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Assessment of genetic association and Direct-Indirect Effects of Morphological and Quality Traits on Marketable Fruit Yield in Diverse Capsicum (*Capsicum annuum* L.) Genotypes Under the North-Western Himalayas

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Abstract

Capsicum (*Capsicum annuum*) is a high-value vegetable and an important and versatile cash crop. The correlation between different quantitative characters provides an idea of association that effectively formulates selection strategies for improving yield components. For any effective selection programme, it is desirable to consider the relative magnitude of association of various characters with yield. The present investigations, comprising 96 genotypes, were evaluated at Palampur during 2022 and 2023 following an alpha lattice design, replicated thrice. A highly significant and positive genotypic and phenotypic correlation of marketable fruit yield per plant was found with fruit width, fruit weight, TSS, and ascorbic acid. Therefore, the main emphasis should be given to these characters while making a selection. The maximum positive and direct effect towards marketable fruit yield was contributed by average fruit weight, followed by harvest duration. The improvement of these characters will lead to higher yields in bell peppers.

Keywords: *Capsicum annuum*, Correlation, Path Analysis, Yield

Capsicum annuum, commonly known as capsicum, belongs to the Solanaceae family and is widely valued for its nutritional and economic significance. It is a rich source of vitamins, carotenoids, flavonoids, and various other bioactive compounds that contribute to its antioxidant, anti-inflammatory, and immunomodulatory activities. Research indicates that capsicum exhibits various health-promoting effects, including antimicrobial, anti-obesity, anticancer, and neuroprotective activities, making it beneficial in managing neurodegenerative diseases like Alzheimer's and Parkinson's (Penella & Calatayud 2018). The red varieties of capsicum have been shown to possess the highest antioxidant capacity, correlating strongly with their phenolic and carotenoid content (Nevestenko *et al.* 2023; Imran *et al.* 2018; Manda *et al.* 2020). Furthermore, the bioactive compounds in capsicum, such as capsaicinoids, have demonstrated potential in reducing cholesterol levels and improving metabolic health (Panja *et al.* 2025; Ronald *et al.* 2024; Arti *et al.* 2024).

However, climate change continues to affect capsicum cultivation by intensifying abiotic stresses such as heat, drought, and salinity, ultimately influencing plant growth, fruit set, and biochemical attributes (Smith *et al.* 2020). In this context,

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correlation coefficient and path analysis serve as powerful statistical tools in crop improvement programmes, helping researchers disentangle complex trait relationships and identify key yield-contributing characters in capsicum. Correlation analysis helps determine the direction and magnitude of associations among traits, revealing how components such as fruit length, fruit width, pericarp thickness, and number of fruits per plant contribute to overall yield (Wang *et al.* 2024). However, correlation alone may mask indirect effects; therefore, path analysis provides a more detailed understanding by partitioning correlations into direct and indirect effects, enabling precise identification of traits that exert the strongest direct influence on marketable fruit yield (Sharma & Sharma 2006; Sood *et al.* 2020). These analytical approaches are essential for formulating effective breeding strategies aimed at developing high-yielding and stress-resilient capsicum genotypes under changing climatic conditions.

In this context, the present study was conducted to evaluate 96 capsicum genotypes to facilitate the development of climate-resilient cultivars through breeding strategies.

MATERIALS AND METHODS

The study was conducted over two consecutive seasons across four environments from February to July in 2022 and 2023 at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Agricultural University, Palampur, India. The site is located at an altitude of 1290.8 meters above mean sea level, at 32°06′3.6″ N latitude and 76°32′49.2″ E longitude.

Capsicum annuum genotypes were developed over the years using hybridisation, selection, and other breeding techniques that led to the identification of 96 genotypes exhibiting improved horticultural traits. These 96 genotypes were evaluated in the field with row-to-row spacing of 60 cm and 45 cm between plants, following an alpha design with three replications. Standard agronomic practices were consistently followed throughout the cropping period to promote healthy plant growth and development. Additionally, soil fertility was maintained through the application of recommended doses of fertilisers and organic amendments to ensure optimal nutrient availability. Pest and disease incidences were regularly monitored, and integrated management strategies were implemented to minimise crop losses.

A total of 14 morphological traits *viz*., days to 50 per cent flowering, days to first picking, plant height (cm), harvest duration (days), lobes per fruit, fruit length (cm), fruit width (cm), fruit shape index, pericarp thickness (mm), average fruit weight (g), marketable fruits per plant, marketable fruit yield per plant (g), total soluble solids (°Brix), and ascorbic acid content (mg/100g) were evaluated in this study.

Five healthy plants were randomly tagged in each replication, and data were recorded at different growth stages for 12 morphological traits viz., days to 50 per cent flowering, days to first picking, plant height (cm), number of lobes per fruit, fruit length (cm), fruit width (cm), pericarp thickness (mm), average fruit weight (g), number of marketable fruits per plant and marketable fruit yield per plant (g), total soluble solids (°Brix), ascorbic acid content following method of Sadasivam and Balasubramanian (1987).

The homogeneity of error variances for each measured trait was evaluated using Bartlett's test to validate the individual experiments before conducting the analysis. The results indicated that all parameters across the two cropping seasons were homogeneous. The correlation analysis was performed by using R Studio software version 4.2.2, using the methodology suggested by Pearson (1948). Principal component analysis was computed by using Past 4.03 software.

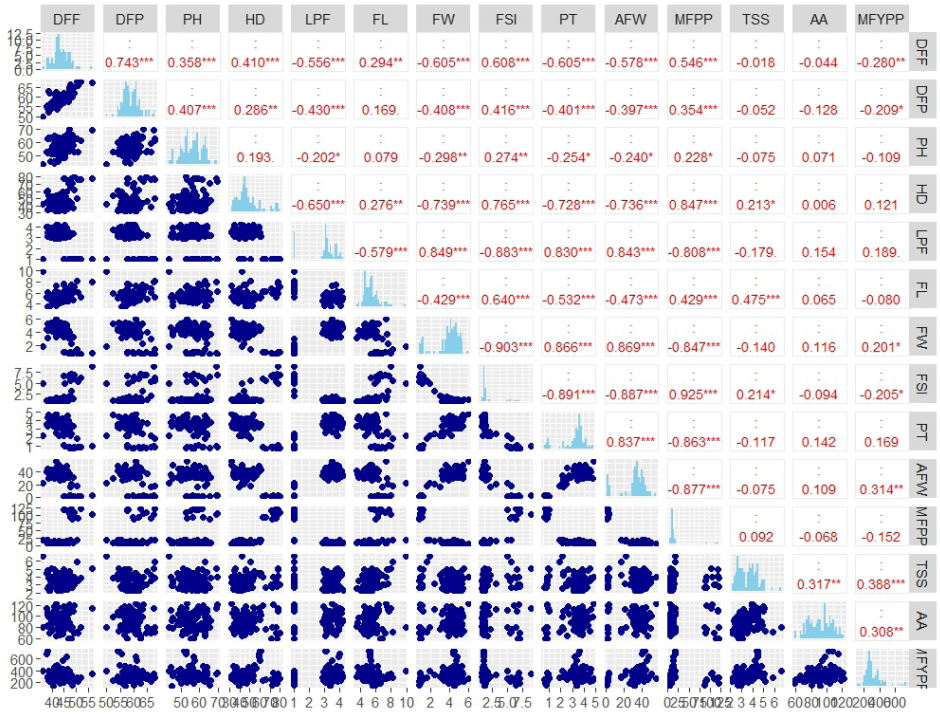
RESULTS AND DISCUSSION

Pearson's correlation coefficients across four environments (Figure 1) revealed that fruit width (0.201), average fruit weight (0.314), total soluble solids (0.388), and ascorbic acid (0.308) exhibited significant positive correlations with marketable fruit yield per plant. This indicates that an increase in these characters directly enhances yield potential, as larger and denser fruits with higher biochemical quality contribute more to overall productivity. On the other hand, significant negative correlations were observed for days to 50 per cent flowering (-0.280), days to first picking (-0.209), and fruit shape index (-0.205) with marketable fruit yield per plant, suggesting that genotypes which bloom

and mature earlier tend to produce higher yields. Such earliness is beneficial in utilising the growing period more efficiently, allowing better resource allocation towards fruit development and yield formation.

However, very weak and positive non-significant correlations were observed for harvest duration (0.121), lobes per fruit (0.189), and pericarp thickness (0.169), whereas plant height (-0.109), fruit length (-0.080), and marketable fruits per plant (-0.152) showed insignificant negative correlations with marketable fruit yield per plant. These weak associations indicate that while these traits contribute to overall plant architecture and fruit morphology, their influence on yield is indirect and often masked by other dominant yield-contributing traits such as fruit weight and biochemical attributes. The positive association of total soluble solids and ascorbic acid with fruit yield further emphasises that genotypes with superior internal fruit quality also tend to exhibit better fruit yield. Similar findings have been reported by Sharma *et al.* (2017), Thakur *et al.* (2019), Lata *et al.* (2022) and Arti *et al.* (2024), who also observed that fruit weight, total soluble solids, and ascorbic acid exhibited strong positive associations with fruit yield in *Capsicum annuum*.

Path analysis revealed that the direct effects obtained at the phenotypic level differed significantly from those obtained at the genotypic level (Table 2). The direct effects were observed to be of opposite sign for plant height (0.004 and -0.006), and marketable fruits per plant (0.248 and -0.066) at corresponding phenotypic and genotypic levels, respectively. Average fruit weight (0.772 and 0.667) had the maximum positive direct effect on marketable fruit yield per plant, followed by harvest duration (0.493 and 0.683) at both levels. However, the maximum positive indirect effects of fruit width *via* average fruit weight (0.664 and 0.582) and pericarp thickness *via* average fruit weight (0.641and 0.560) significantly increased marketable fruit yield per plant. The residual effects were 0.00462 and 0.00032 at phenotypic and genotypic levels, respectively.



DFF- days to 50 per cent flowering, DFP- days to first picking, PH- plant height, HD- harvest duration, FL- fruit length, FW- fruit width, FSI- fruit shape index, LPF- lobes per fruit, PT- pericarp thickness, AFW- average fruit weight, MFPP- marketable fruits per plant, MFYPP- marketable fruit yield per plant, TSS- total soluble solids, and AA- ascorbic acid

Figure 1. Correlation coefficient for fruit yield traits in 96 capsicum genotypes across four environments.

Table 1. Estimates of direct and indirect effects of fruit yield traits on marketable fruit yield per plant across four environments

Trait		DFF	DFP	PH	HD	LPF	FL	FW	FSI	PT	AFW	MFPP	TSS	AA	MFYPP
DFF	P	**-0.127**	0.026	0.001	0.189	0.037	-0.002	0.054	-0.229	0.095	-0.423	0.128	-0.004	-0.001	-0.255*
	G	**-0.150**	0.023	-0.002	0.287	0.055	-0.006	0.038	-0.224	0.132	-0.393	-0.037	-0.005	-0.005	-0.290*
DFP	P	-0.086	**0.038**	0.002	0.125	0.028	-0.001	0.036	-0.150	0.061	-0.278	0.081	-0.015	-0.010	-0.170*
	G	-0.116	**0.029**	-0.003	0.205	0.043	-0.002	0.026	-0.156	0.088	-0.275	-0.024	-0.015	-0.025	-0.224*
PH	P	-0.039	0.014	**0.004**	0.087	0.012	-0.001	0.027	-0.103	0.040	-0.174	0.054	-0.022	0.008	-0.095
	G	-0.057	0.012	**-0.006**	0.136	0.017	-0.004	0.019	-0.101	0.055	-0.163	-0.015	-0.022	0.015	-0.114
HD	P	-0.049	0.010	0.001	**0.493**	0.044	-0.002	0.068	-0.298	0.118	-0.557	0.206	0.065	0.006	0.105*
	G	-0.063	0.009	-0.001	**0.683**	0.062	-0.007	0.045	-0.278	0.156	-0.494	-0.056	0.061	0.009	0.127
LPF	P	0.063	-0.014	-0.001	-0.288	**-0.076**	0.003	-0.068	0.291	-0.118	0.567	-0.181	-0.014	0.015	0.180*
	G	0.080	-0.012	0.001	-0.411	**-0.104**	0.010	-0.044	0.267	-0.154	0.497	0.049	-0.013	0.027	0.193
FL	P	-0.026	0.002	0.0005	0.107	0.027	**-0.008**	0.028	-0.136	0.073	-0.324	0.092	-0.044	-0.003	-0.211*
	G	-0.033	0.002	-0.001	0.157	0.037	**-0.029**	0.018	-0.125	0.096	-0.287	-0.025	-0.041	-0.004	-0.234*
FW	P	0.073	-0.014	-0.001	-0.356	-0.054	0.002	**-0.095**	0.357	-0.142	0.664	-0.209	-0.043	0.010	0.191*
	G	0.093	-0.012	0.002	-0.508	-0.075	0.009	**-0.061**	0.327	-0.185	0.582	0.056	-0.040	0.019	0.205*
FSI	P	-0.073	0.014	0.001	0.368	0.055	-0.003	0.085	**-0.399**	0.146	-0.675	0.228	0.066	-0.007	-0.194*
	G	-0.093	0.013	-0.002	0.527	0.077	-0.010	0.055	**-0.361**	0.191	-0.594	-0.061	0.061	-0.012	-0.210*
PT	P	0.073	-0.014	-0.001	-0.352	-0.054	0.003	-0.082	0.353	**-0.165**	0.641	-0.213	-0.036	0.007	0.160*
	G	0.093	-0.012	0.002	-0.501	-0.075	0.013	-0.053	0.322	**-0.213**	0.560	0.057	-0.033	0.012	0.172
AFW	P	0.070	-0.014	-0.001	-0.355	-0.056	0.003	-0.081	0.349	-0.137	**0.772**	-0.215	-0.023	0.007	0.319*
	G	0.089	-0.012	0.001	-0.506	-0.077	0.013	-0.053	0.321	-0.179	**0.667**	0.058	-0.021	0.012	0.312*
MYPP	P	-0.065	0.012	0.001	0.409	0.055	-0.003	0.080	-0.366	0.141	-0.669	**0.248**	0.029	-0.004	-0.131*
	G	-0.084	0.011	-0.001	0.582	0.076	-0.011	0.052	-0.335	0.185	-0.588	**-0.066**	0.026	-0.007	-0.160
TSS	P	0.002	-0.002	0.000	0.102	0.003	0.001	0.013	-0.084	0.019	-0.057	0.023	**0.313**	0.032	0.366*
	G	0.003	-0.002	0.000	0.147	0.005	0.004	0.009	-0.077	0.025	-0.050	-0.006	**0.286**	0.055	0.397*
AA	P	0.001	-0.003	0.000	0.023	-0.009	0.000	-0.007	0.022	-0.009	0.045	-0.008	0.078	**0.128**	0.261*
	G	0.004	-0.004	0.000	0.034	-0.015	0.001	-0.006	0.023	-0.014	0.043	0.002	0.083	**0.188**	0.337*

Residual effect at phenotypic level (P) = 0.00462 and genotypic level (G) = 0.00032; Bold values indicate direct effects, *, SignificantatP≤0.05,

DFF- days to 50 per cent flowering, DFP- days to first picking, PH- plant height, HD- harvest duration, FL- fruit length, FW- fruit width, FSI- fruit shape index, LPF- lobes per fruit, PT- pericarp thickness, AFW- average fruit weight, MFPP- marketable fruits per plant, MFYPP- marketable fruit yield per plant, TSS- total soluble solids, and AA- ascorbic acid

Path coefficient analysis provided insight into direct and indirect relationships among traits (Table 1). The high positive direct effects of average fruit weight and harvest duration on marketable fruit yield per plant confirms their primary role in determining yield performance. In addition, strong indirect effects of fruit width and pericarp thickness *via* average fruit weight emphasised their secondary contribution to yield. The low residual effects at both phenotypic and genotypic levels suggest that traits included in the analysis sufficiently explain the variability in fruit yield of Capsicum. The similar results were observed by Sharma *et al.* (2010), Sharma *et al.* (2016) and Sood *et al.* (2023).

CONCLUSION

The study on 96 genotypes of *Capsicum annuum* revealed considerable interrelationships among key morphological and biochemical traits contributing to

fruit yield. Correlation and path analysis demonstrated that fruit width, average fruit weight, total soluble solids, and ascorbic acid exhibited significant positive associations with marketable fruit yield per plant, highlighting their importance in yield improvement. Among all yield components, average fruit weight and harvest duration had the highest positive direct effects on yield, indicating that these traits play a decisive role in determining productivity. Furthermore, the strong indirect effects of fruit width and pericarp thickness via average fruit weight emphasise their secondary contribution to yield performance. The low residual effects observed at both phenotypic and genotypic levels suggest that most of the variation in fruit yield was explained by the traits under study. Hence, these traits can be effectively utilised as selection criteria in future breeding programmes aimed at developing high-yielding and nutritionally rich capsicum varieties adapted to diverse environments.

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REFERENCES

Arti D, Mehta DK, Vikram A, Dogra R, Kumar R and Shraddha 2024. Estimates of genetic variability, correlation and path analysis for yield and yield contributing traits in bell pepper. Indian Journal of Horticulture **81(04):** 379-384. https://doi.org/10.58993/ijh/2024.81.4.7

Imran M, Butt MS and Suleria HAR 2018. *Capsicum annuum* bioactive compounds: Health promotion perspectives. In JM Mérillon and K Ramawat (Eds) Bioactive Molecules in Food. Reference Series in Phytochemistry. Springer, Cham. https://doi.org/10.1007/978-3-319-54528-8_47-1 PMCid:PMC6223983

Lata H and Sharma A 2022. Evaluation, genetic variability, correlation and path analysis studies in chilli (*Capsicum annuum* L.) genotypes. Himachal Journal of Agricultural Research **48:** 56-64.

Manda RR, Addanki VA and Srivastava S 2020. Bacterial wilt of solanaceous crops. International Journal of Chemical Studies **8(6):** 1048-1057. https://doi.org/10.22271/chemi.2020.v8.i6o.10903

Niavestsenka NA, Puhachova IG, Dabrodzkin MM and Kilchevsky AV 2023. Sweet pepper (*Capsicum annuum* L.) breeding on yield and fruits quality according to the cultivar model for unheated soil greenhouses. Vegetable Crops of Russia, **1:** 14-22. https://doi.org/10.18619/2072-9146-2023-1-14-22

Panja S, Saha S and Manna T 2025. Genetic association and characterization of chilli (*Capsicum annuum* L.) germplasm for yield and its component characters. Plant Archives **25(1):** 831-837. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.111

Penella C and Calatayud A 2018. Pepper crop under climate change: Grafting as an environmental friendly strategy. Climate Resilient Agriculture - Strategies and Perspectives. https://doi.org/10.5772/intechopen.72361 PMCid:PMC7535529.

Ronald S, Kambham MR and Singh LJ 2024. Exploring genetic variability, heritability and genetic advance in fruit quality traits within Capsicum germplasm lines. Plant Archives **24(2):** 2789-2793. https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.239

Sadasivam S and Balasubramanian T 1987. Practical manual in biochemistry. Tamil Nadu Agricultural University, Coimbatore, India.

Sharma A and Sharma S 2006. Variation studies for bell pepper [*Capsicum annuum* (L.) Sendt. var. grossum] improvement under cold desert conditions of North-Western Himalayas. Indian Journal of Genetics and Plant Breeding **66(4):** 357-358.

Sharma KC, Verma S, Sharma A and Sharma P 2010. Genetic divergence and path analysis in early maturing garden peas. Himachal Journal of Agricultural Research **35:** 176-179.

Sharma A, Devi J and Katoch V 2016. Genetic variability and genotypic × environment interaction for seed yield and related traits in French bean germplasm. Indian Journal of Plant Genetic Resources **29(2):** 156. https://doi.org/10.5958/0976-1926.2016.00022.x

Sharma A, Swain D and Sekhon BS 2017. Breeding strategies based on diversity analysis in advance breeding lines of chilli (*Capsicum annuum* var. annuum L.). Electronic Journal of Plant Breeding **8(4):** 1247-1257. https://doi.org/10.5958/0975-928x.2017.00179.x

Smith A, Jones B and Taylor C 2020. Genetic diversity in Capsicum species under abiotic stress. Journal of Horticultural Science **45(2):** 123-135.

Sood T, Basandrai D, Rana V and Basandrai AK 2020. Genetic diversity analysis for various agro morphological, yield and yield related traits in wheat (*Triticum aestivum* L.). Himachal Journal of Agricultural Research **46(2):** 136-144.

Sood T, Sood S, Sood VK, Badiyal A, Kapoor AS, Sood V and Kumar N 2023. Characterisation of bell pepper (*Capsicum annuum* L. var. grossum Sendt.) accessions for genetic diversity and population structure based on agro-morphological and microsatellite markers. Scientia Horticulturae **321:** 112308. https://doi.org/10.1016/j.scienta.2023.112308

Thakur S, Negi R and Mehta DK 2019. Correlation and path coefficient studies in bell pepper (*Capsicum annuum* L. var. grossum) under mid hill conditions of Solan District of Himachal Pradesh, India. International Journal of Current Microbiology and Applied Sciences **8(01):** 1788-1796. https://doi.org/10.20546/ijcmas.2019.801.190

Wang Y, Ma S, Cao X, Li Z, Pan B, Song Y, …, Sun L 2024. Morphological, histological and transcriptomic mechanisms underlying different fruit shapes in *Capsicum spp*.. PeerJ **12:** e17909. https://doi.org/10.7717/peerj.17909 PMid:39364369 PMCid:PMC11448748