Suitability of Widely Cultivated *Capsicum* Species for Consumer Preferred Traits

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Abstract

Chilli is consumed in various ways and forms across countries of the world. No single *Capsicum* species is suitable for all the customer use patterns across countries. In this background, we characterized and evaluated 35 genotypes belonging to three cultivated *Capsicum* species namely *C. annuum*, *C. chinenese* and *C. baccatum* to explore their suitability to different end uses. The genotypes were evaluated for seven quantitative traits along with pungency and color at maturity during 2019 and 2020 rainy seasons. The genotypes of *C. annuum*, C. *chinenese* differed significantly for all the traits, while those of *C. baccatum* differed only for fruit related traits. Among the three species, genotypes belonging to *C. annuum* were more suitable for culinary usage while those belonging to *C. baccatum* and *C. chinenese* were suitable for snacks preparations and capsaicin extraction, respectively. *C. annuum* genotypes namely CMS 10B, VI012911 and LCA 333 were most suitable for culinary purpose, while Byadgi Dabbi and CMS 6B were suitable for sauce preparations and natural color extraction, Gouribidanoor local for dry fruit end uses. *C. chinense* genotypes VI064771 and VI029244 were potential genotypes for ornamental chilli. Hence, it could be inferred that, demands from various end users can be unambiguously met through genotypes belonging to all the three cultivated chilli species either directly or through involvement in improving *C. annuum*.

Keywords : Chilli, Culinary, Natural color, Medicinal usage, Ornamental chilli

Chilli, native to tropical-central and south America, are being grown worldwide. India is the leading country in chilli production and export (Anonymous, 2021a). In India, Andhra Pradesh is the major producer of chilli followed by Telangana, Madhya Pradesh, Karnataka and West Bengal in that order accounting for 35, 17, 12, 11 and 6 per cent of total production, respectively. In Karnataka, Ballary, Gadag, Dharwad and Haveri are the major chilli producing districts (Anonymous, 2021b). Among different species under the genus, *Capsicum annuum* is the most grown species owing to its greater economic importance in India and worldwide. In contrast, production of *C. chinenese* is largely confined to north eastern states of India (Bhutia *et al*., 2019) while, *C. baccatum* is grown only in small patches in India.

Chilli is consumed in various ways and forms in India and across the world. Even within the country, its consumption patterns, end uses differ with the states and districts (Rao *et al*., 2020). For convenience, the utility and consumption patterns could be classified into seven major types. These are, culinary purpose (green and dried chilli), snacks preparations, natural color extraction, sauce preparation, pharmaceutical active ingredient extraction and as ornamental plants. The quantitative traits / chemical composition requirements differ with each end-use / consumption pattern.

Preliminary survey on different *Capsicum* species indicated that no single *Capsicum* species harbor all the quantitative traits / chemical composition required for all the described uses of chilli (Silva and Silva, 2021). However, systematic studies on comparison of widely used species for different consumer preferred traits is scanty. Hence, the present study was conducted with an objective to characterize and evaluate chilli genotypes belonging to three different cultivated species namely *Capsicum annuum* L., *Capsicum baccatum* L. and *Capsicum chinense* Jacq. for fruit type / traits and chemical composition.

Material and Methods

The present study consisted of 35 chilli genotypes (Table 1) belonging to three widely cultivated *Capsicum* species, procured from different countries of the world (Fig. 1). Out of 35 genotypes, 15 belonged to *C. annuum*, 14 to *C. chinense* and 6 to *C. baccatum*. Three species were unambiguously identified based on key floral traits (Table 2). Nineteen of 35 genotypes used in the study were procured from World Vegetable Center (WVC), Taiwan and remaining 16 genotypes were obtained from hot pepper improvement unit, Department of Genetics and Plant Breeding (GPB), College of Agriculture (CoA),

Table 1

Pedigree and fruit traits of chilli genotypes used in the study

Accession Number	Species	Fruit bearing habit	Green fruit pericarp thickness (mm)
VI064770	*C. chinense*	Solitary Pendant	1.00
VI012271	*C. chinense*	Solitary Pendant	0.90
VI012270	*C. chinense*	Solitary Pendant	1.00
VI012668	*C. chinense*	Solitary Pendant	2.00
VI012642	*C. chinense*	Solitary Pendant	1.20
VI029244	*C. chinense*	Solitary Pendant	1.20
VI064769	*C. chinense*	Solitary Pendant	1.00
VI064771	*C. chinense*	Solitary Pendant	1.50
VI012270	*C. chinense*	Solitary Pendant	1.00
VI012665	*C. chinense*	Solitary Pendant	0.70
VI012596	*C. chinense*	Solitary Pendant	1.40
Bhut Jalokia	*C. chinense*	Solitary Pendant	1.10
Carolina reaper	*C. chinense*	Solitary Pendant	1.50
Chinensis	*C. chinense*	Solitary Pendant	1.80
VI012528	*C. baccatum var pendulum*	Solitary Pendant	2.00
VI012497	*C. baccatum var pendulum*	Solitary Pendant	1.80
VI012478	*C. baccatum var pendulum*	Solitary Pendant	2.50
VI014924	*C. baccatum var pendulum*	Solitary Pendent	1.90
PBC 80	*C. baccatum*	Solitary Pendant	2.50
PBC 81	*C. baccatum*	Solitary Pendant	2.50
CMS 10B	*C. annuum*	Solitary Pendant	1.10
Phule Jyothi	*C. annuum*	Multiple Pendant	1.80
Tiwari	*C. annuum*	Solitary Erect	1.70
ByadgiDabbi	*C. annuum*	Solitary Pendant	2.50
Gowribidano or Local	*C. annuum*	Solitary Pendant	1.80
LCA 424	*C. annuum*	Solitary Pendant	1.90
LCA 333	*C. annuum*	Solitary Pendant	1.60
Pusasada bahar	*C. annuum*	Multiple Erect	1.80
Aparna	*C. annuum*	Solitary Pendant	1.80
VI037607	*C. annuum*	Solitary Pendant	1.90
VI012911	*C. annuum*	Solitary Pendant	1.10
CMS 6B	*C. annuum*	Solitary Pendant	2.20
Utkal Awa	*C. annuum*	Solitary Erect	1.80
PBC 142	*C. annuum*	Solitary Erect	2.00
AVPP 1105	*C. annuum*	Solitary Pendant	2.00

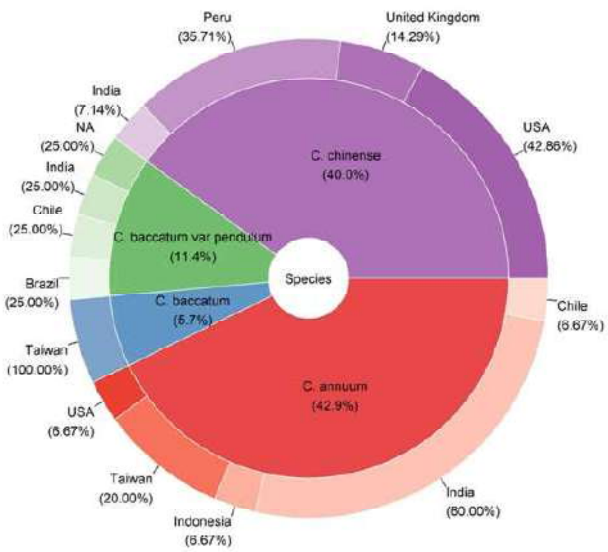

Fig. 1: Species identity of 35 genotypes used in the study and their country of collection

(Figures in the parenthesis represent proportion of genotypes belonging to respective *Capsicum* species collected from particular country)

TABLE 2
Distinguishable key floral traits of the three *Capsicum* species

Cultivated Species	Distinguishable morphology
C. annuum	White corolla and white filaments
C. baccatum	Yellow, brown or dark green spots on the corolla
C. chinense	Greenish corolla with annular constriction on pedicel

Gandhi Krishi Vigyana Kendra (GKVK), Bengaluru. Field evaluation of genotypes was carried out during 2019 and 2020 rainy seasons in randomized complete block design with two replications. The experiment was conducted in experimental plots of Department of GPB, K-block, CoA, GKVK, Bengaluru. The experimental site is located at 13.0801° N, 77.5785° E and 924m above mean sea level. Initially, seedlings of 35 genotypes, in both the seasons, were raised in nursery bed with all plant protection measures. Forty days old seedlings were transplanted to experimental field in beds of 5m length with a spacing of 0.75m between rows and 0.45m within a row. All recommended package of practices were followed to raise a healthy crop. A total of 14 plants were maintained for each genotype in each replication. Twelve plants in each genotype across replications were tagged, excluding plants at borders. At green fruit maturity stage, data were recorded on six out of twelve tagged plants on quantitative traits such as plant height (cm), fruit length (cm), fruit width (cm), single fruit weight (g), fruit number plant^{-1} and green fruit yield plant^{-1} (g). The remaining six plants were allowed till red fruit maturity to record data on dry fruit yield plant^{-1} expressed in grams.

Further, the genotypes were characterized for pungency based on organoleptic assay. A panel of three persons were requested to taste mature green fruits and rate the pungency of genotypes on 1-5 scale where 1 is highly pungent, 2 is pungent, 3 moderately pungent, 4 is less pungent and 5 is non-pungent. Similarly, color of the fruits at color break and ripe maturity stage were visually observed and assigned to different classes on 1-6 scale where, 1=yellow, 2=orange, 3=red, 4=deepred, 5=brown and 6=green (modified from PPV&FR, 2021). Data on fruit wall thickness (Table 1) was obtained from genotype characterization data base of WVC, Taiwan and our own studies at hot pepper improvement unit, GKVK, Bangalore.

Statistical Analysis

Trait mean values for each genotype were subjected to statistical analysis. From two season evaluation, due to prevalence of seasonal influence on the data, best linear unbiased estimates (BLUPs) were estimated employing generalized linear model $Y_{ijk} = \mu + g_i + r_j - S_k + e_{ijk}$ (Piepho *et al*., 2008). Where, Y_{ijk} is trait value for ith genotype in jth replication and kth season and g_i, r_j, s_k are, respectively the main effects of genotype, replication and season ; μ is experimental mean. In the model, all effects except experimental mean were considered random and assumed to follow multivariate normal distribution. The analysis was implemented through META-R software version 6.03 (Gregorio *et al.,* 2015). The BLUP values across seasons for two replications were used for further statistical analysis.

BLUPs of genotypes for all the traits were used for analysis of variance (ANOVA). Total variation among the genotypes was partitioned into those attributable to genetic and non-genetic sources for all the seven quantitative traits. Genotypic variation was further partitioned into species, which were further divided into those due to *C.annuum*, *C.baccatum* and *C. chinense* to detect if the genotypes of each species differ significantly. The critical difference estimated from error mean sum of squares of ANOVA was used to assess the significance of pairwise differences between three species. The significance or otherwise, so estimated, were depicted using box-whisker plots. Homogeneity of variances among the three species was examined using Levene's test (Levene, 1960). All the analysis in the study were carried out through R software (R core, 2020).

TABLE 3

Analysis of variance for yield and attributing traits in three species of chilli

Sources of Variation	Degree of freedom	Mean sum of squares						
		Plant height (cm)	Fruit length (cm)	Fruit width (cm)	Single fruit weight (g)	Fruit number plant^{-1}	Green fruit yield plant^{-1}(g)	fruit yield plant^{-1} (g)
Replications	1	605.08 **	4.14	0.13 **	20.48 **	240.09	32322.89 **	1107.44 **
Genotypes	34	190.09 **	15.67 **	0.92 **	31.84 **	1070.60 **	10428.41 **	582.90 **
Species	2	120.48	44.57 **	8.51 **	281.42 **	3564.62 **	58756.82 **	761.28
Capscicum annuum	14	223.84 *	9.46 **	0.24 **	9.30 **	1300.83 *	6088.14 *	722.81 **
Capscicumbaccatum	5	123.65 **	14.71 **	0.68 **	9.77	69.04	12944.59	548.21 **
Capscicumchinense	13	201.96 **	16.68 **	0.67 **	25.24 **	814.87 **	6299.71 *	435.60 **
Residuals	34	25.45	1.32	0.01	2.35	252.63	3265.34	58.51

RESULTS AND DISCUSSION

The results of ANOVA indicated prevalence of significant variability ($p<0.01$) among genotypes for all the seven quantitative traits (Table 3). The genotypes belonging to *C. annuum* and *C. chinense* differed significantly for all the traits. On the contrary, the genotypes belonging to *C. baccatum* differed significantly only for four out of seven traits. These results, by and large suggested existence of substantial variability among the three species considered for the study for most of the traits. These results were in agreement with those of Silva and Silva (2021) and Bianchi *et al.* (2020). Jayaram and Rao (2015) also reported significant variability for quantitative traits among *C. annuum* genotypes.

Different end uses of chilli are defined based on various traits / chemical compositions. To illustrate, for culinary purposes, chilli fruits should be of medium fruit length and width with moderate to high pungency. For snacks preparation, stout and longer fruits with mild to no pungency are preferred. Industries extracting natural color prefer deep red or yellow peel-coloured ripped fruits (Shamina *et al.*, 2007). Genotypes bearing longer and wider green chilli fruits with thick pericarp are suitable for sauce preparations (Silva and Silva, 2021) while those bearing high pungent fruits are suitable for capsaicin extraction for medicinal end-use. Dry chilli with red to deep red color are suitable for processed foods such as pickles, flakes etc. On the other hand, plants with short stature and non-routine fruit / leaf colours are suitable for ornamental purposes (Ari *et al.,* 2016).

Genotypes of *C.annuum* bore significantly longer fruits than those of *C. chinense,* though they were comparable to *C. baccatum* genotypes (Fig. 2 and 3). Similarly, genotypes of *C. annuum* bore greater number of fruits than those of *C. baccatum* but comparable with those of *C. chinense*. The geno types of all the three species were comparable for plant height and dry fruit yield plant^{-1}. These results suggest that it is possible to find genotypes suitable for dry fruit and ornamental end-uses from any of the three species. However, genotypes of *C. annuum* were more suitable for culinary use, natural color extraction, sauce preparation and processed foods.

Genotypes belonging to *C. baccatum* exhibited significantly greater green fruit yield plant^{-1} than those belonging to other two species. Genotypes of *C. baccatum* bore longer fruits than those of *C. chinenese* and comparable to those of *C. annuum*. Further, the genotypes of *C.baccatum* harboured

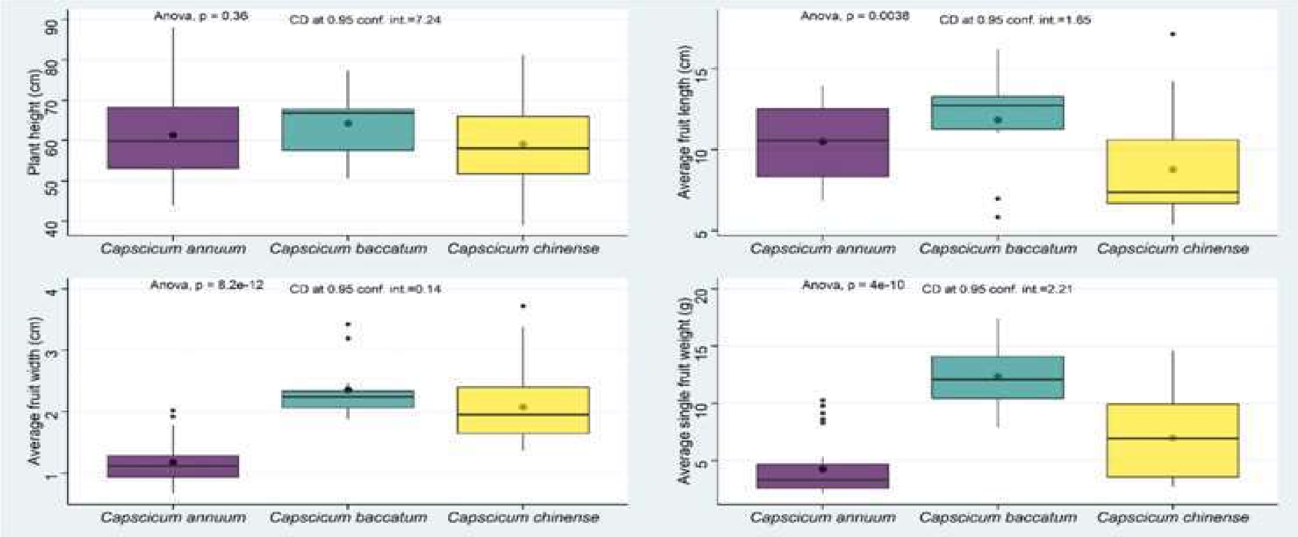

Fig. 2 : Box-whisker plots depicting variation among the three species of *Capsicum* for green fruit yield and yield related traits in chilli

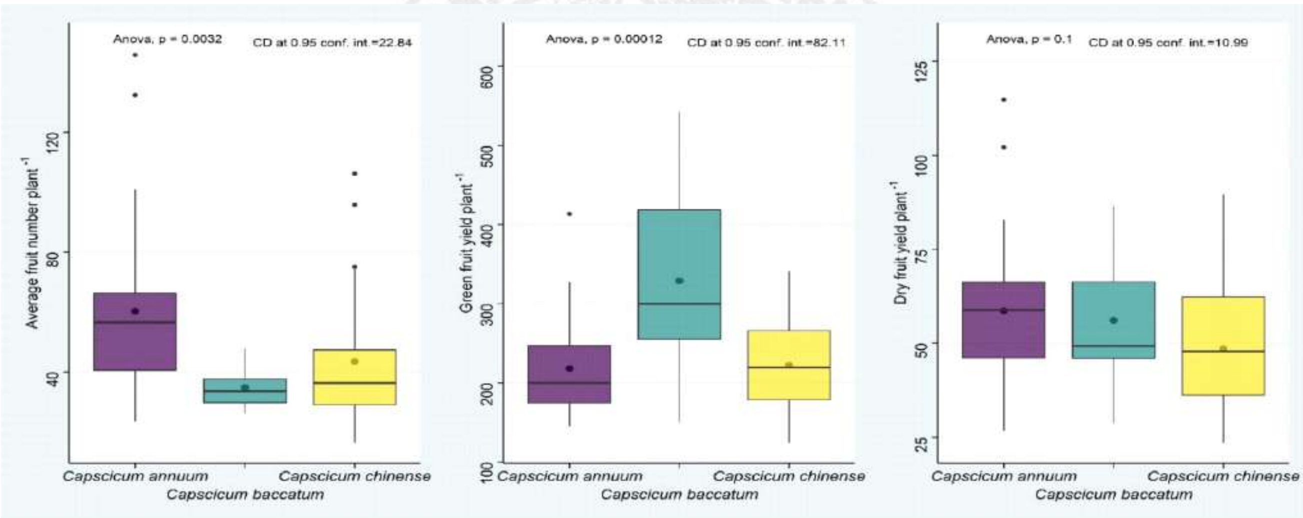

Fig 3: Box-whisker plots denoting variation among the three *Capsicum* species for plant growth and green fruit yield related traits in chilli

wider and heavier fruits than those of other two species. On the contrary, average number of fruits plant^{-1} were comparable to that of *C. chinense*. Fruits of genotypes belonging to *C. baccatum* were more suitable for snacks (*bajji / bonda*) preparations.

C. chinense genotypes bore significantly wider fruits and heavier fruits than *C. annuum* genotypes ; significantly narrower and lighter fruits than *C. baccatum* genotypes (Fig. 2 and 3). Whereas, fruits number of *C. chinense* genotypes were comparable to that of genotypes belonging to other two species. However, most of the genotypes in *C. chinense*

TABLE 4

Levene's test for homogeneity of variances between chilli species

Traits	Degrees of freedom	Probability
Plant height (cm)	2	0.31
Fruit length (cm)	2	0.75
Fruit width (cm)	2	0.12
Single fruit weight (g)	2	<0.01
Fruit number plant^{-1}	2	0.05
Green fruit yield plant^{-1} (g)	2	0.08
Dry fruit yield plant^{-1} (g)	2	0.88

TABLE 5

Pungency and color of genotypes of *Capsicum* species used in the study

Accession number	Fruit pungency scale	Fruit pungency class	Fruit color scale at fruit maturity stage	Fruit color class at color-break stage	Fruit color class at fruit maturity stage
		Capsicum chinense			
VI064770	1	Highly pungent	5	Green	Brown
VI012271	1	Highly pungent	3	Orange	Red
VI012270	1	Highly pungent	3	Orange	Red
VI012668	2	Pungent	5	Green	Brown
VI012642	4	Less Pungent	5	Brown	Brown
VI029244	1	Highly pungent	3	Orange	Red
VI064769	1	Highly pungent	3	Green	Red
VI064771	2	Pungent	5	Yellow	Brown
VI012270	1	Highly pungent	3	Orange	Red
VI012665	4	Pungent	5	Brown	Brown
VI012596	2	Pungent	3	Orange	Red
Bhut Jalokia	1	Highly pungent	2	Orange	Orange
Carolina reaper	1	Highly pungent	3	Red	Red
Chinensis	1	Highly pungent	3	Red	Red
		Capsicumbaccatum			
VI012528	3	Moderate	6	Green	Green
VI012497	5	Not pungent	2	Yellow	Orange
VI012478	3	Moderately Pungent	2	Orange	Orange
VI014924	3	Moderately Pungent	2	Yellow	Orange
PBC 80	4	Less Pungent	3	Green	Red
PBC 81	4	Less Pungent	2	Green	Orange
		Capsicum annuum			
CMS 10B	3	Moderately Pungent	3	Green	Red
Phule Jyothi	3	Moderately Pungent	3	Orange	Red
Tiwari	2	Pungent	3	Green	Red
ByadgiDabbi	5	Not pungent	4	Red	Deep Red
Gowribidanoor Local	2	Pungent	3	Orange	Red
LCA 424	2	Pungent	3	Red	Red
LCA 333	2	Pungent	3	Red	Red
Pusa sadabahar	2	Pungent	3	Green	Red
Aparna	5	Not pungent	1	Green	Yellow
VI037607	5	Not pungent	3	Brown	Red
VI012911	3	Moderately Pungent	3	Green	Red
CMS 6B	5	Not pungent	4	Green	Deep Red
Utkal Awa	3	Moderately Pungent	3	Green	Red
PBC 142	2	Pungent	3	Green	Red
AVPP 1105	3	Moderately Pungent	3	Green	Red

were pungent and exhibited higher variability for fruit color at color-break and maturity stages (Table 5). Bosland and Baral (2007) have also reported that world's most pungent genotypes belong to *C. chinense*. Overall, genotypes belonging to *C. chinense* were more suitable for pharmaceutical use and ornamental chilli end-uses. Despite existence of significant differences between means of three species for most of the traits, the three species differed significantly only for average single fruit weight (Table 4).

In *C. annuum*, CMS 10B, VI012911 and LCA 333 were suitable for culinary use. Further, Byadgi Dabbi (BD), CMS 6B, Aparna are candidates for natural color extraction. BD and CMS 6B can be candidates for production of sauces and use in processed foods. Gouribidanoor local could be suitable for dry fruit end-use, which is already in the markets of study area and *C. baccatum* genotypes VI012528 and VI012497 were more suitable for snack preparations. In similar lines, most of the genotypes of *C. chinense* were suitable for capsaicin extraction and use as donors in improving *C. annuum* genotypes for pungency. Genotypes of *C. chinense* with yellow (VI064771) and orange (VI029244) fruits could be suitable for ornamental (Costa *et al.,* 2019) end-use with average plant height of 45 cm.

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References

Anonymous, 2021a, Vanakalam (*kharif*) 2021-22 pre-sowing price forecast of chilli. Professor Jayashankar Telangana Agricultural University, Hyderabad.

Anonymous, 2021b, Major commodities, Rashtriya e-market service private limited. www.remsl.in

Ari, E., Yildirim, T., Mutlu, N., Buyukalaca, S., Gokmen, U. and Akman, E., 2016, Comparison of different androgenesis protocols for doubled haploid plant production in ornamental pepper (*Capsicum annuum* L.). *Turkish J. Bio.,* **40** : 944 - 954.

Bhutia, K. L., Bhutia, N. D. and Khanna, V. K., 2019, Rich genetic diversity of *Capsicum* species in Northeast India, as a potential source for chilli crop improvement. *J. Agric. Forest Meteorol. Res.,* **2** (2) : 77 - 83.

Bianchi, P. A., Da Silva, L. R. A., Alencar, A. A. S., Santo, P. H. A. D., Pimenta, S., Sudre, C. P., Corte, L. E., Goncalves, L. S. A. and Rodrigues, R., 2020, Biomorphological characterization of brazilian *Capsicum* chinense *Jacq. Germplasm. Agronomy,* **10**, 447 : 1 - 17.

Bosland, P. W. and Baral, J. B., 2007, Bhut Jolokia'-the world's hottest known chile pepper is a putative naturally occurring interspecific hybrid. *Hort. Sci.*, **42** (2) : 222 - 224.

Costa, G. D. N., Silva, B. M. P., Lopes, A. C. A., Carvalho, L. C. B. and Gomes, R. L. F., 2019, Selection of pepper accessions with ornamental potential. *Rev. Caatinga*, **32** (2) : 566 - 574.

Gregorio, A., Marco, L., Mateo, V., Angela, P., Francisco, R., Juan, B. and Jose, C., 2015, META-R (Multi environment trial analysis with R for windows) Version 6.04, https://hdl.handle.net/11529/10201, CIMMYT Research Data & Software Repository Network, V23.

Jayarama, N. and Rao, A. M., 2015, Identification of stable RIL(s) for and third- and fourth-degree statistics-based genetics of fruit yield and its component traits and resistance to anthracnose disease in chilli (*Capsicum annum* L.). *Mysore J. Agric. Sci.*, **49** (2) : 270 - 273.

Levene, H., 1960, In Contributions to probability and statistics : Essays in honor of harold hotelling, I. Olkin *et al.* eds., Stanford University Press, pp. : 278 - 292.

Piepho, H. P., Mo Hring, J., Melchinger, A. E., Bu Chse, A., 2008, BLUP for phenotypic selection in plant breeding and variety testing. *Euphytica*, **161** (1) : 209 - 228.

Ppv and Fra, 2021, Guidelines for the conduct of tests for distinctiveness, uniformity and stability on Chilli (Hot Pepper), Bell (Sweet) Pepper and Paprika (*Capsicum annuum* L.), pp. : 11.

R. CORE TEAM, 2020, R : A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

RAO, A. M., GANESH PRASAD AND SUSMITHA, B., 2020, The leaf curling in *Capsicum* species : A review. *Mysore J. Agric. Sci.*, **54** (2) : 1 - 13.

SHAMINA, A., SHIVA, K. N. AND PARTHASARATHY, V. A., 2007, Food colours of plant origin. *CAB Rev.* : *Prospects. Agric. Vet. Sci. Nutr. Nat. Resour.*, **2** (87) : 1749-8848. 10.1079/PAVSNNR20072087

SILVA, M. R. E. AND SILVA, R. N. O., 2021, Morpho-agronomic characterization and genetic diversity in peppers (*Capsicum* spp.). *Rev. Caatinga*, **34** (3) : 505 - 513.

WICKHAM, H., 2016, ggplot2: Elegant graphics for data analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

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