Himachal Journal of Agricultural Research
Volume 52, Issue 1, June 2026; pp. 24–38; DOI: 10.18311/HJAR/2026/33042

INFORMATICS JOURNALS
Crop improvement

Genetic Variability, Correlation and Path Coefficients of Different Attributes in Chilli (*Capsicum annuum* L.) to Assess Selection Parameters

Vivek Singh[1]*, Akhilesh Sharma[1], Parveen Sharma[1], Aditi Sankhyan[1], Arshia Prashar[1] and Nimit Singh[2]

[1]Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur – 176062, Himachal Pradesh, India; viveksinghparmar1998@gmail.com
[2]Department of Vegetable Science, Narendra Deva University of Agriculture and Technology, Ayodhya -224229, Uttar Pradesh, India

Abstract

Genetic variability and correlation studies play a vital role in identifying selection parameters for an effective crop improvement programme. Keeping this in view, the present investigation was carried out in chilli using 96 diverse genotypes following an alpha lattice design, replicated twice during summer 2023 and 2024 at two diverse environments using 21 attributes. PCV and GCV were high for leaf area, average fruit weight, red fruits/plant, green/red fruit yield and ascorbic acid across environments. High heritability and genetic advance were observed for fruit diameter, leaf area, length of main stem, average fruit weight, fruits per plant, fruit yield, and ascorbic acid over the environments. Fruit yield showed positive correlation with pedicle length, fruit length, fruit diameter, fruit weight (red/green), green fruits/plant, red fruit yield and harvest duration at both genotypic and phenotypic levels. Fruit weight, fruits (green/red)/plant, days to harvest and leaf area had maximum direct effects on yield. Thus, selection for high-yielding genotypes of chilli must focus on these parameters.

Keywords: Correlation, Direct/Indirect Effects, Fruit Yield, GCV, Genetic Advance, Genotypes, Heritability, PCV, Selection

Chilli or hot pepper (*Capsicum annuum* L.) is an important vegetable cum spice crop belonging to the family Solanaceae (nightshade). The genus Capsicum comprises approximately 25 species, of which five are domesticated, *i.e.*, *Capsicum annuum*, *C. chinense*, *C. frutescens*, *C. baccatum* and *C. pubescens*[1,2]. Among these, *C. annuum* is the most widely cultivated species globally and includes diverse cultivar groups ranging from pungent chillies to non-pungent sweet peppers[3]. In India, chilli was introduced during the 17th century through Portuguese explorers and has since become an integral component of agricultural production and culinary practices[4]. Chilli possesses considerable nutritional, medicinal and industrial importance, being a rich source of vitamins A, C, and E, carotenoids, phenolic compounds, and capsaicinoids that collectively contribute to its antioxidant and health-promoting properties[5].

It covers an area of 2.81 million ha globally, with production of 44.77 million tons and average productivity of 15.90 t ha^{-1}. As an essential element of Indian cuisine and a lucrative cash crop, it is grown in the summer-rainy season, covering 479.67 thousand ha

*Author for correspondence

Manuscript Received: 09.01.2026; Accepted: 20.03.2026

area with production of 5317.98 thousand million tons and average productivity of 11.09 t ha-1 [6]. The chilli exhibits remarkable diversity in growth, flowering behaviour, fruit morphology, yield attributes, pungency levels, and harvest duration[7]. Fruit yield is a complex quantitative trait influenced by several component characters and environmental factors, making its direct improvement challenging. Subsequently, yield enhancement strategies require an understanding of the genetic architecture of yield and its related traits[3,8].

Genetic variability is a fundamental prerequisite for the success of any crop improvement programme. A considerable degree of variability has been reported in chilli crop, largely attributed to its cultivation across diverse environmental conditions[4]. Such extensive variation provides substantial opportunities for exploitation in crop improvement programmes. The systematic identification of promising and useful germplasm is the primary and most critical step in any effective breeding approach[9,10]. High heritability coupled with high genetic advance observed for several yield-related traits suggests the predominance of additive gene action, offering ample scope for effective selection[10]. A broad genetic base facilitates the development of high-yielding cultivars with improved quality, adaptability, and resistance to biotic and abiotic stresses[11]. Conversely, a narrow genetic base or genetic bottleneck can limit breeding progress and pose long-term risks to crop sustainability[12]. In addition to genetic variability and divergence, estimates of heritability and genetic advance provide valuable insights into the relative contribution of genetic and environmental factors to phenotypic expression[13]. Correlation among traits further assists in understanding interrelationships, although indirect effects often necessitate comprehensive evaluation of yield-contributing characters rather than reliance on yield alone, whereas path coefficient analysis partitions this association into direct effects and indirect effects operating through other contributing variables[14]. These parameters aid in identifying traits amenable to selection and in formulating appropriate breeding strategies[15].

Considering the economic importance of chilli and the need for continuous varietal improvement to meet the demands of growers and consumers, a detailed assessment of genetic variability is imperative. Therefore, the present study was undertaken to evaluate the extent of genetic variability and correlation among selected 96 chilli germplasms based on yield and yield-related traits, and to estimate genetic parameters such as variance components, heritability and genetic advance as a selection criterion for further chilli breeding initiatives. The results are expected to provide a scientific basis for the identification of superior genotypes and the formulation of effective selection strategies for future chilli breeding programmes.

MATERIALS AND METHODS

The experiment comprising 96 genotypes (Table 1) was conducted during the summer-rainy season of 2023 and 2024 at Vegetable Research Farm, College of Agriculture, CSK Himachal Pradesh Agricultural University, Palampur and at Research Substation Akrot, Una, during 2024.

The genotypes were evaluated following alpha lattice design with two replications across the environments. The seedlings were raised initially on a nursery seed bed of size 3m×1m×15 cm, and about eight weeks later, healthy seedlings were planted at 45 cm of inter and intra-row spacing under 12 blocks by planting each genotype in two rows of 2.25 m length with eight genotypes in each block. Standard agronomic practices were followed to ensure healthy plant growth throughout the experiment. The observations were recorded on five randomly taken plants of each genotype over the replications for 21 quantitative traits, *viz.*, days to flowering, days to first harvest, pedicel length (cm), fruit length (cm), fruit diameter (cm), leaf length (cm), leaf width (cm), leaf area (cm^2), plant height (cm), length of main stem (cm), primary branches per plant, internodal length, average green fruit weight (g), green fruits per plant (no.), green fruit yield per plant (g), average red fruit weight (g), red fruits per plant, red fruit yield per plant (g), harvest

Table 1. The list of genotypes utilised in the study along with their respective sources

S. No.	Source	Genotype
1	Department of Vegetable Science and Floriculture, CSKHPKV, (H.P.)	DPCh-Uj, VVG, DPCh-10, DPCh-40, DPCh-9Y, DPCh-U-62, DPCh-133, DPCh-29-121, DPCh-29-122, DPCh-29-123, DPCh-38-1211, DPCh-38-1213, DPCh-38-1214, DPCh-38-1221, DPCh-39-1211, DPCh-39-1212, DPCh-39-122, DPCh-40-2, DPCh-101, DPCh-501, DPCh-27-1, DPCh-22-C, DPCh-U-1-F, DPCh-U-11, DPCh-U-12, DPCh-U-131, DPCh-U-132, DPCh-U-141, DPCh-U-16, DPCh-U-142, DPCh-U-2, DPCh-U-21-1S, DPCh-U-21-211, DPCh-U-21-213, DPCh-U-21-22, DPCh-U-21-31, DPCh-U-21-32, DPCh-26-1, DPCh-29-2, DPCh-9-2, DPCh-11-2, DPCh-23-1, DPCh-18-1, DPCh-Paprika, DPCh- Jallapeno-1, Him Palam Mirch-1(Check), Him Palam Mirch-2(Check), Surajmukhi (Check)
2	LAM Research Station, Guntur, Andhra Pradesh	LCA-424, LCA-235, LCA-334, LCA-305, LCA-353, LCA-620, LCA-206, LCA-436, LCA-625, CA-960
3	Punjab Agriculture University, Ludhiana	GS-10, Punjab Sindhuri, Punjab Gucchedar, Punjab Tej, PBC-535, OC-22, PC-2062, BC-25, USCN-2022
4	Division of Vegetable Science, IARI, New Delhi	Paprika, Pusa Jwala, Tiwari, MI-2, SL-221, SL-2237, LS-22, SL-222, KTPL -19, DLS-10, RA-11, SNP-709, B-4, B-6, B-7
5	Indian Institute of Horticulture Research, Bengaluru	Arka Abhir, Arka Lohit
6	Indian Institute of Vegetable Research, Varanasi	Kashi Sindhoori, Kashi Anmol, Kashi Gaurav, Kashi Abha
7	UAS, Dharwad	Byadgi Dabbi, Byadagi Kaddi
8	Sher-e-Kashmir University of Agriculture Science and Technology of Jammu (Jammu and Kashmir	Kashmiri Chilli
9	UAS, Bengaluru	Gauri Bidanoor
10	Kerala Agriculture University	Samrudhi
11	Anand Agriculture University, Anand, Gujarat	GVC-101, GVC-111
12	Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni (H.P.)	DKC-8

duration (days), ascorbic acid (mg/100g) and total soluble solids (^{0} Brix).

Statistical analysis for different variability parameters, correlation coefficients (both genotypic and phenotypic levels), and path coefficients based on the phenotypic dataset for different traits was undertaken using OPSTAT. Genotypic and phenotypic coefficients of variation were computed as per the

method described by Burton and DeVane[16]. Broad-sense heritability and genetic advance as a percentage of mean were estimated using formulae of Johnson *et al.*[17]. Correlation coefficients at both genotypic and phenotypic levels were calculated following the approach of Al-Jibouri *et al.*[18]. Path coefficient analysis, to determine the direct and indirect contributions of various traits on green fruit yield per plant, was performed following the methodology proposed by Dewey and Lu[19].

RESULTS AND DISCUSSION

Components of Variability

A critical insight into the magnitude of genetic variability present in a crop provides the basis for effective selection and the possibility to improve the yield and quality through a strategic breeding programme[20,21]. The knowledge of Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) helps predict the amount of variation present in the given genetic stock, which in turn helps in formulating an efficient breeding programme[22]. In the present study, the PCV was higher than the GCV for all traits, indicating that environmental factors played a significant role in influencing these traits. PCV and GCV were high for green fruit yield per plant, leaf area, average green fruit weight, average red fruit weight, red fruits per plant, red fruit yield per plant and ascorbic acid at Palampur during 2023 and 2024, and Akrot during 2024 along with pooled over environments while the same effects were observed for green fruits per plant at Palampur during 2024 (Table 2) indicating substantial variability for these traits that ensure ample scope for its improvement through selection[23]. In general, PCV and GCV were moderate in magnitude for most of the traits, *viz.,* fruit length, fruit diameter, leaf length, leaf width, plant height, length of main stem, primary branches per plant, internodal length and total soluble solids during all the environments and pooled over environments along with pedicel length at Palampur during 2023, 2024 and Akrot during 2024, while moderate PCV was recorded for green fruits per plant at Palampur during 2023, Akrot during 2024 and pooled over environments suggesting that selection for these traits should be taken up with cautions in crop improvement[24]. The rest of the traits showed low PCV and GCV.

The knowledge of heritability influences the choice of breeding procedures to predict gain from selection and to determine the relative importance of genetic effects[25]. The magnitude of heritability in the broad sense indicates the reliability with which a genotype can be recognised by its phenotypic expression and is helpful in predicting the expected amount of improvement to be achieved through selection together with the genotypic coefficient of variation[26]. In the present study, high heritability estimates (>80%) were observed for all the traits during 2023 and 2024 at Palampur, at Akrot during 2024 and pooled over environments (Table 2), indicating lesser influence of environment and greater role of genetic components of variation[22] and thus, focus should be given to such traits for effective selection. However, the high heritability does not necessarily mean high genetic gain and is insufficient alone to make improvement through simple phenotypic selection. It is therefore useful to study genetic advance along with heritability.

The high heritability along with high genetic advance expressed as percent of mean (>50%) was observed for fruit diameter, leaf area, length of main stem, average green fruit weight, green fruits per plant, green fruit yield per plant, average red fruit weight, red fruits per plant, red fruit yield per plant and ascorbic acid at Palampur during 2023 and 2024, Akrot during 2024 and pooled over environments along with total soluble solids at Palampur during 2023 and 2024 and pooled over environments indicating the presence of additive gene action in the inheritance of these traits and hence, are likely to respond better to selection[27]. The moderate estimates of genetic advance and high heritability were recorded for pedicel length, fruit length, leaf length, leaf width, plant height, primary branches per plant, and internodal length during 2023 and 2024 at Palampur, Akrot during 2024 and pooled over environments along with total soluble solids at Akrot during 2024, indicating the importance of both additive and non-additive gene action[13]. All

Table 2. Estimates of parameters of genetic variability for various attributes related to marketable green and red ripe crop of chilli

Traits	Environment	GCV (%)	PCV (%)	Heritability (h^2_{bs})	Genetic Advance (% of mean)
Days to flowering	E1	9.50	9.88	92.50	18.83
	E2	9.22	9.79	88.80	17.91
	E3	10.06	10.62	89.70	19.63
	Pooled	8.71	8.89	95.80	17.56
Days to first harvest	E1	7.64	8.09	89.20	14.86
	E2	7.85	8.31	89.10	15.26
	E3	8.27	8.88	86.70	15.87
	Pooled	7.16	7.36	94.60	14.35
Pedicel length (cm)	E1	15.57	15.84	96.60	31.52
	E2	15.59	16.53	89.00	30.29
	E3	15.93	16.12	97.60	32.42
	Pooled	12.94	13.12	97.30	26.30
Fruit length (cm)	E1	23.43	23.52	99.30	48.10
	E2	24.31	24.75	96.50	49.20
	E3	23.50	23.58	99.30	48.24
	Pooled	22.04	22.11	99.40	45.26
Fruit diameter (cm)	E1	24.93	25.06	98.90	51.09
	E2	26.91	27.26	97.40	54.73
	E3	27.00	27.11	99.20	55.41
	Pooled	25.45	25.50	99.50	52.30
Leaf length (cm)	E1	20.48	20.57	99.20	42.03
	E2	19.28	19.39	98.90	39.48
	E3	18.77	18.84	99.30	38.53
	Pooled	18.47	18.53	99.30	37.91
Leaf width (cm)	E1	19.49	19.59	99.10	39.97
	E2	18.75	18.85	98.90	38.41
	E3	21.16	21.25	99.10	43.41
	Pooled	17.67	17.75	99.10	36.24

Table 2 Continued

Leaf area (cm2)	E1	37.67	37.77	99.50	77.39
	E2	34.61	34.75	99.20	71.02
	E3	34.14	34.24	99.40	70.11
	Pooled	33.79	33.88	99.50	69.42
Plant height (cm)	E1	22.19	22.65	95.90	44.76
	E2	22.09	22.53	96.20	44.62
	E3	16.64	17.80	87.40	32.06
	Pooled	19.78	20.05	97.40	40.22
Length of main stem (cm)	E1	27.94	28.25	97.80	56.92
	E2	24.88	25.06	98.50	50.88
	E3	25.73	26.25	96.00	51.93
	Pooled	25.24	25.40	98.80	51.68
Primary branches per plant	E1	17.21	18.27	88.80	33.41
	E2	16.41	17.14	91.60	32.35
	E3	16.99	17.97	89.40	33.11
	Pooled	14.41	14.78	95.00	28.93
Internodal length	E1	19.15	19.68	94.60	38.37
	E2	19.04	19.68	93.60	37.93
	E3	19.38	20.20	92.00	38.29
	Pooled	17.41	17.78	96.00	35.14
Average green fruit weight (g)	E1	58.95	59.05	99.70	121.22
	E2	61.96	62.08	99.60	127.41
	E3	53.79	53.91	99.60	110.55
	Pooled	58.14	58.19	99.80	119.67
Green fruits per plant (no.)	E1	29.32	29.53	98.60	59.96
	E2	33.34	33.67	98.00	67.99
	E3	26.94	27.21	98.00	54.94
	Pooled	28.59	28.72	99.10	58.65
Green fruit yield per plant (g)	E1	40.08	40.28	99.00	82.13
	E2	45.28	45.43	99.30	92.96
	E3	38.66	38.85	99.00	79.27
	Pooled	40.18	40.26	99.60	82.60

Table 2 Continued

Average red fruit weight (g)	E1	52.58	52.82	99.10	107.81
	E2	55.86	55.98	99.60	114.81
	E3	45.68	45.84	99.30	93.76
	Pooled	51.07	51.14	99.70	105.06
Red fruits per plant (no.)	E1	31.60	31.82	98.60	64.65
	E2	38.20	38.31	99.40	78.48
	E3	34.43	34.58	99.20	70.63
	Pooled	32.73	32.79	99.60	67.29
Red fruit yield per plant (g)	E1	37.81	37.93	99.40	77.65
	E2	43.76	43.86	99.50	89.93
	E3	39.38	39.55	99.20	80.79
	Pooled	37.93	37.98	99.70	78.02
Harvest duration (days)	E1	7.62	8.07	89.00	14.80
	E2	7.22	7.66	88.90	14.03
	E3	10.21	10.91	87.60	19.69
	Pooled	7.41	7.62	94.60	14.85
Ascorbic acid (mg/100g)	E1	49.69	49.99	98.80	101.75
	E2	49.43	49.79	98.60	101.10
	E3	38.54	38.93	98.00	78.60
	Pooled	44.80	44.97	99.20	91.93
Total soluble solids (^{0} Brix)	E1	22.06	22.50	96.10	44.57
	E2	23.06	23.23	98.60	47.17
	E3	26.41	26.54	99.00	54.14
	Pooled	23.25	23.36	99.10	47.69

where: E1 - Palampur 2023, E2 - Palampur 2024, E3 - Akrot 2024; GCV and PCV represent Genotypic and phenotypic coefficients of variation, respectively.

the remaining characters *viz.,* days to flowering, days to first harvest and harvest duration during all the environments and pooled over environments exhibited low estimates for genetic advance.

Correlation and Path Analysis

Selection for yield would only be effective if yield components influencing it directly or indirectly are taken into consideration. When selection pressure is exercised for improvement of any character highly associated with yield, it simultaneously affects a number of other correlated traits. Therefore, after getting the knowledge on the nature and magnitude of genetic variation, it is also important to gather information on the association of yield with other characters and among themselves, and their basis to

identify characters for increasing the efficiency of both direct and indirect selection and thereby, defining an ideal plant type[28,29]. In general, the genotypic correlation coefficients were higher in magnitude than the corresponding phenotypic ones, which revealed that though there is a strong inherent association between various characters, the phenotypic expression of the correlation gets reduced under the influence of environment[15].

The marketable green and red fruit yield per plant showed positive and significant correlations with pedicle length, fruit length, fruit diameter, average green fruit weight, average red fruit weight, marketable green fruits per plant, and harvest duration at both genotypic and phenotypic levels (Table 3). Earlier reports of many research workers have also revealed significant and positive association for green fruit yield per plant with related attributes[27,30], through the evaluation of different breeding materials at their respective locations. Therefore, these traits need to be given special focus for the improvement of fruit yield. Besides this, marketable green fruit yield per plant showed negative and significant correlation with days to flowering and days to first harvest, which is quite desirable to select genotypes with early fruit harvest. Days to flowering and days to first harvest exhibited positive association with leaf length, leaf width, leaf area, plant height and internodal length, whereas days to flowering also positively correlated with days to first harvest. Pedicel length, fruit length and fruit diameter were positively associated with average green fruit weight, average red fruit weight, green fruit yield per plant and red fruit yield per plant. A positive correlation among different traits was also recorded, *i.e.* pedicel length with fruit length, plant height and internodal length, fruit length with internodal length, harvest duration and total soluble solids, and fruit diameter with leaf width and harvest duration. Similarly, leaf length, leaf width, leaf area and plant height were positively correlated with each other, while plant height had a positive association with length of main stem and internodal length. The positive association of plant height with these traits is due to the increased allocation of photosynthates to the sink[31]. Lata and Sharma[4] and Banyal *et al.*[11] also reported positive association of these characters with each other.

In contrast, number of marketable green fruits per plant was negatively associated with average green fruit weight, indicating that the competition among the large number of fruits is responsible for reduced fruit size[31]. Therefore, breeders need to maintain a balance between increasing productivity and meeting consumer preference. Days to flowering and days to first harvest showed a significant correlation with fruit length, fruit diameter, average green fruit weight, average red fruit weight, red fruit yield per plant, harvest duration, ascorbic acid, total soluble solids and green fruit yield per plant. It indicates that early flowering as well as early maturing genotypes produce fruits with reduced length, width, and weight[31,32]. Fruit diameter is negatively associated with primary branches per plant, green fruit per plant and red fruit per plant; leaf width and leaf area are negatively associated with harvest duration, ascorbic acid and total soluble solids. Based on correlation studies and their coefficients of determination, it can be concluded that the selection for pedicel length, fruit length, fruit diameter, average green fruit weight, green fruit per plant and average red fruit weight can be effective for isolating plants with higher green as well as red fruit yield.

The product yield has often been described as the product of its component traits, which show inter-dependence[33]. The path coefficient analysis allows partitioning of correlation coefficients into direct and indirect effects of various traits towards the dependent variable and thus, helps in assessing the cause-effect relationship as well as effective selection. Average green fruit per plant had the maximum positive direct effect on green fruit yield per plant (Table 4), followed by marketable green fruits per plant, marketable red fruits per plant, days to harvest and leaf area with substantial magnitude. The earlier researchers have also reported direct and positive effects of these traits on green fruit yield per plant in different environments[30]. A critical analysis of direct and indirect effects of various traits on green fruit yield per plant revealed that association of red fruit yield with green fruit yield per plant was

Table 3. Estimates of genotypic and phenotypic correlation coefficients for different pairs of traits during pooled over the environments

Traits		DTH	PL	FL	FD	LL	LW	LA	PH	LMS	PBP P	IL	AGFW	MGF PP	ARF W	MRF PP	MRF YPP	HD	AA	TSS	MGF YPP
DTF	P	0.984*	-0.052	-0.280*	-0.337*	0.233*	0.287*	0.296*	0.490*	0.017	0.055	0.166*	-0.405*	-0.010	-0.407*	0.026	-0.353*	-0.984*	-0.205*	-0.227*	-0.416*
	G	0.999*	-0.047	-0.298*	-0.356*	0.243*	0.299*	0.308*	0.534*	0.015	0.070	0.183*	-0.422*	-0.011	-0.429*	0.031	-0.371*	-0.999*	-0.211*	-0.236*	-0.435*
DTH	P		-0.050	-0.267*	-0.330*	0.212*	0.262*	0.269*	0.479*	0.015	0.059	0.153*	-0.394*	-0.025	-0.395*	0.008	-0.353*	-0.999*	-0.199*	-0.226*	-0.414*
	G		-0.057	-0.287*	-0.355*	0.222*	0.272*	0.280*	0.527*	0.009	0.076	0.166*	-0.416*	-0.025	-0.422*	0.014	-0.376*	-1.000*	-0.213*	-0.239*	-0.438*
PL	P			0.420*	0.111	0.065	0.069	0.055	0.205*	-0.065	-0.023	0.253*	0.203*	0.069	0.208*	0.086	0.269*	0.052	0.032	0.080	0.256*
	G			0.430*	0.112	0.071	0.073	0.059	0.209*	-0.064	-0.025	0.267*	0.208*	0.077	0.216*	0.085	0.275*	0.056	0.030	0.086	0.266*
FL	P				0.097	0.037	0.094	0.065	0.107	-0.001	-0.225*	0.148*	0.398*	-0.099	0.413*	-0.134	0.313*	0.266*	0.080	0.146*	0.405*
	G				0.096	0.037	0.094	0.065	0.109	0.001	-0.238*	0.152*	0.401*	-0.096	0.417*	-0.134	0.315*	0.288*	0.080	0.147*	0.411*
FD	P					-0.025	0.186*	0.062	-0.043	-0.043	-0.238*	0.098	0.758*	-0.380*	0.753*	-0.351*	0.414*	0.330*	-0.030	-0.007	0.506*
	G					-0.026	0.186*	0.061	-0.049	-0.045	-0.249*	0.099	0.763*	-0.384*	0.757*	-0.354*	0.416*	0.355*	-0.029	-0.007	0.510*
LL	P						0.625*	0.901*	0.191*	0.036	0.082	0.083	-0.050	-0.043	-0.052	0.054	0.036	-0.212*	-0.143*	-0.137	-0.051
	G						0.633*	0.903*	0.196*	0.037	0.085	0.083	-0.052	-0.043	-0.053	0.055	0.035	-0.222*	-0.146*	-0.140	-0.051
LW	P							0.885*	0.374*	0.072	-0.046	0.175*	0.117	-0.139	0.123	-0.037	0.117	-0.263*	-0.151*	-0.203*	0.071
	G							0.887*	0.389*	0.075	-0.045	0.179*	0.116	-0.139	0.121	-0.035	0.117	-0.272*	-0.153*	-0.206*	0.070
LA	P								0.295*	0.057	0.043	0.122	0.012	-0.076	0.014	0.031	0.074	-0.270*	-0.152*	-0.164*	-0.002
	G								0.305*	0.059	0.046	0.123	0.010	-0.075	0.012	0.033	0.073	-0.280*	-0.154*	-0.166*	-0.002
PH	P									0.338*	-0.167*	0.662*	-0.006	-0.069	-0.010	-0.031	-0.042	-0.479*	-0.025	-0.024	-0.052
	G									0.355*	-0.185*	0.701*	-0.007	-0.071	-0.012	-0.031	-0.045	-0.526*	-0.021	-0.022	-0.054
LMS	P										-0.141*	0.306*	-0.073	-0.002	-0.078	-0.031	-0.092	-0.014	0.015	0.075	-0.073
	G										-0.152*	0.322*	-0.071	-0.004	-0.077	-0.033	-0.091	-0.008	0.014	0.076	-0.072

Table 3 Continued

PBPP	P											-0.162*	-0.378*	0.457*	-0.379*	0.411*	-0.045	-0.059	0.065	-0.031	-0.116
	G											-0.186*	-0.397*	0.482*	-0.395*	0.431*	-0.043	-0.077	0.073	-0.037	-0.121
IL	P												0.134	-0.036	0.125	0.025	0.064	-0.152*	0.051	0.016	0.046
	G												0.140	-0.037	0.129	0.027	0.068	-0.166*	0.052	0.013	0.048
AGFW	P													-0.460*	0.998*	-0.456*	0.577*	0.394*	-0.022	0.007	0.734*
	G													-0.461*	1.000*	-0.457*	0.579*	0.417*	-0.022	0.008	0.737*
MGFPP	P														-0.460*	0.874*	0.274*	0.025	0.097	0.214*	0.181*
	G														-0.464*	0.882*	0.278*	0.025	0.098	0.215*	0.178*
MRFW	P															-0.459*	0.583*	0.395*	-0.017	0.003	0.738*
	G															-0.457*	0.584*	0.423*	-0.018	0.003	0.741*
MRFPP	P																0.373*	-0.008	0.049	0.115	0.089
	G																0.375*	-0.014	0.050	0.118	0.091
MRFYPP	P																	0.353*	0.008	0.105	0.884*
	G																	0.376*	0.009	0.109	0.889*
HD	P																		0.199*	0.226*	0.414*
	G																		0.213*	0.240*	0.437*
AA	P																			0.183*	-0.004
	G																			0.184*	-0.003
TSS	P																				0.112
	G																				0.113

Table 4. Estimates of direct and indirect effects of different traits of chilli on marketable green fruit yield per plant at genotypic (G) and phenotypic (P) levels during pooled over the environments

Traits		DTF	DTH	PL	FL	FD	LL	LW	LA	PH	LMS	PBP P	IL	AGF W	MGF PP	ARF W	MRF PP	MRF YPP	HD	AA	TSS	r
DTF	P	**0.030**	0.153	0.001	-0.011	0.008	-0.006	0.005	0.002	0.012	0.000	0.000	-0.004	-0.268	-0.007	0.134	-0.017	-0.260	-0.207	0.007	0.011	-0.416*
	G	**-1.431**	0.634	-0.002	0.007	0.022	-0.036	0.000	0.073	-0.007	0.000	-0.005	0.004	-0.650	-0.008	0.521	-0.020	-0.272	0.717	0.005	0.013	-0.435*
DTH	P	0.029	**0.155**	0.001	-0.010	0.008	-0.005	0.004	0.002	0.012	0.000	-0.001	-0.003	-0.260	-0.018	0.130	-0.005	-0.261	-0.210	0.007	0.011	-0.414*
	G	-1.429	**0.636**	-0.002	0.006	0.022	-0.033	0.000	0.067	-0.006	0.000	-0.005	0.004	-0.641	-0.019	0.513	-0.009	-0.276	0.718	0.005	0.013	-0.438*
PL	P	-0.002	-0.008	**-0.012**	0.016	-0.003	-0.002	0.001	0.000	0.005	0.000	0.000	-0.005	0.134	0.049	-0.069	-0.055	0.199	0.011	-0.001	-0.004	0.256*
	G	0.115	-0.093	**0.033**	-0.009	-0.007	-0.010	0.000	0.014	-0.003	0.001	0.002	0.006	0.320	0.059	-0.262	-0.056	0.201	-0.040	-0.001	-0.005	0.266*
FL	P	-0.008	-0.041	-0.005	**0.039**	-0.002	-0.001	0.002	0.001	0.003	0.000	0.002	-0.003	0.263	-0.070	-0.136	0.086	0.231	0.056	-0.003	-0.007	0.405*
	G	0.725	-0.470	0.014	**-0.022**	-0.006	-0.005	0.000	0.015	-0.001	0.000	0.016	0.004	0.617	-0.074	-0.506	0.088	0.231	-0.206	-0.002	-0.008	0.411*
FD	P	-0.010	-0.051	-0.001	0.004	**-0.025**	0.001	0.003	0.001	-0.001	0.000	0.002	-0.002	0.500	-0.269	-0.248	0.226	0.306	0.070	0.001	0.000	0.506*
	G	0.866	-0.580	0.004	-0.002	**-0.062**	0.004	0.000	0.015	0.001	0.000	0.017	0.002	1.174	-0.293	-0.920	0.233	0.305	-0.255	0.001	0.000	0.510*
LL	P	0.007	0.033	-0.001	0.001	0.001	**-0.024**	0.011	0.007	0.005	0.000	-0.001	-0.002	-0.033	-0.030	0.017	-0.035	0.026	-0.045	0.005	0.007	-0.051
	G	-0.591	0.363	0.002	-0.001	0.002	**-0.147**	0.000	0.215	-0.002	0.000	-0.006	0.002	-0.079	-0.033	0.064	-0.036	0.026	0.159	0.003	0.007	-0.051
LW	P	0.008	0.041	-0.001	0.004	-0.005	-0.015	**0.017**	0.007	0.009	0.000	0.000	-0.004	0.077	-0.098	-0.040	0.024	0.087	-0.055	0.005	0.010	0.071
	G	-0.727	0.445	0.002	-0.002	-0.012	-0.093	**0.001**	0.211	-0.005	-0.001	0.003	0.004	0.178	-0.106	-0.147	0.023	0.086	0.195	0.003	0.011	0.070
LA	P	0.009	0.042	-0.001	0.003	-0.002	-0.022	0.015	**0.008**	0.007	0.000	0.000	-0.003	0.008	-0.053	-0.005	-0.020	0.055	-0.057	0.005	0.008	-0.002
	G	-0.748	0.458	0.002	-0.001	-0.004	-0.132	0.000	**0.238**	-0.004	-0.001	-0.003	0.003	0.016	-0.057	-0.015	-0.021	0.054	0.201	0.004	0.009	-0.002
PH	P	0.015	0.074	-0.003	0.004	0.001	-0.005	0.006	0.002	**0.025**	-0.001	0.001	-0.014	-0.004	-0.049	0.003	0.020	-0.031	-0.101	0.001	0.001	-0.052
	G	-1.299	0.862	0.007	-0.002	0.003	-0.029	0.000	0.073	**-0.012**	-0.004	0.013	0.017	-0.010	-0.054	0.014	0.021	-0.033	0.378	0.000	0.001	-0.054
LMS	P	0.001	0.002	0.001	0.000	0.001	-0.001	0.001	0.000	0.008	**-0.002**	0.001	-0.006	-0.048	-0.002	0.026	0.020	-0.068	-0.003	-0.001	-0.004	-0.073
	G	-0.037	0.014	-0.002	0.000	0.003	-0.005	0.000	0.014	-0.004	**-0.010**	0.010	0.008	-0.109	-0.003	0.093	0.022	-0.067	0.006	0.000	-0.004	-0.072

Table 4 Continued

PBP P	P	0.002	0.009	0.000	-0.009	0.006	-0.002	-0.001	0.000	-0.004	0.000	**-0.009**	0.003	-0.250	0.323	0.125	-0.264	-0.033	-0.013	-0.002	0.001	-0.116
	G	-0.171	0.125	-0.001	0.005	0.015	-0.012	0.000	0.011	0.002	0.002	**-0.069**	-0.005	-0.611	0.368	0.480	-0.283	-0.031	0.055	-0.002	0.002	-0.121
IL	P	0.005	0.024	-0.003	0.006	-0.002	-0.002	0.003	0.001	0.017	-0.001	0.001	**-0.021**	0.089	-0.026	-0.041	-0.016	0.047	-0.032	-0.002	-0.001	0.046
	G	-0.444	0.271	0.009	-0.003	-0.006	-0.012	0.000	0.029	-0.009	-0.003	0.013	**0.024**	0.216	-0.029	-0.157	-0.018	0.050	0.119	-0.001	-0.001	0.048
AGF W	P	-0.012	-0.061	-0.002	0.016	-0.019	0.001	0.002	0.000	0.000	0.000	0.003	-0.003	**0.660**	-0.326	-0.329	0.293	0.426	0.083	0.001	0.000	0.734*
	G	1.027	-0.681	0.007	-0.009	-0.047	0.008	0.000	0.002	0.000	0.001	0.027	0.003	**1.539**	-0.352	-1.215	0.301	0.425	-0.299	0.001	0.000	0.737*
MGF PP	P	0.000	-0.004	-0.001	-0.004	0.009	0.001	-0.002	-0.001	-0.002	0.000	-0.004	0.001	-0.304	**0.707**	0.152	-0.561	0.202	0.005	-0.003	-0.010	0.181*
	G	0.026	-0.042	0.003	0.002	0.024	0.006	0.000	-0.018	0.001	0.000	-0.033	-0.001	-0.710	**0.764**	0.564	-0.581	0.204	-0.018	-0.002	-0.011	0.178*
ARF W	P	-0.012	-0.061	-0.003	0.016	-0.019	0.001	0.002	0.000	0.000	0.000	0.003	-0.003	0.659	-0.326	**-0.330**	0.294	0.430	0.083	0.001	0.000	0.738*
	G	1.042	-0.691	0.007	-0.009	-0.047	0.008	0.000	0.003	0.000	0.001	0.027	0.003	1.540	-0.354	**-1.215**	0.301	0.428	-0.304	0.000	0.000	0.741*
MR FPP	P	0.001	0.001	-0.001	-0.005	0.009	-0.001	-0.001	0.000	-0.001	0.000	-0.004	-0.001	-0.301	0.618	0.151	**-0.642**	0.275	-0.002	-0.002	-0.006	0.089
	G	-0.075	0.022	0.003	0.003	0.022	-0.008	0.000	0.008	0.000	0.000	-0.030	0.001	-0.703	0.674	0.555	**-0.658**	0.275	0.010	-0.001	-0.006	0.091
MRF YPP	P	-0.010	-0.055	-0.003	0.012	-0.010	-0.001	0.002	0.001	-0.001	0.000	0.000	-0.001	0.381	0.194	-0.192	-0.239	**0.738**	0.074	0.000	-0.005	0.884*
	G	0.903	-0.615	0.009	-0.007	-0.026	-0.005	0.000	0.017	0.001	0.001	0.003	0.002	0.892	0.213	-0.710	-0.247	**0.733**	-0.270	0.000	-0.006	0.889*
HD	P	-0.029	-0.155	-0.001	0.010	-0.008	0.005	-0.004	-0.002	-0.012	0.000	0.001	0.003	0.260	0.018	-0.130	0.005	0.260	**0.211**	-0.007	-0.011	0.414*
	G	1.430	-0.637	0.002	-0.006	-0.022	0.033	0.000	-0.067	0.006	0.000	0.005	-0.004	0.642	0.019	-0.514	0.009	0.275	**-0.718**	-0.005	-0.013	0.437*
AA	P	-0.006	-0.031	0.000	0.003	0.001	0.003	-0.003	-0.001	-0.001	0.000	-0.001	-0.001	-0.015	0.069	0.006	-0.032	0.006	0.042	**-0.035**	-0.009	-0.004
	G	0.513	-0.348	0.001	-0.002	0.002	0.021	0.000	-0.037	0.000	0.000	-0.005	0.001	-0.034	0.075	0.021	-0.033	0.006	-0.153	**-0.023**	-0.010	-0.003
TSS	P	-0.007	-0.035	-0.001	0.006	0.000	0.003	-0.003	-0.001	-0.001	0.000	0.000	0.000	0.004	0.151	-0.001	-0.074	0.078	0.048	-0.006	**-0.048**	0.112
	G	0.574	-0.390	0.003	-0.003	0.000	0.021	0.000	-0.040	0.000	-0.001	0.003	0.000	0.012	0.164	-0.004	-0.078	0.080	-0.172	-0.004	**-0.053**	0.113

Significant at P ≤0.05; Residual effect: P : 0.028, G : 0.030, Where bold values indicate direct effects of correlation coefficient (r) with marketable red fruit yield per plant.

where: DTF-Days to flowering; DTH-Days to harvest; PL-pedicel length, FL-fruit length, FD-fruit diameter, LL-Leaf length, LW-Leaf width, LA-Leaf area, PH-Plant height, LMS-length of main stem, PBPP-Primary branches per plant, IL-Internodal length, AGFW-Average green fruit weight, MGFPP-Marketable green fruits per plant, ARFW-Average red fruit weight, MRFPP-Marketable red fruits per plant, MRFYPP-Marketable red fruit yield per plant, HD-Harvest duration, AA-Ascorbic acid; TSS-Total soluble solids.

mainly due to indirect effects via average green fruit weight and green fruit per plant at both phenotypic and genotypic levels, respectively. Similarly, positive association of pedicle length, fruit length and fruit diameter was mainly due to indirect effects via average green fruit weight and red fruit yield per plant along with green fruit per plant to a certain extent at both phenotypic and genotypic levels, respectively. Indirect effects via red fruit yield per plant and red fruit weight also contributed to the association with average green fruit weight at both phenotypic and genotypic levels, respectively. The magnitude of correlation of green fruit per plant and average red fruit weight was contributed indirectly through average red fruit weight and red fruit yield per plant, though average green fruit weight also contributed significantly to the association of average red fruit weight with green fruit yield. These findings suggest that these traits may not be directly selected for yield improvement, but their indirect effect on key yield-contributing traits can significantly enhance fruit yield in chilli. It can be concluded that selection of high-yielding genotypes of chilli on the basis of average green fruit per plant, marketable green fruits per plant, marketable red fruits per plant, days to harvest and leaf area would be effective.

CONCLUSION

High heritability coupled with high genetic advance was observed for average green/red fruit weight, green/red fruits per plant, green/red fruit yield, indicating the role of additive gene action and improvement in the early generations could be achieved through phenotypic selection. Correlation and path coefficient analysis revealed that pedicle length, fruit length, fruit diameter, fruit weight (red/green), green fruits/plant, red fruit yield and harvest duration at both genotypic and phenotypic levels would be considered as the best selection parameters for evolving high-yielding genotypes of chilli.

ACKNOWLEDGEMENT

Our sincere thanks to the Head, Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India, for providing the necessary facilities, support, and encouragement to carry out this research.

CONFLICT OF INTEREST

The authors declare no conflict of interest in relation to this Research article

REFERENCES

1. Thakur A, Sharma A, Sharma P, Rana RS. An insight into the problem of bacterial wilt in *Capsicum* spp. with special reference to India. Crop Prot. 2021; 140:105420. https://doi.org/10.1016/j.cropro.2020.105420
2. Lata H, Sharma A. Exploitation of heterosis in chilli using genetic male sterile lines for red fruit yield with special reference to high rainfall conditions. Sci Rep. 2024; 14(1):23061. https://doi.org/10.1038/s41598-024-73728-7 PMid:39367002 PMCid:PMC11452634
3. Negi PS, Sharma A. Genetic diversity of chilli (*Capsicum annuum* L.) genotypes. Int J Curr Microbiol Appl Sci. 2019a; 8:1820-1828. https://doi.org/10.20546/ijcmas.2019.804.211
4. Lata H, Sharma A. Evaluation, genetic variability, correlation and path analysis studies in chilli (*Capsicum annuum* L.) genotypes. Himachal J Agric Res. 2022; 1:56-64.
5. Singh V, Sharma A, Kumar N, Rana N, Srishti. Stability models regulate the adaptation of male sterility-based chilli hybrids for agro-ecologically diverse regions of north-western Himalayas. Sci Rep. 2025; 15(1):34742. https://doi.org/10.1038/s41598-025-18393-0 PMid:41053325 PMCid:PMC12500983
6. Anonymous. FAO world food and agriculture database [Internet]. 2024 [cited 2026 May 28]. Available from: https://www.fao.org/faostat/en/#data/QCL/visualize
7. Sharma A, Swain D, Sekhon BS. Breeding strategies based on diversity analysis in advanced breeding lines of chilli (*Capsicum annuum* var. *annuum* L.). Electron J Plant Breed. 2017; 8(4):1247-1257. https://doi.org/10.5958/0975-928X.2017.00179.X
8. Gokulakrishnan J, Nagaraja C, Prakash M. Genetic variability and correlation studies in chilli (*Capsicum annuum* L.). Plant Arch. 2020; 20(1):686.

9. Sharma A, Devi J. Genetic divergence in French bean for pod yield-related traits. SABRAO J Breed Genet. 2013; 45(2):240-247.
10. Sharma A, Sood M, Rana A, Singh Y. Genetic variability and association studies for green pod yield and component horticultural traits in garden pea under high hill dry temperate conditions. Indian J Hortic. 2007; 64(4):410-414.
11. Banyal N, Sharma A, Lata H. Genetic variability and trait relationship in green chilli (*Capsicum annuum* L.) under high altitude conditions. Electron J Plant Breed. 2024; 15(1):185. https://doi.org/10.37992/2024.1501.017
12. Mahardika RT, Waluyo B. Analysis of genetic variability, heritability and genetic advance in chilli (*Capsicum annuum* L.) lines. J Underutilized Crops Breed. 2025; 1(2):79-84.
13. Thakur A, Sharma A. Genetic variability, correlation and path analysis studies in cauliflower (*Brassica oleracea* var. *botrytis*). Himachal J Agric Res. 2023; 27:185-193.
14. Sharma A, Sharma P, Kumar N, Prashar A, Singh V. Genetic variability and correlation analysis in F2 segregating population of cross Him Palam Matar-1 × L-40-1014 of garden pea (*Pisum sativum* L.). Himachal J Agric Res. 2025a; 25:37-44.
15. Sharma A, Sharma S, Kumar N, Rana RS, Sharma P, Kumar P, *et al*. Morpho-molecular genetic diversity and population structure analysis in garden pea (*Pisum sativum* L.) genotypes using simple sequence repeat markers. PLoS One. 2022; 17(9). https://doi.org/10.1371/journal.pone.0273499 PMid:36112614 PMCid:PMC9480992
16. Burton GW, DeVane EH. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. Agron J. 1953; 45:478-481. https://doi.org/10.2134/agronj1953.00021962004500100005x
17. Johnson HW, Robinson HF, Comstock RE. Estimates of genetic and environmental variability in soybeans. Agron J. 1955; 47:314-318. https://doi.org/10.2134/agronj1955.00021962004700070009x
18. Al-Jibouri HA, Miller PA, Robinson HF. Genotypic and environmental variances and covariances in an upland cotton cross of interspecific origin. Agron J. 1958; 50:633-636. https://doi.org/10.2134/agronj1958.00021962005000100020x
19. Dewey DR, Lu KH. A correlation and path-coefficient analysis of components of crested wheatgrass seed production. Agron J. 1959; 51:515-518. https://doi.org/10.2134/agronj1959.00021962005100090002x
20. Sharma A, Sekhon BS, Sharma S, Kumar R. Newly isolated intervarietal garden pea (*Pisum sativum* L.) progenies (F7) under north western Himalayan conditions of India. Exp Agric. 2020; 56(1):76-87. https://doi.org/10.1017/S0014479719000115
21. Sharma S, Sharma A. Srishti. Studies on genetic variability and character association for green pod yield and component horticultural traits in garden pea (*Pisum sativum* L.) under North-Western Himalayas. Vegetos. 2025b; 9:1-10. https://doi.org/10.1007/s42535-025-01261-7
22. Sharma A, Rana V, Basandrai D, Kumar S, Kumar N, Mohapatra A, *et al*. Genetic variability and correlation studies based on diverse wheat panel for grain yield and related attributes under north-western Himalayan conditions. Vegetos. 2025c; 1-12. https://doi.org/10.1007/s42535-025-01400-0
23. Sharma A, Devi J, Katoch V. Genetic variability and genotypic × environment interaction for seed yield and related traits in French bean germplasm. Indian J Plant Genet Resour. 2016; 29(2):156-162. https://doi.org/10.5958/0976-1926.2016.00022.X
24. Sekhon BS, Sharma A, Katoch V, Kapila RK, Sood VK. Assessment of genetic diversity in advanced breeding lines derived from intraspecific crosses of garden pea (*Pisum sativum* L.). Legume Res. 2019; 42(2):145-152. https://doi.org/10.18805/LR-3923
25. Devi J, Sharma A, Singh Y, Katoch V, Sharma KC. Genetic variability and character association studies in French beans (*Phaseolus vulgaris* L.) under North-western Himalayas. Legume Res. 2015; 38(2):149-156. https://doi.org/10.5958/0976-0571.2015.00066.1
26. Banyal N, Sharma A. Genetic variation and association among quantitative and qualitative traits to design breeding strategy in red ripe chilli (*Capsicum annuum* L.) under North-Western Himalayas. Veg Sci. 2023; 50(2):322-329. https://doi.org/10.61180/vegsci.2023.v50.i2.09
27. Sharma A, Swain D. Estimation of genetic variability in advance breeding lines derived from inter-varietal crosses in chilli. Indian J Hortic. 2018; 75(3):440-445. https://doi.org/10.5958/0974-0112.2018.00074.9
28. Sharma A, Bhardwaj A, Katoch V, Sharma JD. Assessment of genetic diversity of garden pea (*Pisum*

sativum) as perspective to isolate horticulturally desirable transgressive segregants. Indian J Agric Sci. 2013; 83(12):1334-1339.

29. Bhardwaj A, Sharma A, Lata H. Genetic variability for pod yield and related traits in garden pea (*Pisum sativum* L.). Electron J Plant Breed. 2020; 11(4):1233-1238. https://doi.org/10.37992/2020.1104.199
30. Negi PS, Sharma A. Determination of selection parameters for genetic improvement by evaluating F7 progenies of green chilli. Veg Sci. 2019b; 46(1-2):102-106. https://doi.org/10.61180/4a4sp204
31. Lekshmanan DK, Pradeepkumar T, Minimol JS, Mathew D, Aswini A, Resmi CR. Association of yield and its attributing characters for selecting superior genotypes in chilli (*Capsicum annuum* L.). Biol Forum Int J. 2024; 16(10):104-108.
32. Ajjappalavara PS, Patil SS, Hosmani RM, Patil AA, Gangaprasad S. Correlation and path coefficient analysis in chilli. Karnataka J Agric Sci. 2005; 18(3):748-751.
33. Wilson DR. New approaches to understanding the growth and yield of pea crops. Agron Soc N Z. 1987; 6:23-28.

AUTHORS CONTRIBUTION

VS: executed the experimental work, analyzed the data and prepared the initial manuscript draft. AS: conceived the research, designed the methodology, facilitated the study and critically revised the manuscript. PS: data organization and validation. AS: assisted with data acquisition and curation. AP: experimental investigations, data interpretation and manuscript review. NS: data analysis and manuscript review.