. Kefu et al., (1981) stated that LAE were contributed more to photosynthesis thus indirectly favour the yield.

Principal component analysis (PCA) is a technique that is used to reduce the complexity of variables to a smaller set of uncorrelated variables without affecting the original data. It was used to visualize the multi-dimensional and to identify the underlying variables. In maize, many authors used PCA to find...
the divergence among inbred lines (Mishra, 2016). In the present study Principal component analysis (PCA) was performed for 16 morpho-physiological and yield related traits of eight inbred lines. PCA sorted out the total variables into eight main principal components (PCs) (PC1 to PC8) in which the first principal component 1 (PC1) contributes 32.3% and the last PC8 contributes almost nil.

Among the eight PCs first six PCs showed more than one eigen value and their cumulative contribution towards the variation is 98.4% among the inbred lines. According to Walle et al., (2019) Eigen values should be more than one for PCs to contributing significant variation towards genetic diversity.

Table 3. Per se performance of morpho-physiological parameters.

| Inbred lines | ASI (Days) | DT (Days) | DS (Days) | LBE | LAE | LDM (g) | SDM (g) | CPH (cm) |
|--------------|------------|-----------|-----------|-----|-----|---------|---------|---------|
| S38          | 2.0 ± 0.58bc | 53.3 ± 0.67d | 55.7 ± 1.33c | 5.0 ± 0.00c | 5.0 ± 0.00b | 21.72 ± 1.19d | 107.36 ± 1.21c | 68.33 ± 1.83c |
| S157         | 1.3 ± 0.33cde | 55.0 ± 0.00bc | 56.3 ± 0.33bc | 5.3 ± 0.33bc | 6.0 ± 0.00a | 27.45 ± 1.40c | 111.94 ± 5.03bc | 74.17 ± 1.74c |
| S289         | 1.7 ± 0.33cd | 56.3 ± 0.33b  | 58.0 ± 0.00b  | 5.3 ± 0.33bc | 6.0 ± 0.00a | 28.63 ± 1.07c | 85.10 ± 3.31d | 72.33 ± 2.05c |
| S322         | 0.7 ± 0.33e  | 51.0 ± 0.00e  | 51.7 ± 0.33d  | 6.0 ± 0.00b  | 6.0 ± 0.00a | 27.16 ± 0.86c | 73.46 ± 0.75e | 72.17 ± 1.01c |
| D164         | 1.0 ± 0.00d  | 54.0 ± 1.00cd | 55.0 ± 1.03c  | 4.7 ± 0.33d  | 6.0 ± 0.00a | 27.45 ± 1.40c | 84.97 ± 1.83c | 72.17 ± 0.93c |
| D200         | 1.3 ± 0.33cde| 57.3 ± 0.33cd | 55.0 ± 0.03c  | 5.7 ± 0.33bc | 6.0 ± 0.00a | 27.16 ± 0.86c | 73.46 ± 0.75e | 72.17 ± 1.01c |
| D360         | 3.0 ± 0.00a  | 62.7 ± 0.33a  | 65.7 ± 0.33a  | 7.3 ± 0.33a  | 6.0 ± 0.00a | 33.29 ± 1.25b | 118.70 ± 4.15b | 105.17 ± 2.73a |
| D435         | 2.7 ± 0.67ab | 55.7 ± 0.33b  | 58.3 ± 0.33b  | 7.7 ± 0.33a  | 5.0 ± 0.00b | 28.18 ± 1.48c | 138.86 ± 4.52a | 94.17 ± 0.88b |

± SE values (n=3) with different alphabets were significantly different at (P<0.05) level

According to Walle et al., (2019) the factor score should above ±0.3 said to be significantly contributing either positively or negatively to the divergence. PC1 contributes 32.3% in total variation in which ASI (-0.39), SDM (-0.355), CPH (-0.344) and DS (-0.317) were negatively and significantly contributed more for PC1. PC2 gives 23% variation in total variation in which LDM (0.434), LAD (0.338), Cob length (0.391) and LAE (0.352) were positively and significantly contributed more for PC2. PC3 contributes 17% in total variation in which stover yield (0.383), and 100-grain weight (0.412) were significantly contributed more for PC3.

In the present study, the biplot of PCA (Figure. 1) showed that D200, S322, D164 were scattered close to each other. It showed less diversity among them and they had similar profiles. The inbreds S157, S38, D360 were laid far away from each other and they said to be more diverse.

Table 4. Correlation among the morpho-physiological and biochemical traits for studied maize

| CPH | LDM | SDM | LAD | AGR | Stover yield | Cob length | Cob girth | No of grains | 100 grain wt | Total chl | DT | DS | ASI | LBE | LAE |
|-----|-----|-----|-----|-----|-------------|------------|-----------|-------------|-------------|------------|-----|----|----|-----|-----|-----|
| CPH | 1   |     |     |     |             |            |           |             |             |            |     |    |    |     |     |     |
| LDM | 0.089 | 1   |     |     |             |            |           |             |             |            |     |    |    |     |     |     |
| SDM | 0.707* 0.143 | 1   |     |     |             |            |           |             |             |            |     |    |    |     |     |     |
| LAD | 0.778* 0.58 | 0.517 | 1   |     |             |            |           |             |             |            |     |    |    |     |     |     |
| AGR | -0.354 -0.036 | -0.506 -0.272 | 1   |     |             |            |           |             |             |            |     |    |    |     |     |     |
| Stover yield | 0.056     0.800* 0.448 | 0.335 | -0.319 | 1   |             |            |           |             |             |            |     |    |    |     |     |     |
| Cob length | 0.122 0.828* | 0.223 | 0.556 | 0.923 | 0.558 | 1   |             |            |             |            |     |    |    |     |     |     |
| Cob girth | -0.232 0.313 | -0.748* | 0.14 | 0.36 | -0.249 | 0.209 | 1   |             |             |            |     |    |    |     |     |     |
| No of grains | -0.088 0.395 | -0.465 | 0.269 | 0.463 | -0.155 | 0.506 | 0.758* | 1   |             |             |            |     |    |    |     |     |     |
| 100 grain wt | -0.27 0.734* | 0.117 | 0.11 | -0.034 | 0.734* | 0.639 | 0.076 | -0.026 | 1   |             |             |            |     |    |    |     |     |     |
| Total chl | 0.208 | -0.02 | -0.042 | 0.049 | 0.342 | 0.059 | -0.077 | -0.068 | -0.109 | -0.34 | 1   |     |    |    |     |     |     |
| DT | .821* | 0.233 | 0.464 | .717* | -0.652 | 0.164 | -0.036 | 0.039 | -0.046 | -0.129 | 0.026 | 1   |     |    |    |     |     |
| DS | .846* | 0.15 | 0.544 | 0.672 | -0.694 | 0.148 | -0.095 | -0.083 | -0.151 | -0.155 | 0.006 | .991** | 1   |     |    |     |     |
| ASI | .838* | 0.141 | .778* | 0.468 | -0.688 | 0.052 | -0.204 | -0.488 | -0.437* | -0.213 | 0.108 | .795* | .869** | 1   |     |    |     |
| LBE | .904* | -0.105 | 0.693 | 0.654 | -0.098 | 0.146 | -0.156 | -0.317 | -0.111 | -0.318 | 0.165 | 0.529 | 0.574 | 0.712* | 1   |     |    |     |
| LAE | -0.086 | 0.55 | -0.532 | 0.38 | 0.192 | 0.118 | 0.309 | .829* | 0.633 | 0.108 | 0.262 | 0.173 | 0.04 | -0.447 | 0.262 | 1   |     |    |     |

Anthesis silking interval (ASI), days to 50% tasseling (DT), days to 50% silking (DS), Shoot dry matter (SDM), leaf dry matter (LDM), leaves below the ear (LBE), leaves above the ear (LAE), cob placement height (CPH), Leaf area duration (LAD) and Average growth rate (AGR)
The biplot was constructed based on the first two PCs and previously Vijayakumar et al., (2020) constructed a PC biplot with a similar method. In the present study S157, S322 and D164 had performed well and located in the first quadrant, and the least performed S38, D435 located in the third quadrant. Inbreds located in the first quadrant (labelled in roman) performed well compare to the other quadrants. Inbreds located in the third quadrant (labelled in italic) performed least compare to the other quadrants. Both PCs had negative scores (Tamilselvi et al., 2015). The total number of kernels, cob girth, LAE, AGR, and LDM had a positive association with S157, S322, and D164. ASI and SDM had a negative association with these inbreds. The total number of kernels, cob girth, LAE, AGR, and LDM had a negative association with S38 and D435. ASI and SDM had a positive association with the inbreds. Variables positioned opposite sides of the plot in diagonally opposite quadrants are said to be negatively correlated. Two variables positioned in the same quadrant were positively correlated. Variables positioned near to the origin had a lower loading factor which had less contribution towards diversity. Variables away from the origin had a higher loading factor which had more contribution towards diversity (Vijayakumar et al., 2020).

**CONCLUSION**

The present study conferred that the diversity among inbreds with different canopy structures was existing for various morpho-physiological traits. The genotypes with more PAR distribution had a positive association with yield-related traits. This variation could be used to develop the perfect ideotypes with high yielding potential. Leaf dry matter has more correlation with the yield attributes than the shoot dry matter. Leaves above the ear had a positive association with yield attributes than the leaves below the ear. The best performing genotypes (S157, S322) and least performing genotypes (D435, S38) for the given variables were determined by using PCA. This will be useful in eradicating the duplicated genotypes thereby conserving and increasing the diversity in maize breeding programs. The selected inbreds could further be utilized for developing new varieties in maize breeding plans.

**REFERENCES**

Awal, M. A., Koshi, H., & Ikeda, T. 2006. Radiation interception and use by maize/peanut intercrop canopy. *Agricultural and forest meteorology*, 139(1-2), 74-83.

Edmeades, G. O., Fischer, K. S., & Islam, T. M. T. 1986. *Improvement of maize yield under drought stress* (No. CIS-943. CIMMYT).

Gao, Y., Duan, A., Qiu, X., Sun, J., Zhang, J., Liu, H., & Wang, H. 2010. Distribution and use efficiency of photosynthetically active radiation in strip intercropping of maize and soybean. *Agronomy journal*, 102(4), 1149-1157.

Hallauer, A. R., Russell, W. A., & Lamkey, K. R. 1988. Corn breeding. *Corn and corn improvement*, 18, 463-564.

Iqbal, J., Shinwari, Z. K., & Rabbani, M. A. 2014. Investigation of total seed storage proteins of Pakistani and Japanese maize (*Zea mays L.*) through SDS-PAGE markers. *Pakistan Journal of Botany*, 46(3), 817-822.

Iqbal, J., Shinwari, Z. K., & Rabbani, M. A. 2015. Maize (*Zea mays L.*) germplasm agro-morphological characterization based on descriptive, cluster and principal component analysis. *Pak J Bot*, 47, 255-264.

Kefu, z. 1981. Effect of the leaves of different positions in maize on the corn yield and the photosynthetic properties of those leaves after the growing out of the female flowers [j]. *Acta agronomica sinica*, 4(005).

Knoema, 2020. Maize Production Quantity. Retrieved from https://knoema.com/atlas/topics/Agriculture/Crops-Production-Quantity-tonnes/Maize-production (Accessed on 11.03. 2021).

Liu, T., Song, F., Liu, S., & Zhu, X. 2011. Canopy structure, light interception, and photosynthetic characteristics under different narrow-wide planting patterns in maize at silking stage. *Spanish Journal of Agricultural Research*, (4), 1249-1261.

Machado, S., Bynum, E. D., Archer, T. L., Lascano, R. J., Wilson, L. T., Bordovsky, J., & Xu, W. 2002. Spatial and temporal variability of corn growth and grain yield: Implications for site-specific farming. *Crop Science*, 42(5), 1564-1576.

Paul, V., Pandey, R., & Anand, A. 2017. Manual of ICAR Sponsored Training Programme for Technical Staff of ICAR Institutes on Physiological Techniques to Analyze the Impact of Climate Change on Crop Plants. *ICAR-Indian Agricultural Research Institute (IARI)*.

Pepper, G. E., Pearce, R. B., & Mock, J. J. 1977. Leaf orientation and yield of maize 1. *Crop Science*, 17(6), 883-886.

Sali, A. L. I. U., Rusinovici, I., Fetahu, S., & Bisilimi, K. 2013. Morpho-physiological Traits and Mineral Composition on Local Maize Population Growing in Agro Ecological Conditions in Kosova. *Notulae Scientia Biologicae*, 5(2), 232-237.

Shrestha, J. 2013. Agro-morphological characterization of maize inbred lines. *Wudpecker Journal of Agricultural Research*, 2(7), 209-211.

Shrestha, J. 2014. Morphological variation in maize inbred lines. *International Journal of Environment*, 3(2), 98-107.

Tamilselvi, S. M., Chinnadurai, C., Ilamurugu, K., Arulmozhiselvan, K., & Balachandar, D. 2015. Effect of long-term nutrient managements on biological and
biochemical properties of semi-arid tropical Alfisol during maize crop development stages. *Ecological Indicators*, 48, 76-87.

Tang, L., Ma, W., Noor, M. A., Li, L., Hou, H., Zhang, X., & Zhao, M. 2018. Density resistance evaluation of maize varieties through new “Density–Yield Model” and quantification of varietal response to gradual planting density pressure. *Scientific reports*, 8(1), 1-16.

Vijayakumar, E., Thangaraj, K., Kalaimagal, T., Vanniarajan, C., Senthil, N., & Jeyakumar, P. 2020. Multivariate analysis of 102 Indian cowpea (Vigna unguiculata (L.) Walp.) germplasm. *Electronic Journal of Plant Breeding*, 11(01), 176-183.

Walle, T., Mekbib, F., Amsalu, B., & Gedil, M. 2019. Genetic diversity of Ethiopian cowpea [Vigna unguiculata (L) Walp] genotypes using multivariate analyses. *Ethiopian Journal of Agricultural Sciences*, 29(3), 89-104.