Intra and interspecific morphological variations of three species of *Capsicum* (Solanaceae)

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**ABSTRACT**

The widely cultivated pepper, *Capsicum* spp., important as a vegetable and spice crop worldwide, is one of the most diverse crops. Considerable morphological variation, especially in fruit shape, color, and size exist in the genus. The present study analysed the intra and interspecific morphological variations of three species of *Capsicum* (Solanaceae) using thirty nine morphological characters. Morphological variations with respect to vegetative, floral and fruit characteristics were observed among the members of the same species. Morphological data was used to obtain UPGMA derived dendrogram and the cluster analysis indicated genetic divergence among the three species. Present observations imply a great potential for chili breeding through a hybridization programme or direct use of the varieties for the successful production of promising cultivars.

**KEYWORDS:** *Capsicum*, Intra-specific, Morphology, Solanaceae

**INTRODUCTION**

The genus *Capsicum* belongs to the family Solanaceae (Nightshade) and is one of the most commonly used spices, condiments and vegetables across the world. It is also an important cash crop for small and marginal farmers in many developing countries across Asia (China, India, Pakistan, Bangladesh, Thailand and Indonesia) and Africa (Egypt, Ethiopia, Nigeria and Ghana) (Rai et al., 2013). India is the largest producer of dry chilli fruits, accounting for more than 43% of the world’s total dry chilli production (FAOSTAT, 2011).

Currently, 38 species of Capsicum are reported. Of these, five (*C. annuum*, *C. frutescens*, *C. chinense*, *C. pubescens*, and *C. baccatum*) are thought to have been domesticated through at least five independent events. These domesticates are believed to be derived from three distinct genetic lineages, with *C. pubescens* and *C. baccatum* each representing independent lineages while the domesticated taxa *C. annuum*, *C. frutescens* and *C. chinense* are considered members of a species complex that were each independently derived from wild progenitors that may or may not be independent species (Kothari et al., 2010; Hill et al., 2013). *Capsicum* species are diploids with most of them having 24 chromosomes (n=x=12), but species with a genome sizes of 2n=2x=32 and 2n=2x=48 also have been reported (Wang & Bosland, 2006; Dafadar et al., 2012). It is a self-pollinated dicot plant. However, the occurrence of cross pollination leads to the formation of variants within the species. It is probably introduced by the Portuguese into Southern parts of India and cultivation spread out throughout India by the end of 19th century. Due to the long history of cultivation, selection and popularity of crops sufficient genetic variability has been generated. A rich diversity of *Capsicum* exists due to the varied geoclimatic regions of the Indian continent. Rich variability in morphological traits in hot pepper occurs throughout India, particularly in southern peninsular region, North Eastern foot hills of the Himalayas and Gangetic plains (Bass & De, 2003; Pradheep & Veeraragavathatham, 2006). The Indian germplasm is mainly represented by two species, *C. annuum* and *Capsicum frutescens*, with a number of varieties cultivated throughout the country and cultivated mainly in southern states of India nearer to the tropics where the climate is very favorable for *C. annuum*.

Collection and maintenance of the genetic diversity in *Capsicum* are important to avoid genetic erosion. Besides the identification of species, the characterization and evaluation of genotypes maintained in gene banks are of fundamental importance (Sudre et al., 2010). Genetic cataloguing based on standard descriptors helps to easily describe the morphological features of a genotype and thus helps the exchange of information about new genotypes.
Characterization and evaluation of germplasm are prerequisite for the utilization of the available diversity in the chilli improvement programme. Desirable parental combinations provide the basis for selection in the follow up hybrid breeding process for the exploitation of heterosis (Thul et al., 2009). The desirable parental combination can be identified on the basis of cluster analysis. To initiate any breeding work, it is necessary to assess the genetic variability present in the indigenous genotypes (Datta & Das, 2013). Genetic resources play a pivotal role in its economical utilization and desirable traits improvements. Capsicum species are traditionally identified by morphological descriptors or related traits. Morphological descriptors are considered essential for a more accurate germplasm characterization, such as the ones indicated by the IPGRI et al. (1995). Characterization and evaluation of the domesticated species of Capsicum are particularly interesting for gene bank curators, since a wide variability, not yet fully known and exploited, is available in these species. Genetic diversity studies of chilli accessions from different countries have been reported earlier (Rai et al., 2013; Hill et al., 2013). Previous reports are available on the genetic variability of Capsicum from different regions of India including Kerala (Manju & Sreelathakumary, 2002; Sreelathakumary & Rajamony, 2004). Fruit morphological features in five varieties of C. annuum in order to evaluate the reliability of these characters and their relevance to the taxonomic consideration of the C. annuum varieties were reported earlier (Zhigla et al., 2014). Hence the present study was conducted with the objective to contribute additional information on the genetic variability of Capsicum landraces from the Thiruvananthapuram district of Kerala to help the ongoing crop improvement efforts.

MATERIALS AND METHODS

The plant materials used for the present study include ten Capsicum varieties viz., C. annuum, C. annuum (Guder), C. chinense, C. chinense (round), C. chinense (blue), C. chinense (Small), C. frutescens, C. frutescens (white), C. frutescens (small) and C. frutescens (large). The experiment was conducted in January-May 2013. Healthy seeds of ten varieties were collected from different localities of Thiruvananthapuram district, Kerala, India and were sowed in plastic bags of 20L containing sand soil and cow dung (1:1) as ten seeds per bag. Three replicas were maintained for each variety. Healthy seedlings were transferred to pots after two weeks and maintained well. Morphological data based on twenty six qualitative (Table 1) and thirteen quantitative traits (Table 2) were taken from ten plants of each variety. Quantitative traits viz., Number of Seeds, Internodal length, Leaf length, Petiole length, Leaf width and Pedicel length were measured using a centimeter scale and the results were expressed as mean ± Standard error. Vegetative characters were evaluated a hundred days after planting, and reproductive characters were evaluated after the flowering and fruiting stage. A total of thirty nine traits were assessed based on different descriptor states (IPGRI et al., 1995) and each descriptor state was numerically coded and the coded data were tabulated and compiled. The coded morphological data were used to assess intra and interspecific variations among the species by means of cluster analysis. Cluster analysis was performed on the basis of UPGMA derived dendrogram based on Euclidean distance measures using the software MVSP.

RESULTS AND DISCUSSION

Capsicum varieties analysed in the present study showed considerable variations in both vegetative and reproductive characters (Tables 3, 4, 5 & 6). Qualitative characters showed variation between species however quantitative characters differed among members of the same species. Erect plant habit was observed in most of the varieties studied. The stem was green in colour, quadrangular and short in most with a few exceptions. Capsicum chinense (blue) possessed a pubescent stem, bluish green leaves and bluish green sepals. Internodal length showed considerable variation from 2.92 ± 1.2545

| Table 1: List of qualitative characters used for the morphological characterization of ten Capsicum varieties |
|---|---|---|
| Sl. No. | Descriptor name | Descriptor state |
| 1 | Habit | 1- Erect 2- Intermediate 3- Erect branched |
| 2 | Plant growth habit | 1-light green 2-green 3- Dark green |
| 3 | Stem colour | 4-Yellow |
| 4 | Fruit shape | 1-Quadrangular 2-Round |
| 5 | Quad | 1-Short 2- Long |
| 6 | Pubescence | 0- Absent 1- Present |
| 7 | Leaf | 1- light green 2- green 3- Dark green |
| 8 | Leaf colour | 4-bluish green |
| 9 | Leaf shape | 1-Cordate 2- Long 3- Obtuse |
| 10 | Leaf surface | 1-Coriaceous |
| 11 | Pubescence | 0- Absent 1-Present |
| 12 | Inflorescence | 1-One 2-Two 3- Three or more |
| 13 | Number of flower axil | 4-Many flower in branches but each in individual axis |
| 14 | Pedicel position at anthesis | 1- Axillary 2-Terminal |
| 15 | Flower colour | 1- Green 2- Greenish blue |
| 16 | Calyx colour | 1- White 2- Yellow 3- yellow 4- greenish yellow 5- blue |
| 17 | Corolla colour | 1- Yellow 2- Yellow Green 3- Green 4- Greenish blue |
| 18 | Corolla throat colour | 1- Companulate |
| 19 | Androecium | 1- Blue 2- Green 3-Yellow |
| 20 | Filament colour | 1- Blue 2- Green 3- Bluish yellow 4- Blue green 5-Yellow |
| 21 | Anther colour | 1- Capitate 2- Simple 3- Bilfid |
| 22 | Gynoecium | 1- Blue 2- Green 3- Bluish yellow 4- Blue green 5-Yellow |
| 23 | Number of seeds | 1- Light green 2- Dark green 3- Green brown 4- Blue green 5-Yellow |
| 24 | Fruit colour at immature stage | 1- Dark green 2- Blue 3- Red 4- Brown |
| 25 | Fruit colour at mature stage | 1- Triangular 2- Elongate 3- Round |
| 26 | Fruit shape | 1- Rough 2- Smooth |
| 27 | Fruit surface | 1- Pulvinate 2- Lobate 3- Obtuse |
| 28 | Fruit shape at pedicel attachment | 1- Axillary 2- Nodes 3- Terminal 4- Terminal/Axillary |
| 29 | Seed colour | 1- White 2- Yellow |
| 30 | Seeds | 1- Round 2- Half circle |
(C. frutescens (large) to 9.79 ± 2.1849 (C. chinense (Small)). The leaf surface was coriaceous in all varieties. Leaf shape was long, cordate or obtuse. Colour of corolla ranged from white to blue. Corolla throat colour also showed variations with respect to different varieties. The shape of corolla was campanulate in most. Anther colour ranged from yellow to blue in varieties under study. Fruit colour at immature and mature stages, shape, fruit surface and fruit length showed variation among members of the same species. The shape at pedicel attachment was also different among members of C. chinense. Seed colour was white except in C. chinense (blue) in which bluish white seeds were observed. The seed shape was round except in C. annuum in which it was half circle. The number of seeds ranged from 12.4±0.7266 (C. frutescens (large)) to 88.4 ± 0.3765 (Capsicum chinense (blue)).

UPGMA derived dendrogram grouped the samples into two major clusters (Figure 1). Cluster I grouped C. chinense (round) C. chinense (blue) together. All the other samples were grouped in Cluster II. The second major cluster was further divided into two main clusters Cluster II A and Cluster II B. Cluster II A grouped all the frutescences samples together while Cluster II B grouped C. annuum and the rest of the C. chinense samples separately.

The Capsicum varieties analysed in the present study were highly variable with respect to morphological characters as reported earlier. Flower morphology, such as flower color, calyx constriction, and number of flowers per node, is among the mostly used taxonomic descriptors in identification studies of Capsicum. White-flowered species include the domesticated species C. annuum L., C. baccatum L., C. chinense Jacq., and C. frutescens L. Purple-flowered species include one domesticated (C. pubescens R. and P) and three undomesticated species (C. eximium A.T. Hunz, C. cardenasi Heiser & Smith, and C. tovarii Eshbaugh, Smith & Nickrent) (Thul et al., 2011). In the present study, C. frutescens corolla was yellow coloured and blue in C. chinense (blue). A clear difference was observed for different species in relation to the flower color in the earlier reports also (Thul et al., 2009).

In the present study, fruit characters seem to be more discriminating among accessions. The genus Capsicum (sweet and hot pepper) showed intra- and inter-specific diversity in fruit type, colour and shape as in the previous studies (Zhigila et al., 2014). Fruit shapes can be used for the classification of the varieties and cultivars of Capsicum annuum as reported earlier (Zhigila et al., 2014). Fruits form as the result of the development and differentiation of the gynoecium after fertilization. They are therefore the product of late morphological and structural modifications in the carpels. A considerable degree of divergence was reported at intergenetic stock (between genotypes), intercluster (between clusters), and intracharacter (within cluster) levels of diversification in C. annuum and other related species (Thul et al., 2011). Fruit diameter, number of fruits per plant, and leaf diameter played the greatest role in differentiation at intercluster and intergenotype level (Yatung et al., 2014).

Table 2: List of quantitative characters used for the morphological characterization of ten Capsicum varieties

| Sl. No. | Descriptor name               | Descriptor state |
|--------|-------------------------------|------------------|
| 1      | Plant height                  | < 25             |
|        |                               | 25-45            |
|        |                               | 46-65            |
|        |                               | 66 – 85          |
| 2      | Internodal length (cm)        | 4 – 6            |
|        |                               | 6-8              |
|        |                               | 8 – 10           |
| 3      | Length of petiole             | < 2.5            |
|        |                               | 2.5 – 5.5        |
|        |                               | 5.5 – 7.5        |
|        |                               | 7.5 – 8.5        |
| 4      | Leaf length (cm)              | < 6              |
|        |                               | 6.1-12>12        |
| 5      | Leaf width (cm)               | 1-5              |
|        |                               | 5.1-10           |
| 6      | Flower                        | 0.5-2            |
|        |                               | 2-4              |
| 7      | Number of Sepals              | 1.5              |
| 8      | Corolla length (cm)           | 1.3              |
|        |                               | 2.5              |
| 9      | Number of filaments           | 1.5              |
| 10     | Anther length (mm)            | 1.2              |
| 11     | Fruit length (cm)             | 1. < 2.9         |
|        |                               | 2.3.0–5.9        |
|        |                               | 3.6 – 8.9        |
| 12     | Fruit width (cm)              | 1. < 2.5         |
|        |                               | 2.2.5–5.5        |
|        |                               | 3.5 – 7.5        |
|        |                               | 4.7.5 – 8.5      |
| 13     | Number of Locules             | 1.2              |
|        |                               | 2.3              |
|        |                               | 3.4              |
| 14     | Number of seeds               | 1. 10 – 25       |
|        |                               | 2. 25-50         |
|        |                               | 3. 50-75         |
|        |                               | 4. 75-100        |

Table 3: Morphological characterization of three Capsicum species based on qualitative traits (Stem, Leaf)

| Species               | Plant habit | Height (cm) | Stem | Leaf |
|-----------------------|-------------|-------------|------|------|
|                       |             | Colour      | Shape | Colour | Shape | Surface | Pubescence |
| C. annuum             | Erect       | 40-60       | Light green | Quadrangular | Long | - | Dark green | Long | Coriaceous | - |
| C. annuum (Guder)     | Erect       | 50 – 60     | Green   | Quadrangular | Long | - | Green | Cordate | Coriaceous | - |
| C. chinense           | Erect       | 45 – 60     | Light green | Quadrangular | Long | - | Light green | Cordate | Coriaceous | - |
| C. chinense (blue)    | Erect       | 50 – 60     | Yellow  | Round     | Short | Pubescent | Bluish green | Obtuse | Coriaceous | Pubescent |
| C. chinense (round)   | Intermediate | 20-40     | Dark green | Round     | Short | - | Dark green | Long | Coriaceous | Pubescent |
| C. chinense (Small)   | Erect       | 45 – 60     | Light green | Quadrangular | Long | - | Light green | Cordate | Coriaceous | - |
| C. frutescens (large) | Erect       | 45 – 55     | Green   | Quadrangular | Short | - | Dark green | Cordate | Coriaceous | - |
| C. frutescens (white) | Erect branched | 45 – 50   | Green   | Quadrangular | Short | - | Dark green | Long | Coriaceous | - |
| C. frutescens (small) | Erect       | 20 – 30     | Green   | Quadrangular | Short | - | Dark green | Cordate | Coriaceous | - |
| C. frutescens (large) | Erect       | 20 – 50     | Green   | Quadrangular | Short | - | Dark green | Cordate | Coriaceous | - |
Table 4: Morphological characterization of three *Capsicum* species based on qualitative traits (Inflorescence, Calyx, Corolla, Androecium, Gynoecium)

| Species               | Inflorescence | Calyx | Corolla | Androecium | Gynoecium |
|-----------------------|---------------|-------|---------|------------|-----------|
|                       | No. of flowers per axil | Pedicel position at anthesis | No. of sepal(s) | Colour at throat | Shape | Length (cm) | No. of filaments | Colour at stigma | Length (cm) | Shape of stigma |
| *C. annuum*            | 1 – 2         | Axillary | Green  | 5           | White | Green | Campulate | 5 | Green | 2 | Capitate |
| *C. annuum* (Guder)    | 2-3           | Axillary | Green  | 5           | Yellow | Green | Campulate | 3 | Green | 2 | Capitate |
| *C. chinense*          | 2 – 3         | Terminal | Greenish blue | 5 | White | Green | Campulate | 5 | Blue | 2 | Simple |
| *C. chinense* (blue)   | 1 – 2         | Terminal | Green  | 5           | Yellow | Blue  | Greenish blue | Campulate | 5 | Dark green | 2 | Simple |
| *C. chinense* (round)  | 3 – 5         | Axillary | Green  | 5           | Yellow | green | Yellow | Campulate | 5 | Yellow | 2 | Simple |
| *C. chinense* (Small)  | 2-3           | Terminal | Green  | 5           | Yellow | Green | Campulate | 5 | Blue | 2.1 | Simple |
| *C. frutescens*        | 3             | Axillary | Green  | 5           | Yellow | Yellow | Campanulate | 3 | Blue | 2 | Bifid |
| *C. frutescens* (white)| 2-3           | Terminal/Axillary | Green  | 5           | Yellow | Green | Campanulate | 3 | Blush yellow | 2 | Bifid |
| *C. frutescens* (small)| 2 – 3         | Axillary | Green  | 5           | Yellow | Yellow | Campanulate | 3 | Blue | 2 | Bifid |
| *C. frutescens* (large)| 1-3           | Axillary | Green  | 5           | Yellow | Yellow | Campanulate | 3 | Blue | 2 | Bifid |

Table 5: Morphological characterization of three *Capsicum* species based on qualitative traits (Fruit, Seed)

| Species               | Fruit | Seed |
|-----------------------|-------|------|
|                       | Colour at immature stage | Colour at mature stage | Shape | Length (cm) | Surface | Shape at pedicel attachment | No. of locules | Position | Colour | Shape |
| *C. annuum*            | Light green | Dark green | Elongate | 8.5 | Rough | Pulvinate | 3 | Nodes | White | Half circle |
| *C. annuum* (Guder)    | Yellow | Yellow | Triangular | 8.5 | Smooth | Pulvinate | 2 | Axillary | White | Round |
| *C. chinense*          | Light green | Dark green | Triangular | 4.5 | Rough | Lobate | 2 | Terminal | White | Round |
| *C. chinense* (blue)   | Blue   | Blue green | Triangular | 2.5 | Rough | Obtuse | 2 | Terminal | Whithish blue | Round |
| *C. chinense* (round)  | Green yellow | Dark green | Round | 1.4 | Smooth | Pulvinate | 4 | Terminal | White | Round |
| *C. chinense* (Small)  | Light green | Dark green | Triangular | 4.5 | Rough | Obtuse | 2 | Terminal | White | Round |
| *C. frutescens*        | Light green | Dark green | Triangular | 1.5 | Rough | Pulvinate | 2 | Axillary | White | Round |
| *C. frutescens* (white)| Yellow | Red | Triangular | 5.5 | Rough | Pulvinate | 2 | Terminal | White | Round |
| *C. frutescens* (small)| Light green | Dark green | Short | 6 | Smooth | Pulvinate | 2 | Nodes | White | Round |
| *C. frutescens* (large)| Light green | Dark green | Triangular | 1.6 | Rough | Pulvinate | 2 | Nodes | White | Round |

Table 6: Morphological observations on quantitative traits of three *Capsicum* species

| Name of variety | Number of Seeds (Mean ± SE) | Length of internodes (cm, Mean ± SE) | Length of leaves (cm, Mean ± SE) | Length of petiole (cm, Mean ± SE) | Leaf width (cm, Mean ± SE) | Length of pedicel (cm, Mean ± SE) |
|-----------------|-----------------------------|--------------------------------------|----------------------------------|----------------------------------|----------------------------|-------------------------------|
| *C. annuum*     | 18 ± 0.7483                | 4.86 ± 0.3014                       | 9.04 ± 0.6029                    | 2.26 ± 0.0963                    | 7.08 ± 0.7845               | 1.08 ± 0.8492                 |
| *C. annuum* (Guder) | 36.6 ± 0.5899            | 5.64 ± 1.7889                       | 8.86 ± 0.2325                    | 3.12 ± 0.2528                    | 4.08 ± 0.1559               | 1.46 ± 0.3418                 |
| *C. chinense*   | 20.4 ± 0.4117              | 3.88 ± 1.6035                       | 7.46 ± 0.6703                    | 2.32 ± 0.9020                    | 7.02 ± 0.7317               | 1.2 ± 0.0489                  |
| *C. chinense* (blue) | 88.4 ± 0.3765           | 5.68 ± 0.6851                       | 5.32 ± 0.2551                    | 1.2 ± 0.0489                     | 2.94 ± 0.2342               | 2.5 ± 0.1232                  |
| *C. chinense* (round) | 32.8 ± 0.6588           | 7.26 ± 2.0744                       | 11.0 ± 0.6212                    | 2.6 ± 0.1469                     | 4.66 ± 0.1991               | 3.18 ± 0.5715                 |
| *C. chinense* (Small) | 31.4 ± 0.5366           | 9.79 ± 2.1849                       | 14.68 ± 0.4951                   | 1.16 ± 0.1436                    | 5.24 ± 0.1661               | 2.12 ± 0.9717                 |
| *C. frutescens* | 33 ± 0.7975                | 9.78 ± 2.2454                       | 14.7 ± 0.0628                    | 1.16 ± 0.2296                    | 4.94 ± 0.0829               | 2.12 ± 0.6343                 |
| *C. frutescens* (white) | 39.2 ± 0.1099          | 7.84 ± 0.8851                       | 8.78 ± 0.2440                    | 3.04 ± 0.1522                    | 5.9 ± 0.1938                | 2.12 ± 0.4037                 |
| *C. frutescens* (small) | 33.2 ± 0.5214           | 3.42 ± 2.5020                       | 9 ± 0.1370                      | 8.2 ± 0.3346                     | 3.92 ± 0.1579               | 1.2 ± 0.0489                  |
| *C. frutescens* (large) | 12.4 ± 0.7266          | 2.92 ± 1.2545                       | 5.72 ± 0.1774                    | 1.36 ± 0.1332                    | 6.22 ± 0.2249               | 1.08 ± 0.8989                 |

In the present study, accessions of *C. annuum* and *C. frutescens* showed a clustering pattern indicating a single lineage for each. *C. chinense* accessions were grouped into two subclusters. In the previous reports, also all the accessions of *C. annuum* were grouped together indicating a single lineage and all the other accessions of different species were formed separate clusters apart from the major *C. annuum* cluster, and the accessions of *C. frutescens* and *C. chinense* formed another subcluster (Thul et al., 2011).

Crop improvement is made by generating variability in desired traits followed by selection. Continued success in crop improvement can only be realized when new substantial variability is found and used in a population. The divergence between any two parents expresses the allelic differences between them (Yatung et al., 2014). The genotypes grouped into the same cluster presumably diverge very little from one another. Crossing of genotypes belonging to the same cluster is not expected to yield desirable segregants. Consequently, a
crossing programme should be conducted with putative parents belonging to different characters. Therefore, crosses between the members of clusters separated by inter-cluster distances are likely to be beneficial for further improvement (Yatung et al., 2014).

CONCLUSIONS

From this study, it may be concluded that a wide range of variations for almost all morphological traits is present in this crop. This implies a great potential for breeding through a hybridization programme or direct use as a variety for successful chilli production. Further, one or two promising genotypes from different clusters may be chosen for further genetic studies either by way of diallel or line x tester analysis.

Significance Statement

The present study observed considerable morphological variations among the members of the same species in the genus *Capsicum* which reveals greater potential for the varieties under study to be used directly in crop improvement efforts.

REFERENCES

Basu, S. K., & De, A. K. (2003). *Capsicum: Historical and botanical perspectives*. In A. K. De (Eds.), *The genus Capsicum* (pp. 1-15) London, UK: CRC Press.

Dafadar, A., Das, A., Bandopadhayay, B., & Jha, T. B. (2012). *In vitro propagation and molecular evaluation of Capsicum annuum* L. cultivar with high chromosome number (2n=48). *Scientia Horticulturae*, 140, 119-124. https://doi.org/10.1016/j.scienta.2012.04.001

Datta, S., & Das, L. (2013). Characterization and Genetic variability analysis in *Capsicum annuum* L. Germplasm. *SAARC Journal of Agriculture*, 17(1), 91-103. https://doi.org/10.3329/sja.v17i1.18387

FAOSTAT (2011). Food and Agriculture Organization of the United Nations.

Hill, T. A., Ashraf, H., Reyes-Chin-Wo, S., Yao, J., Stoffel, K., Truco, M. J., Kozik, A., Michelmore, R. W., & Deynne, A. V. (2013). Characterization of *Capsicum annuum* genetic diversity and population structure based on parallel polymorphism discovery with a 30K Unigene Pepper GeneChip. *PLoS ONE*, 8(2), e56200. https://doi.org/10.1371/journal.pone.0056200

IPGRI, AVRDC and CATIE (1995). *Descriptors for Capsicum (Capsicum spp.)*. International Plant Genetic Resources Institute, Asian Vegetable Research and Development Center and Tropical Agricultural Research and Training Centre, 114.

Kothari, S. L., Joshi, A., Kachhawaha, S., & Ochoa-Alejo, N. (2010). Chilli pepper - A review on tissue culture and transgenics. *Biotechnology Advances*, 28(1-4), 35-48. https://doi.org/10.1016/j.biotechadv.2009.08.005

Manju, P. R., & Sreelathakumary, I. (2002). Genetic variability, heritability and genetic advance in hot chilli (*Capsicum chinense Jacq.*). *Journal of Tropical Agriculture*, 40, 4-6.

Pradheep, K., & Veeraragavathatham, D. (2006). Characterization of *Capsicum* spp. germplasm. *Indian Journal of Plant Genetic Resources*, 19(2), 180-183.

Rai, V. P., Kumar, R., Kumar, S., Rai, A., Kumar, S., Singh, M., Singh, S. P., Rai, A. B., & Paliwal, R. (2013). Genetic diversity in *Capsicum* germplasm based on microsatellite and random amplified microsatellite polymorphism markers. *Physiology and Molecular Biology of Plants*, 19(4), 575-586. https://doi.org/10.1007/s12298-013-0185-3

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

Sudre, C. P., Goncalves, L. S. A., Rodrigues, R., do Amaral Júnior, A. T., Riva-Souza, E. M., & Bento, C. D. S. (2010). Genetic variability in domesticated *Capsicum* spp as assessed by morphological and agronomic data in mixed statistical analysis. *Genetics and Molecular Research*, 9(1), 283-294. https://doi.org/10.4238/vol9-1gmr698

Thul, S. T., Lal, R. K., Shasany, A. K., Darokar, M. P., Gupta, A. K., Gupta, M. M., Verma, R. K., & Khanuja, S. P. S. (2009). Estimation of phenotypic divergence in a collection of *Capsicum* species for yield related traits. *Euphytica*, 168, 189–196. https://doi.org/10.1007/s10681-009-9882-y

Thul, S. T., Darokar, M. P., Shasany, A. K., & Khanuja, S. P. S. (2011). Molecular Profiling for Genetic Variability in *Capsicum* Species Based on ISSR and RAPD Markers. *Molecular Biotechnology*, 51(2), 137-147. https://doi.org/10.1007/s12298-011-9466-y

Wang, D., & Bosland, P. W. (2006). The genes of *Capsicum*. *HortScience*, 41(5), 1169-1187.

Yatung, T., Dubey, R. K., Singh, V., & Upadhyay, G. (2014). Genetic diversity of chilli (*Capsicum annuum L.*) genotypes of India based on morpho-chemical traits. *Australian Journal of Crop Science*, 8(1), 97-102.

Zhigila, D. A., AbdulRahaman, A. A., Kolavole, O. S., & Oladele, F. A. (2014). *Fruit Morphology as Taxonomic Features in Five Varieties of Capsicum annuum L.* *Solanaeaceae*. *Journal of Botany*, 2014, 540868. https://doi.org/10.1155/2014/540868