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RESEARCH PAPER

# Genetic diversity and association analysis for different morphological traits in *Capsicum annuum* L.

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## Abstract

*Capsicum annuum* L. is the extensively cultivated species of peppers (chilies) in all over the world. Its fruits are used for spiciness (capsaicin) and color (capsanthin) in our daily foods. Pakistan is the leading chili consuming country. Genetic divergence among 25 accessions (local and exotic) collected from Ayub Agriculture Research Institute (AARI) Faisalabad, Pakistanwas estimated from the data collected during the year 2014 in the *Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan* for different morphological and growth parameters viz fruit width, fruit length, peduncle length, number of primary branches, inter nodal length, plant height, seed index, 1000 seed weight, fresh and dry fruit weight, pericarp thickness, leaf area and seeds per fruit. Based on this characterization the plants were grouped into 5 clusters and diversity among accessions was indicated by the wide range of $D^2$ values whereas phenotypic correlation for all the characters was found significant. Five components were selected as principle components with Eigen values > 1. These components exhibited 77.2% of the variation. The first principal component (PC I) explained 27.2% of total variation in original data, second component (PC II) explained 18.9%, and third principal component (PC III) explained 12.5% of variation. The other principal components (PC IV and PC V explained an additional 18.6% of the variation (a total 77.2% of explained variation. Accessions with distinct identity were marked, which are likely to be quite suitable for breeding through hybridization by combining desirable traits. High estimates of broad sense heritability (90%) for all the characters except peduncle length predicted that selection could be awarding in late segregating generations and above accessions could be utilized in hybridization programme for *C. annuum* crop improvement.

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## Introduction

Pepper (*Capsicum spp.*) is a complex of species originating from the inter-tropical America. The *Capsicum* genus belongs to the Solanaceae family and includes 27 recognized species (Baral and Bosland, 2002). Hot pepper are grown and used for vegetable, spice, condiment, paste, pickle and medicinal purpose. Capsicum (pepper) constitutes the most important spice is grown all over the world except in colder regions. Peppers with greater pungency are cultivated in tropical states; viz. Pakistan, India, China, Nigeria, Malaysia, Japan and Turkey. Total world green pepper production is 7 to 8 million tones and 2 to 3 million tons in dry form. It is a good source of ascorbic acid, vitamin A, E and chili oleoresin. Chilies are popular for the abundant content of vitamin C (Ascorbic acid) larger than other vegetables and fruits (Durust *et al.,* 1997; Osunagarcia *et al.,* 1998).

Pepper was familiarized to Europe by Columbus in 15th century and expanded to rest of the globe. Pepper (*Capsicum annuum* L.) is the second biggest product in the international trade after black pepper (*Piper nigrum* L.) (Anonymous, 2012). The genus capsicum is often cross pollinated crop and natural cross pollination may go up to 50% depending upon the extent of style exertion, time of dehiscence of anthers, wind direction and insect population (Murthy and Murthy, 1962 and Hosmani, 1993). The pungency of chilies is due to capsaicin which is an alkaloid present in placenta of chili fruit (Reddy and Lokesh, 1992; Kogurea *et al.,* 2002; Bhattacharya *et al.,* 2010).

*Capsicum annum L.* is broadly cultivated species due to variable in shape, size, color, pungency and texture (Russo and Biles, 2004). In Pakistan the area under chilies has reduced from 84.5 to 74.8 thousand hectares but production has increased from 174.6 to 188.9 thousand tones (Govt. of Pakistan, 2013). Sindh is the major pepper growing province with mean area of 55.3 thousand hectares and production of 122.9 thousand tons (Khokhar, 2010). Chilies are substantial vegetable crop of tropical, subtropical and temperate climate of the world (Hazra *et al.,* 2011).

A wide range of variability has been reported in the pepper crop (Sreelathakumary and Rajamony, 2004). Genetic difference is basic requirement for real selection within population and population arising out of hybridization. Genetic resources play an important role for desirable traits improvement. Genetic differences help to select the better parents for breeding program (Singh and Choudry, 1985). The importance of genetic diversity in the crop improvement has been studied in both self and cross pollinated crops (Griffing and Lindstrom, 1954; Murthy and Anand, 1966; Gaur *et al.,* 1978).

Genetic diversity is an importance tool to know about desirable genes within the germplasm (Tomooka, 1991). For most cultivated species, the loss of genetic variability started as soon as the domestication process, and may have been worsened with migration events from original to secondary diversification sites depending on the history of plant species exploitation (Tang *et al.*, 2010).Multivariate analysis is used for the assessment of degree of variability and contribution of various characters to total variability in self-pollinated crops (Das and Gupta, 1984; Natarajan *et al.,* 1988; Golakia and Maken, 1992; Sindhu *et al.,* 1992). Yatung *et al* (2014) assessed the genetic variability of thirty hot pepper entries observed abundant diversity for different morphological characters. Cluster analysis grouped thirty accessions into six clusters, highest number of genotypes were present in cluster three (14) and lowest in cluster four and five. Inter cluster distance between two and four clusters was maximum (459.8) and minimum in one and four cluster (36.04). Maximum intra cluster was found in cluster three ($D^2$=67.66) and minimum in cluster two ($D^2$=11.19). Chattopadhyay *et al.* (2011) observed extreme variability present among the cultivars/landraces for shape, size, yield, quality, and other characters existing in India germplam and concluded 'Chaitali Pointed' and 'BC CH Sel-4' most promising genotypes with respect to green fruit yield (272.79 g, 221.10 g per plant) and dry fruit yield (54.56 g, 44.44 g per plant). Phenotypic and genotypic Coefficient of Variation values for green fruit weight (119.95%, 111.26%), green fruit girth (89.76%, 48.93%), weight of red ripe fruit (112.02%, 111.93%), weight of dry fruit (111.63%, 110.97%) and number of fruits per plant (86.05%, 85.02%). Dutonde *et al.* (2008) studied the genetic diversity of forty accessions of hot pepper through cluster analysis. The genotypes were grouped into seven clusters, each cluster containing different accessions of hot pepper. Cluster four and seven showed highest inter cluster distance ($D^2$104.98). Cluster two, four and seven was used to develop high yielding varieties with desirable characters through crossing among genotypes belonging to these clusters. Del *et al.* (2007) estimated the morphological and phenotypic variation of both vegetative and reproductive features of hot pepper (*Capsicum annuum* L.) by following Principles Components Analysis (PCA) and analyzed hierarchical conglomeration (AHC). Ample variability was found in entries for length of limb, diameter of the limb, shape and color of leaf, fruit calyx and days to flowering and fructification. Manju and Sreelathakumary (2004) grouped 32 accessions of hot pepper into 6 clusters showing maximum intra cluster distance in clusters 1 because 21 genotypes were present in this cluster. Karad *et al.* (2002) grouped 40 genotype of pepper (indigenous and exotic) into 8 cluster and their $D^2$ values ranged 0.1032 to 8.7702. The maximum inter cluster distance between cluster II and V was (7.45) and minimum inter cluster distance was between cluster III and VII (1.15). The objective the present study was to evaluate the existing chili germplasm for genetic diversity and correlation among the plant growth traits because capsicum is known to have relatively low levels of genetic diversity. A better understanding of variation and relationships among possible sources of novel genes would be valuable because it provides valuable information for future breeding programs to develop high yielding varieties.

## Materials and methods

Genetic divergence among twenty-five genotypes (local and exotic) of chilies (*Capsicum annuum* L.) was found. The germplasm was collected from Ayub Agriculture Research Institute (AARI) Faisalabad, Pakistan. Seeds were sown in peat trays to establish nursery and at four true leaf stage seedlings were transplanted in the field keeping 50 cm row-to-row and 30 cm plant-to-plant distance. Experiment was performed following randomized complete block design (RCBD) with two replications. All the plant protection measures, fertilizers and other management practices were applied as per package. At maturity data was collected for different morphological and yield contributing traits during the year 2014 in *Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan.* Five plants were selected in each replication that were tagged and the mean data were used for statistical analysis. Analysis of variance, cluster analysis based on Tocher's method using squared Euclidean distance (Kumar *et al.*, 2012) was performed using the statistical software Indo-stat and statistical package for agricultural research (SPAR) version 2.0 programme. The genetic divergence was calculated according to Mahalanobis $D^2$ statistics (1936).

**Table 1.** Name of genotype and code.

| Genotypes code | Genotypes name |
|---|---|
| HP-1 | Main levara |
| HP-2 | Main C-9-2012 |
| HP-3 | Main UK–1- 2012 |
| HP-4 | Main 37-1-2012 |
| HP-5 | 32-1-2012 |
| HP-6 | 9-1-2012 |
| HP-7 | N-2012 |
| HP-8 | I-9 Dolinward |
| HP-9 | C-217 |
| HP-10 | S-32-2012 |
| HP-11 | Golden prize |
| HP-12 | 32-2-2012 |
| HP-13 | C-9 -2012 |
| HP-14 | C-9 -2012 |
| HP-15 | S-5 2012 |
| HP-16 | 2-29 Ikram1 |
| HP-17 | Main 1-26 |
| HP-18 | 39-1-2012 |
| HP-19 | S-120 |
| HP-20 | 8-35 Ikram 2 |
| HP-21 | 6-33 Ikram 3 |
| HP-22 | 4-31 Ikram 4 |
| HP-23 | 30-3 Ikram -5 |
| HP-24 | 9-46 Ikram 6 |
| HP-25 | 5-64-2012 |

*Statistical Analysis*

Five plants per plot were selected and the mean data points were used for statistical analysis. Analysis of variance (Steel *et al.,* 1997), cluster analysis based on Tocher's method using squared Euclidean distance (Kumar *et al.*, 2012) was performed using the statistical software Indo-stat and statistical package for agricultural research (SPAR) version 2.0 programme. The genetic divergence was calculated according to Mahalanobis $D^2$ statistics (1936).

## Results and discussion

Phenotypic and genotypic variances observed in all the pepper genotypes for all the characters were significantly different and all the genotypes showed similar behavior towards genotypic and phenotypic coefficient of variation. Heritability estimates of all the characters observed were high (90%) coupled with high values of genetic advance indicating the possibility of improvement through heterosis breeding. Similar findings were observed in the previous studies (Mini and Khader, 2004; Nandadevi and Hosamani, 2003; Das and Maurya, 2004; Rajamony, 2004).

**Table 2.** Genetic variability, heritability and genetic advance.

| Variable | $V_G$ | $V_P$ | $h^2_{bs}$ (%) | GCV | PCV | GA | GA% |
|---|---|---|---|---|---|---|---|
| FW | 17.4881 | 17.5151 | 99.85 | 0.350 | 0.351 | 8.608 | 72.100 |
| FL | 3.8196 | 3.8430 | 99.39 | 0.234 | 0.235 | 4.014 | 48.084 |
| PL | 0.0982 | 0.1068 | 91.92 | 0.171 | 0.178 | 0.619 | 33.705 |
| PB | 1.8472 | 2.3270 | 79.38 | 0.243 | 0.272 | 2.494 | 44.523 |
| INL | 0.9101 | 0.9182 | 99.11 | 0.148 | 0.149 | 1.956 | 30.394 |
| PH | 200.7022 | 201.7315 | 99.49 | 0.212 | 0.212 | 29.109 | 43.511 |
| SI | 1.9471 | 1.9544 | 99.63 | 0.316 | 0.316 | 2.869 | 64.918 |
| FRFW | 4.9512 | 4.9531 | 99.96 | 0.600 | 0.600 | 4.583 | 123.570 |
| DRFW | 0.1273 | 0.1328 | 95.87 | 0.289 | 0.295 | 0.720 | 58.322 |
| PT | 0.1679 | 0.1693 | 99.19 | 0.322 | 0.323 | 0.841 | 65.993 |
| LA | 84.5479 | 84.7151 | 99.80 | 0.333 | 0.333 | 18.922 | 68.428 |
| SPF | 280.9289 | 282.1204 | 99.58 | 0.218 | 0.219 | 34.455 | 44.825 |

Five components were selected as principle components with Eigen values > 1. These components exhibited 77.2% of the variation. The first principal component (PC 1) explained 27.2% of total variation in original data, second component (PC 2) explained 18.9%, and third principal component (PC 3) explained 12.5% of variation. The other principal components (PC 4 and PC 12) explained an additional 18.6% of the variation (a total 77.2% of explained variation, Table 2). The %age of variance explained by the 5 components and the correlation between the PC and the original morphological characteristics of the pepper genotypes are shown in Table 2. The 77.2% total variability obtained in PCA showed a moderate percentage of variation (Pla, 1986).

**Table 3.** Eigen values and proportion of variance explained by the 5 principal components with respect to 25 pepper genotypes.

| | PC Axis | | | | |
|---|---|---|---|---|---|
| | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 |
| Eigen value | 3.5396 | 2.4557 | 1.6268 | 1.3316 | 1.0773 |
| Explained proportion of variation (%) | 0.272 | 0.189 | 0.125 | 0.102 | 0.083 |
| Cumulative proportion of variation (%) | 0.272 | 0.461 | 0.586 | 0.689 | 0.772 |

** PC (Principal component).

The PC 1 contributed by positive loading of FW, INL, PH, FRFW, DRFW, PT, and Y, followed by negative and minor loading of PL, SI and FL, PB, LA and SPF (Table 2). The PC 2 contributed by positive loading of FW. The PC 3 contributed by positive loading for SI and DRFW followed by negative and minor loading of FW, PL, PB, PT and Y (Table 2). FCSC and FL have been previously reported as significant contributors to the main principal component in morphological characterization of *C. annuum* for the PC 1 (Latournerie *et al.*, 2002; Castanon-Najera *et al.*, 2008). It showed that fruit morphological variables are the principal contributors of the variation in shape of fruit of *C. annuum* L. (Pardey *et al.*, 2006; Moscone *et al.*, 2007; Castanon-Najera *et al.*, 2010).

Data regarding cluster analysis is presented in fig.1. Based on the D² value 25 genotypes were grouped into five clusters. The results showed that Cluster I comprised of 7 genotypes i.e HP-1, HP-15, HP-8, HP-24, HP-18, HP-7 and HP-5. Cluster II also comprised of 7 genotypes i.e. HP-13, HP-23, HP-22, HP-20, HP-19, HP-21 and HP-25. Cluster III comprised of 3 genotypes i.e. HP-2, HP-9 and HP-14. Cluster IV comprised of 5 genotypes which are HP-3, HP-12, HP-16, HP-11 and HP-17. Cluster V comprised of 3 genotypes i.e. HP-4, HP-6 and HP-10. The clustering pattern showed that genotypes were associated with each other and geographical distribution for the formation of cluster in genetic divergence. Similar findings were also reported by Sreelathakumary (2004) and Indra *et al.* (2000).

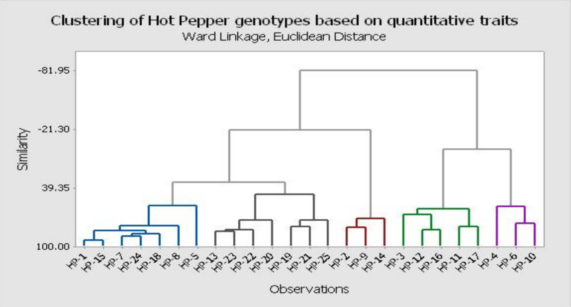

**Fig. 1.** Clusters of pepper genotypes.

**Table 4.** Average inter and intra cluster distances of 25 pepper genotypes.

| | Cluster I | Cluster II | Cluster III | Cluster IV | Cluster V |
|---|---|---|---|---|---|
| Cluster I | 0.0000 | 25.3614 | 26.3753 | 38.3771 | 16.0230 |
| Cluster II | 25.3614 | 0.0000 | 38.4115 | 59.2612 | 39.5281 |
| Cluster III | 26.3753 | 38.4115 | 0.0000 | 36.0652 | 36.0656 |
| Cluster IV | 38.3771 | 59.2612 | 36.0652 | 0.0000 | 36.4439 |
| Cluster V | 16.0230 | 39.5281 | 36.0656 | 36.4439 | 0.0000 |

The data on intra and inter cluster distance have been presented in table 3. Among the different clusters maximum inter Cluster distance (59.2612) was observed in between Cluster II and Cluster IV followed by 39.5281 in Cluster V and Cluster II. Minimum inter cluster distance (16.0230) was observed in Cluster V and Cluster I. Clusters with large inter cluster distance showed that the genotypes included in these clusters have the greater diversity and hence the crossings between the genotypes in these clusters are expected to give desirable combinations. The level of variation found in present genotypes shows high potential for developing pepper genotypes for different desired morphological traits. The results are in line with those of Zewedie and Zeven (1997) who reported variation among hot pepper accessions.

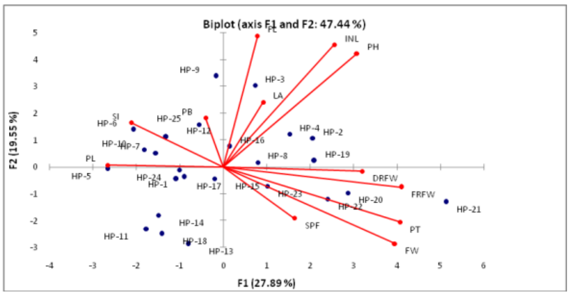

**Fig. 2.** Bi-plot distribution of traits.

Biplot results showed that 25 genotypes of chili are scattered in four quadrants. Each quadrant showed association of genotypes with different characters.

Quadrant 1 showed that HP-12 has strong association with no. of primary branches and HP-6 correlates with seed index, HP-10 and HP-7 are strongly correlated with peduncle length and seed index. In quadrant 2, HP-3 correlates with fruit length and leaf area index whereas HP-16, HP-4, HP-2, HP-8 andHP-19 are correlated with plant height and internodal distance. Similarly in quadrant 3, HP-15 and HP-23 are strongly correlated with seed per fruit and fruit weight. Genotypes HP-22 and HP-20 have good characters like pericarp thickness, dry and fresh fruit weights whereas genotypesHP-21, HP-24, HP-1, HP-17, HP-14, HP-18, HP-11 and HP-5 can be excluded as these have no significance favorable characteristics for crop improvement program.

**Table. 5.**Correlation Matrix among 12 Traits of Hot Pepper.

| | DRFW | FL | FRFW | FW | INL | LA | PB | PH | PL | PT | SI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FL | 0.0665* | | | | | | | | | | |
| FRFW | 0.7499** | -0.0277 | | | | | | | | | |
| FW | 0.3865* | -0.227* | 0.6092** | | | | | | | | |
| INL | 0.1699 | 0.6353** | 0.2232 | 0.124 | | | | | | | |
| LA | 0.0283 | 0.0376* | 0.1524 | -0.0848* | 0.2294 | | | | | | |
| PB | -0.0488 | -0.0091 | -0.0956 | -0.1545 | -0.0887* | 0.1082 | | | | | |
| PH | 0.1909 | 0.5435** | 0.2982 | 0.138 | 0.7551** | 0.3764 | 0.2243 | | | | |
| PL | -0.3262 | -0.131 | -0.2748 | -0.202 | 0.1097* | -0.027 | 0.2062 | -0.2495 | | | |
| PT | 0.2802 | -0.1861 | 0.4614 | 0.7358** | 0.2058 | 0.0547 | -0.0671 | 0.2521 | -0.4106 | | |
| SI | 0.1148 | 0.0664 | -0.165 | -0.4429* | -0.0054 | 0.0683 | -0.2902 | -0.1205 | 0.1192 | -0.5246** | |
| SPF | 0.0139 | -0.0879 | 0.1299 | 0.3227 | -0.0497 | -0.0594 | -0.3653 | 0.1759 | -0.0584 | 0.2516 | -0.1801 |

1. FW = Fruit width
2. FL = Fruit Length
3. PL = Peduncle Length
4. PH = Plant height
5.PB = No. of primary branches
6. INL = Inter nodal length
7. SI = Seed Index
8. FRFW = Fresh red fruit weight
9. DRFW = Dry red fruit weight
10. PT = Pericarp thickness
11. LA = Leaf area
12. SPF = Seeds per fruit

Fruit width has significant positive correlation with dry red fruit weight and highly significant positive correlation with fresh red fruit weight.Highly significant correlation was found between fruit length and dry red fruit weight. Peduncle length has significant correlation with inter nodal length similar results were shown in the previous studies (Kumar *et al.,* 2012 and Sreelathakumary *et al.,* 2002). Number of primary branches has significant negative correlation with intermodal length also found by Prabhakaran *et al.,* 2004.Inter nodal length have positive and significant correlation with fruit length (Choudhury *et al.,* 2004).Plant height has significant positive correlation with fruit length and inter nodal length as found by Bhagyalakshmi *et al.* 1990.Seed index have positive significant correlation with fruit width and negative significant correlation with pericarp thickness (Rathod *et al.*, 2002).

Fresh red fruit weight has highly significant correlation with dry red fruit weight also found in previous research (Acharyya *et al.*, 2003). Pericarp thickness has significant positive correlation with fresh red fruit weight and fruit width (Devi *et al.*, 1999). Leaf area has significant correlation with fruit length and fruit width as concluded by Munshi *et al.* 2000 and Acharyya *et al.* 2003.Seed per fruit have significant negative correlation with PB similar to Chattopadhyay *et al.,* 2011 findings.

## Conclusion

It can be concluded that there is abundant variation among the genotypes for most of the characters studied. So, these germplasm may be utilized for future breeding program. Moreover, selection may be effective and rewarding based on those characters having high heritability along with higher genetic advance indicating additive gene effect.

This study may be helpful in selecting superior genotypes for development of varieties with favorable traits.

## References

**Acharya P, Rajput CBS.** 2003. Variability and correlation studies for different traits in Capsicum with respect to leaf curl complex. Indian Journal of Horticulture **60(4)**, 381-387.

**Baral JB, Bosland P**. 2002. An updated synthesis of the *Capsicum* genus. Capsicum and Eggplant News **21,** 11–21.

**Bhagyalakshmi PV, Ravi Shankar C, Subramanyam D, Ganeshbabu V**. 1990. Study on heritability, genetic advance and character association in chilli (*C. annuum*L). South Indian Journal of Horticulture **38 (1)**, 15-17. 136.

**Bhattacharya A, Chattopadhyay A, Mazumdar D, Chakravarty A, Pal S**. 2010. Antioxidant constituents and enzyme activities in chilli peppers. International Journal of Vegetable Sciences **16(3)**, 201-211.

**Castanon-Najera G, Latournerie-Moreno L, Lesher-Gordillo JM, de la Cruz-Lázaro E, Mendoza-Elos M**. 2010. Identificacion de variables para caracterizar morfológica mentecolectas de chile (Capsicum spp.) en Tabasco, Mexico. Universidad Ciencia **26,** 225-234.

**Castanon-Najera G, Latournerie-Moreno L, Mendoza-Elos M, Vargas-Lopez A, Cardenas-Morales H**. 2008. Coleccion caracterizacion de chile (Capsicum spp.) en Tabasco, México. Phyton. International Journal of Experimental Botany 77, 189-202.

**Chattopadhyay A, Sharangi AB, Dai N, Dutta S**. 2011. Diversity of genetic resources and genetic association analyses of green and dry chillies of eastern India. Chilean Journal of Agricultural Research **71(3)**, 350-356.

**Choudhury BS, Samadia DK**. 2004. Variability and character association in chilli land races and genotypes under arid environment. Indian Journal of Horticulture **61 (2),** 132-136.

**Das PK, Gupta TD**. 1984. Multivariate analysis in Blackgram. Indian Journal of Genetics and Plant Breeding **(2)**, 243-247.

**Del E, Perez CM, Alvarez Arrazate OCA, Damian MATM, Lomeli AP.** 2007. Morphological variation in Guajillo chilli pepper plants (*Capsicum annuum* L.). African Crop Science Conference Proceeding **(8)**, 327-332.

**Devi DS, Arumugam R, Devi DS**. 1999. Correlation and path coefficient analysis in chilli (*C. annuum* L). Crop Research **17(1),** 90-93.

**Durust N, Sumengen D, Durust Y.** 1997. Ascorbic acid and element contents of Trabzon (Turkey). Journal of Agriculture and Food Chemistry **45,** 2085-2087.

**Dutonde SN, Bhalekar MN, Patil BT, Kshrsagar DB, Dhumal SS.** 2008. Genetic diversity in chilli (*Capsicum annuum* L.). Agriculture Science Digest **(1)**, 45-47.

**Gaur PC, Gupta PK, Kishore H**. 1978. Studies on genetic divergence in potato. Euphytica **27**,361-368.

**Golakia PR, Makne VG**. 1992. $D^2$ analysis in Virginia runner groundnut genotypes. Indian Journal of Genetics and Plant Breeding **55(3)**, 252-256.

**Griffing B, Lindstorm EW**. 1954. A study of combining abilities of corn in breds having varying proportions of Corn Belt and non-Corn Belt germplasm. Agronomy Journal **46,** 545-552.

**Hazra P, Chattopadhyay A, Karmakar K, Dutta S**. 2011. Modern technology in vegetable production. 478. New India Publishing Agency, New Delhi, India.

**Hosmani MM**. 1993. Chilli Crop (*Capsicum annuum*), Bharat Photo Offset Works, Dharwad, Karnataka, India.

**Indra P, Peter KV, Unnithan VKG**. 2000. Divergence in pepper. Spice India **13(4),** 15-20.

**Kumar D, Bahadur V, Rangare SB, Singh D**. 2012. Genetic variability, heritability and correlation studies in chilli (*Capsicum annuum* L.). Horticulture Flora Research Spectrum **1(3)**, 248-252.

**Latournerie ML, Chavez J, Perez M, Castanon G, Rodriguez SA, Arias LM, Ramirez P**. 2002. Valoracion in situ de la diversidadmorfologica de chiles (*Capsicum annuum* L. *Capsicum Chinense* Jacq.) En Yaxcaba, Yucatán. Revista Fitotecnia Mexicana **25,** 25-33.

**Mahalanobis PC.** 1936. On the generalized distance in Statistics. Proceedings of the National Institute of Sciences of India **2,** 49-55.

**Manju PR, Sreelathakumary**. 2004. Genetic divergence in hot chilli. Capsicum and Egg Plant Newsletter **23**, 69-72.

**Moscone EA, Scaldaferro MA, Grabiele M, Cecchini NM, Sanchez GY, Jarret RD**. 2007. The evolution of pepper (*Capsicum-Solanaceae*): a cytogenetic perspective. VI International Solanaceae Conference: Genomics Meets Biodiversity. Acta Horticulturae **745**, 137-170.

**Munshi AD, Behra TK, Singh G**. 2000. Correlation and path coefficient analysis in chilli. Indian Journal of Horticulture **57(2),** 157-159.

**Murthy B, Anand IJ**. 1966. Combining ability and genetic diversity in some varieties of *Linnum usitatissimum*. Indian Journal of Genetics and Plant Breeding **26,** 21-36.

**Murthy NSR, Murthy BS**. 1962. Inheritance studies on chili (*Capsicum annuum*). Andhra Pradesh Agriculture Journal **9,** 140-144.

**Natarajan C, Thiyagarajan K, Rathanaswamy R**. 1988. Association and genetic diversity studies in Green grarn. Madras Agriculture Journal **75(7-8)**, 238-245.

**Osunagarcia JA, Wall MM, Waddell CA**. 1998. Endogenous levels of Tocopherols and Ascorbic acid during Fruit ripening of New Mexican-Type Chile (*Capsicum annuum* L.) cultivars. Journal of Agriculture and Food Chemistry **46(12)**, 5093-5096.

**Pardey RC, García DMA, Vallejo CFA.** 2006. Caracterizacionmorfologica de cienintroducciones de Capsicum del banco de germoplasma de la Universidad Nacional de Colombia, sede Palmira. Acta Agronomica **55**, 1-8.

**Pla E.** 1986. Analisismultivariado: Metodo de components principales. 94 p. Secretaria General de la Organizacion de los Estados Americanos, Washington, DC, USA.

**Prabhakaran TS, Natarajan S, Veeragavatham D**. 2004. Studies on genetic variability, heritability and genetic advance in chilli (*Capsicum annuum* L.). South Indian Horticulture **52(1-6)**, 70-72.

**Rathod RP, Dashmukh DT, Sable NH, Rathod NG.** 2002. Genetic variability studies in chilli. Journal of Soils and Crops **12(2),** 210-212.

**Reddy ACP, Lokesh BR**. 1992. Changes in catalase and ascorbic acid oxidase activity in response to lead nitrate treatments. Indian Journal of Plant Physiology **34,** 143-146.

**Russo VM, Biles CL**. 2004. Fertilizer rate and galactosidase and peroxidase activity in pepper fruit at different stages and years of harvest. Plant Foods for Human Nutrition **58**, 231-239.

**Sindhu JS, Ahmed S, Singh MB, Singh KP.** 1992. Multivariate analysis in Blackgram (*Vigna mungo* L.). Legume Research **12(1)**, 35-37.

**Singh RK, Choudhary BD**. 1985. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi 318.

**Sreelathakumary I, Rajamony I**. 2002. Variability, heritability and correlation studies in chilli under shade. Indian Journal of Horticulture **59(1)**, 77-83.

**Sreelathakumary I, Rajamony L**. 2004. Variability, heritability and genetic advance in chilli (*Capsicum annuum* L.). Journal of Tropical Agriculture **42(1-2)**, 35-37.

**Steel RGD, Torrie JH, Dickey DA**. 1997. Principles and Procedures of Statistics: A biometrical approach. McGraw Hill Book Co., New York, USA.

**Tang H, Sezen U, Paterson AH**. 2010. Domestication and plant genomes. Current Opinion in Plant Biology **13,** 160–166.

**Yatung T, Dubey RK, Singh V, Upadhyay G**. 2014. Genetic diversity of chilli (*Capsicum annuum* L.) genotypes of India based on morpho-chemical traits. Australian Journal of Crop Sciences **(1)**, 97-102.

**Zewdie Y, Zeven AC**. 1997. Variation in Yugoslavian hot pepper (*Capsicum annuum* L.) accessions. Euphytica **97,** 81-89.