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RESEARCH PAPER

Genetic variation and association among quantitative and qualitative traits to design breeding strategy in red ripe chili (*Capsicum annuum* L.) under North-Western Himalayas

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Abstract

An attempt was made to determine the degree of genetic variability, the association between different characters, direct and indirect effects of component traits on red ripe fruit yield of chili based on the evaluation of thirty-two genotypes during the summer-rainy season 2020. The analysis of variance revealed that the genotypes differed significantly among themselves for all the traits. Based on mean performance, nine genotypes significantly out yielded standard check 'Him Palam Mirch-2' for red ripe fruit yield while only three genotypes viz., 'DPCH-32-11' (96.16 g) followed by 'DPCH-40-2' (87.32 g) and 'DPCH-38-121' (75.75 g) recorded significantly highest dry fruit yield compared to 'Him Palam Mirch-2'. High phenotypic, genotypic coefficient of variation, and high heritability coupled with high genetic advance were recorded for dry fruit yield per plant, marketable red ripe fruits per plant, and red ripe fruit yield per plant indicating that these traits have a strong potential for effective selection. Red ripe fruit yield per plant had a positive association with dry fruit yield per plant, percent marketable red fruits per plant, marketable red fruits per plant, total red fruits per plant, average red fruit weight, average dry fruit weight, number of seeds per fruit and fruit length, thereby emphasizing a special focus on these traits for the improvement of yield. Path analysis further confirmed to focus on these traits to achieve genetic gain and yield advantage in red ripe chili.

Keywords: Correlation, Genetic variability, Heritability, Path analysis, Red ripe Chili.

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Introduction

Chili (*Capsicum annuum* L.) is one among the five domesticated species and is most widely grown for economic and nutritional considerations (Chandela *et al*., 2021; Talwar *et al*., 2022). It is a spice cum vegetable crop belonging to the family Solanaceae with chromosome number is 2n = 24. It is a native of Mexico, which was brought into India by the Portuguese before 1785 AD from Brazil. After tomato, it is the second most significant solanaceous vegetable grown worldwide (Hasan *et al*., 2015). Chili is an often-cross-pollinated crop with a high rate of natural cross-pollination, which contributes to its variability (Hasanuzzaman *et al*., 2012). Due to its pungency, flavor, color, and taste, it is a necessary spice in every home in the tropical world (Kumar *et al*., 2005). A wide variety of pain issues, including post-mastectomy syndrome, psoriasis urticaria, diabetic neuropathy, pruritis arthritis, contact allergy, and post-surgical neuromas are helped by capsaicin, a crystalline acrid volatile alkaloid, present in the placenta of fruit (Chattar *et al*., 2016; Hasan *et al*., 2015).

There is a great deal of variation in fruit morphology, bearing habit, pungency, and crop duration of the Chili germplasm which is spread throughout North India (Kumar *et al*., 2009). Fruit length in Chili influences consumer

acceptance and directly affects yield (Arjun *et al*., 2018). It has a lot of genetic variety in terms of most yield parameters. Chili hybrids have become popular among farmers all over the world, due to their high-yielding characteristics including high number of fruits per plant and an increase in fruit weight, uniform fruit size, very attractive and uniform fruit color and early maturity. Improvement of yield-related traits has continued to be a top priority in Chili breeding (Herath *et al*., 2021). The productivity of the crop is low due to the large area covered by low-yielding genotypes. Hence, there is a need to discover novel high-yielding cultivars and hybrids. Any crop development effort must prioritize the collection of varied germplasm and its rigorous evaluation. Many local Chili cultivars have experienced increased variability and new genetic combinations as a result of the free exchange of Chili germplasm and a lot of character introgression. Genetic variability in germplasm defines the level of triumph in the perfection of such germplasm through selection (Sharma *et al*., 2019). The information about the variability in germplasm is indispensable for successful conservation, protection and its utilization in breeding programs, and also for augmentation the genetic base of cultivated varieties (Sharma *et al*., 2022). Genetic variability along with heritability should be addressed for measuring the maximal and accurate effect of selection in a crop breeding program because the degree to which variability of a character is transmitted to progeny is of highest relevance. The level of success in improving germplasm through selection is determined by genetic heterogeneity in the germplasm, which provides the opportunity to improve production and quality through a systematic breeding program. Using relevant biometrical and genetic tools, the proportion of genotypic, environmental, and their interaction (G×E) can be estimated. Understanding inter-character relationships is important in plant breeding for indirect selection of traits that are difficult to assess as well as the direct and indirect effects of each component on yield, are all useful in developing an effective breeding strategy (Sharma *et al*., 2007). Thus, the present study was undertaken to identify traits contributing to higher yield in Chili.

Materials and Methods

Thirty-two genotypes of chili (*Capsicum annuum* L.) were grown in a randomized block design with three replications during the year 2020 at the Experimental Farm of the Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, HP. The experimental field is situated at 32^0 6′ N latitude and 76^0 3′ E longitude with an altitude of 1,290.8 m msl reflects the mid-hill zone of Himachal Pradesh which receives 2,500 mm of annual precipitation. The soil is classified as alfisols typic Hapludalf clay with a pH of 5.7. In 32 genotypes of chili, including five genotypes from All India Coordinated Research Project on Vegetable Crops and three checks *viz.,* Him Palam Mirch-1, Him Palam Mirch-2 and Surajmukhi were systematically evaluated in randomized complete block design, replicated thrice. The experimental material was sown in the nursery bed of size 3 m × 1 m × 15 cm. The plot size was two rows of length 2.25 m with spacing of 45 cm between rows and 45 cm between plants within rows.

The observations were recorded on randomly taken five plants of each genotype for seventeen traits in each replication *viz.,* primary branches/plant, secondary branches/plant, plant height, fruit length, pedicel length, fruit girth, average red ripe fruit weight, marketable red ripe fruits/plant, total red ripe fruits/plant, percent marketable red ripe fruits/plant, red ripe fruit yield/plant, harvest duration, average dry fruit weight, dry fruit yield/plant, seeds/fruit, capsaicin content and oleoresin content. Analysis of variance was computed according to the method given by Gomez and Gomez (1983). The capsaicin content in the dry fruit was determined by the Colorimetric method using theFolin–Ciocalteu (FC) reagent described by Bajaj (1980). Oleoresin content was estimated as per the procedure given by A.O.A.C. (1980). The data were analyzed for estimation of the genotypic, phenotypic and environmental coefficient of variation following Burton and De Vane (1953). Correlation coefficients were computed according to the method given by Al-Jibouri *et al*. (1958). Path coefficient analysis was carried out by Dewey and Lu (1959).

Results and Discussion

Based on mean performances, six genotypes significantly had more pedicel length than the best check 'Him Palam Mirch-1' (Table 1). The highest fruit length was recorded in DPCH 502. Genotypes DPCH-39-12 and 2019/CHIVAR 6 had significantly more primary branches per plant whereas DPCH-13-1 developed more secondary branches per plant. Similarly, DPCH-29-12 and 2019/CHIVAR-5 recorded maximum plant height and average red fruit weight, respectively. Two genotypes DPCH-29-11 and DPCH-29-12 found to had significantly high capsaicin content while the other two genotypes DPCH-28-13 and DPCH-33-2 were significantly superior for oleoresin content over best check 'Him Palam Mirch-1' (Table 2). Genotypes DPCH-US-1 and DPCH-32-11 bore a significantly maximum number of total as well as marketable red ripe fruits per plant. The mean performance for red ripe fruit yield per plant differed from 101.47 to 428.83 g with an average value of 279.62 g. Nine genotypes namely, '2019/CHIVAR-6' (428.83 g), 'DPCH-40-2' (428.23 g), 'DPCH-38-121' (417.67 g), 'DPCH-502' (404.58 g), 'DPCH-33-2' (389.33 g), 'DPCH-38-22' (382.50 g), 'DPCH-29-12' (373.83 g), 'DPCH-38-122' (372.11 g) and 'DPCH-US-1' (368.53 g) had significantly higher red ripe fruit yield in comparison to the best check 'Him Palam Mirch-2'. On the other hand, the

Table 1: Mean performance of top 10 genotypes of Chili for red ripe (spice)/dry fruit yield and related traits in comparison to check varieties

Traits	*PL*	*FL*	*FG*	*PBPP*	*SBPP*	*PH*	*ARRFW*	*MRRFPP*	*TRRFPP*	*% MRRFPP*	*RRFYPP*	*HD*	*ADFW*	*DFYPP*	*NSPF*	*CC*	*OC*
DPCH 29-12	2.71	6.38	4.15[2]	2.33	8.83	83.11[1]	4.82[8]	77.57[9]	91.96	84.35	373.83[7]	44.67	0.93[2]	71.86[4]	57.00[9]	0.26[1]	36.24
DPCH 32-11	3.12	6.70	3.33	2.00	11.83	51.90	3.08	118.69[2]	130.13[2]	91.20[3]	363.50[10]	44.67	0.81[8]	96.14[1]	50.67	0.18[9]	48.38
DPCH 33-2	3.07	7.22	2.62	2.44	10.19	52.82	3.67	107.00[4]	120.31[3]	88.95[4]	389.33[5]	43.67	0.58	61.50[10]	34.00	0.20[7]	71.34[2]
DPCH 38-121	3.52	11.03[2]	3.35	2.57	10.36	56.60	5.50[4]	76.50[10]	89.11	85.83[9]	417.67[3]	45.00	0.99[1]	75.75[3]	47.00	0.23[4]	35.09
DPCH 38-122	4.28[3]	10.09[5]	3.62	3.08[5]	11.62	57.99	5.83[2]	63.87	76.95	83.01	372.11[8]	49.00[3]	0.92[3]	68.50[5]	61.00[2]	0.24[3]	41.16
DPCH 38-22	4.07[6]	9.12	3.58	2.92[9]	11.42	64.83[8]	4.67	82.26[7]	98.93[7]	83.14	382.50[6]	45.33	0.83[7]	68.48[6]	59.67[5]	0.22[5]	41.27
DPCH 40-2	3.69	10.62[3]	3.55	2.83	12.86[6]	68.22[3]	4.03	109.22[3]	119.53[4]	91.38[2]	428.53[2]	47.67[6]	0.80[9]	87.32[2]	61.00[2]	0.20[7]	56.90[5]
DPCH 502	4.35[1]	11.38[1]	3.72	3.00[7]	12.75[7]	58.39	5.50[4]	74.43	87.79	84.71[10]	404.58[4]	48.00[5]	0.91[4]	67.96[7]	61.33[1]	0.22[5]	49.85[9]
DPCH-US 1	3.63	7.21	3.68	3.00[7]	12.53[8]	44.23	3.02	122.43[1]	139.54[1]	87.72[5]	368.53[9]	46.67[9]	0.55	67.04[8]	43.67	0.25[2]	45.10
2019/ CHIVAR 6	3.57	8.54	3.82[7]	3.63[2]	11.25	54.04	4.67	92.07[5]	100.49[6]	91.65[1]	428.83[1]	45.33	0.76	70.00	60.67[3]	0.17[10]	59.73[4]
Him Palam Mirch-1 (C)	4.05	6.92	3.15	3.08	13.75	60.38	2.80	116.02	125.27	92.61	324.94	42.33	0.64	73.86	49.33	0.24	65.37
Him Palam Mirch-2 (C)	3.64	8.70	3.90	2.33	12.50	58.33	5.17	70.41	85.66	82.21	363.58	44.67	0.86	60.52	52.67	0.22	37.72
Surajmukhi (C)	3.42	5.87	3.15	3.58	12.55	64.28	2.67	100.94	108.00	93.49	270.67	44.33	0.56	56.55	49.00	0.26	63.77
Mean	3.60	8.36	3.56	2.83	11.52	58.02	4.19	70.37	89.14	76.93	279.62	45.45	0.73	51.27	51.36	0.21	48.42
Range	2.71-4.35	5.39-11.38	2.62-4.37	2.00-3.72	6.75-15.86	34.76-83.11	2.50-7.57	24.87-122.43	53.89-139.54	36.30-93.49	101.47-428.83	40.33-51.33	0.51-0.99	18.40-96.14	34.00-61.33	0.16-0.26	34.44-75.37
S.E(m)	0.12	0.17	0.06	0.17	0.51	1.87	0.16	2.05	2.37	0.99	8.21	1.70	0.02	2.06	1.81	0.01	1.60
C.D (5%)	0.34	0.47	0.16	0.49	1.43	5.27	0.46	5.78	6.69	2.78	23.21	4.79	0.05	5.83	5.12	0.01	4.51
C.V (%)	5.85	3.50	2.78	10.68	7.62	5.56	6.72	5.04	4.59	2.21	5.08	6.46	4.68	6.97	6.10	5.25	5.71

Where, PL: Pedicel length (cm); FL: Fruit length (cm); FG: Fruit girth (cm); PBPP: Primary branches per plant; SBPP: Secondary branches per plant; PH: Plant height (cm); ARRFW: Average red ripe fruit weight (g); MRRFPP: Marketable red ripe fruits per plant; TRRFPP: total red ripe fruits per plant; %MRRFPP: Percent marketable red ripe fruits per plant; RRFYPP: Red ripe fruit yield per plant (g); HD: Harvest duration (days); ADFW: Average dry fruit weight (g); DFYPP: Dry fruit yield per plant (g); NSPF: Numer of seeds per fruit; CC: Capsaicin content (%); OC: Oleoresin content (ASTA units)
*Superscript (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10) indicates top ten ranking genotype

Table 2: Estimates of different parameters of variability for various traits

Traits	*Genotypic variance*	*Phenotypic variance*	*GCV (%)*	*PCV (%)*	h^2_{bs}	*GA (%)*
Primary branches per plant	0.15	0.25	13.87	17.51	62.78	22.65
Secondary branches per plant	3.38	4.15	15.94	17.67	81.37	29.63
Plant height (cm)	81.13	91.58	15.52	16.49	88.59	30.09
Fruit length (cm)	2.37	2.46	18.40	18.73	96.50	37.25
Pedicel length (cm)	0.18	0.22	11.71	13.09	79.99	21.58
Fruit girth (cm)	0.13	0.14	10.26	10.63	93.15	20.41
Average red ripe fruit weight (g)	1.36	1.44	27.78	28.58	94.47	55.63
Marketable red ripe fruits per plant	719.59	732.18	38.11	38.44	98.28	77.84
Total red ripe fruits per plant	501.09	517.89	25.11	25.52	96.75	50.88
Per cent marketable red ripe fruits/ plant	216.82	219.73	19.13	19.26	98.67	39.16
Red ripe fruit yield per plant (g)	9402.50	9604.86	34.67	35.04	97.89	70.67
Harvest duration	4.06	12.69	4.43	7.83	32.00	5.16
Average dry fruit weight (g)	0.02	0.02	17.94	18.54	93.67	35.74
Dry fruit yield per plant	400.85	413.64	39.04	39.66	96.90	79.18
Number of seeds per fruit	47.97	57.82	13.48	14.80	82.97	25.30
Capsaicin content (%)	0.00	0.00	13.11	14.13	86.08	25.06
Oleoresin content (ASTA units)	116.02	123.69	22.24	22.96	93.80	44.38

PCV and GCV represent phenotypic and genotypic coefficients of variation, respectively; h^2_{bs}: Heritability in broad sense; GA (%): Genetic advance (%) of mean

mean performance for dry fruit yield per plant was found to be 51.27 g, which ranged from 18.40 to 96.14 g. The genotype 'DPCH-32-11' (96.16 g) followed by 'DPCH-40-2' (87.32g) and 'DPCH-38-121' (75.75g) recorded significantly highest dry fruit yield compared to 'Him Palam Mirch-2'.

Understanding the phenotypic and genotypic coefficients of variation supports in the establishment of a successful breeding program by predicting the amount of variability in a genetic stock. For all the traits studied (Table 2), PCV was slightly higher than GCV, indicating that the environment had a significant impact on their expression. The highest values of PCV and GCV were recorded in dry fruit yield per plant followed by marketable red ripe fruits per plant and red ripe fruit yield per plant, exhibiting high variability, implying that selection can improve these characteristics. Earlier workers have also reported high PCV and GCV for these traits, *i.e.,* Rathod *et al*. (2002) for red ripe fruit yield per plant, and Tirupathamma *et al*. (2021) for dry fruit yield per plant. Moderate estimates of PCV and GCV were observed for most of the characters demonstrating that hybridization would be a viable option for achieving desirable improvement. The genotypic coefficient of variation measures overall genetic variance, whereas heritability determines how much of a trait's variability is passed on to offspring (Lush, 1940). High heritability (>80%) estimates were observed for all the traits except harvest duration and primary branches per plant. High heritability in these traits indicated that these traits are genetically determined and least influenced by the environment. High heritability, on the other hand, does not always imply high genetic gain and heredity alone is insufficient to predict improvement by simple phenotypic selection. High heritability (>80%) along with high genetic advance (>50%) were observed for marketable red ripe fruits per plant, red ripe fruit yield per plant, dry fruit yield per plant, total red fruits per plant and average red fruit weight (Table 4), proving the significance of additive gene action in the manifestation of these attributes (Negi and Sharma, 2019; Sharma *et al*., 2007).

The genotypic correlation coefficients were significantly greater than the phenotypic correlation coefficients (Table 3), indicating that the traits analyzed were intrinsically linked. Red ripe fruit yield/plant showed positive and significant correlation at both phenotypic and genotypic levels with dry fruit yield/plant followed by percent marketable red fruits/plant, marketable red fruits/plant, total red fruits/plant, average red fruit weight, average dry fruit weight, number of seeds/fruit and fruit length (Negi and Sharma, 2019). Similarly, dry fruit yield/plant revealed a positive correlation with marketable red fruits/plant, percent marketable red fruits/plant, total red fruits/plant, average dry fruit weight and secondary branches/plant. Earlier workers also reported

Table 3: Estimates of phenotypic and genotypic correlation coefficients for different pair of traits in red ripe (spice) Chili

Traits		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
Days to flowering	P	0.262*	0.233*	0.423*	0.05	0.348*	-0.001	-0.029	0.058	-0.119	0.353*	-0.028	0.066	-0.064	0.263*	-0.032	0.175	0.099
	G	0.362*	0.319*	0.496*	0.074	0.415*	-0.006	-0.057	0.058	-0.154	0.406*	-0.036	0.065	-0.094	0.318*	0.015	0.235*	0.098
Primary branches	P		0.300*	-0.106	0.195	0.308*	-0.021	0.099	0.078	0.01	0.17	-0.246*	-0.033	-0.114	0.118	0.052	0.125	0.122
	G		0.383*	-0.177	0.265*	0.442*	0.002	0.145	0.085	-0.002	0.213*	-0.268*	-0.038	-0.17	0.164	0.009	0.178	0.161
Secondary branches	P			0.013	0.032	0.184	-0.138	-0.082	0.246*	0.154	0.333*	-0.028	0.201*	0.135	-0.09	-0.002	0.294*	0.171
	G			-0.02	0.049	0.220*	-0.155	-0.082	0.271*	0.169	0.372*	-0.027	0.223*	0.325*	-0.122	-0.022	0.319*	0.188
Plant height (cm)	P				0.119	-0.166	0.356*	0.263*	-0.117	-0.225*	0.076	0.353*	0.097	-0.046	0.354*	0.105	0.047	0.144
	G				0.121	-0.260*	0.384*	0.289*	-0.132	-0.253*	0.082	0.384*	0.093	-0.044	0.396*	0.145	0.052	0.138
Fruit length (cm)	P					0.368*	0.239*	0.666*	-0.275*	-0.303*	-0.139	0.411*	-0.014	0.051	0.481*	-0.149	-0.250*	0.287*
	G					0.407*	0.254*	0.697*	-0.284*	-0.316*	-0.146	0.429*	-0.017	0.072	0.536*	-0.171	-0.256*	0.291*
Pedicel length (cm)	P						-0.006	0.127	-0.03	-0.118	0.131	-0.036	-0.02	-0.056	0.293*	-0.053	-0.042	0.074
	G						-0.023	0.124	-0.03	-0.137	0.153	-0.042	-0.022	-0.244*	0.321*	-0.064	-0.047	0.079
Fruit girth (cm)	P							0.521*	-0.393*	-0.417*	-0.245*	0.376*	-0.165	0.073	0.434*	0.105	-0.265*	0.003
	G							0.534*	-0.396*	-0.421*	-0.251*	0.385*	-0.171	0.181	0.523*	0.13	-0.266*	0.007
Average red fruit weight (g)	P								-0.456*	-0.549*	-0.187	0.447*	-0.177	-0.06	0.344*	-0.083	-0.239*	0.290*
	G								-0.452*	-0.548*	-0.185	0.474*	-0.166	-0.113	0.384*	-0.087	-0.244*	0.294
Marketable red fruits/plant	P									0.937*	0.798*	-0.17	0.859*	0.021	-0.058	0.169	0.311*	0.687*
	G									0.939*	0.803*	-0.177	0.864*	0.035	-0.073	0.189	0.323*	0.693*
Total red fruits/ plant	P										0.549*	-0.270*	0.739*	0.012	-0.078	0.107	0.240*	0.537*
	G										0.561*	-0.282*	0.744*	0	-0.097	0.121	0.249*	0.544*
Per cent marketable red fruits/plant	P											0.032	0.793*	0.057	0.029	0.237*	0.303*	0.729*
	G											0.032	0.802*	0.119	0.02	0.264*	0.316*	0.736*
Average dry fruit weight (g)	P												0.332*	0.296*	0.315*	0.128	-0.156	0.287*
	G												0.318*	0.573*	0.350*	0.15	-0.153	0.296*
Dry fruit yield/ plant (g)	P													0.126	0.165	0.141	0.176	0.822*
	G													0.226*	0.169	0.168	0.19	0.834*
Harvest duration	P														0.091	0.209*	-0.051	0.02
	G														0.135	0.432*	-0.071	0.019
Number of seeds	P															-0.041	-0.226*	0.282*
	G															-0.031	-0.240*	0.290*
Capsaicin content (%)	P																-0.03	0.094
	G																-0.046	0.121
Oleoresin content (ASTA units)	P																	0.127
	G																	0.136

* Significant at P ≤ 0.05

1-Primary branches per plant; 2-Secondary branches per plant; 3-Plant height (cm); 4-Fruit length (cm); 5-Pedicel length (cm); 6-Fruit girth (cm); 7-Average red fruit weight (g); 8-Marketable red fruits per plant; 9-Total red fruits per plant; 10-Per cent marketable red fruits per plant; 11-Average dry fruit weight (g); 12-Dry fruit yield per plant (g); 13-Harvest duration; 14-Number of seeds; 15-Capsaicin content (%); 16-Oleoresin content (ASTA units); 17-Red ripe fruit yield per plant (g);

Table 4: Estimates of direct and indirect effects of different traits on red ripe fruit yield per plant at phenotypic (P) and genotypic (G) levels in red ripe Chili

Traits		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*r*
Days to flowering	P	0.019	0.003	-0.014	0.020	0.004	0.000	0.000	-0.019	-0.010	-0.111	0.221	-0.006	-0.011	0.000	-0.001	0.002	0.002	0.099
	G	0.273	-0.007	-0.031	-0.042	0.004	-0.011	0.000	-0.042	-0.052	-0.265	0.334	-0.014	-0.018	0.006	-0.036	-0.001	0.001	0.098
Primary branches	P	0.005	0.011	-0.018	-0.005	0.015	0.000	0.000	0.064	-0.013	0.010	0.107	-0.056	0.006	0.001	0.000	-0.004	0.001	0.122
	G	0.099	-0.019	-0.037	0.015	0.014	-0.012	0.000	0.108	-0.077	-0.003	0.176	-0.107	0.010	0.011	-0.019	0.000	0.001	0.161
Secondary branches	P	0.004	0.003	-0.060	0.001	0.002	0.000	0.000	-0.053	-0.041	0.145	0.208	-0.006	-0.034	-0.001	0.000	0.000	0.003	0.171
	G	0.087	-0.007	-0.097	0.002	0.003	-0.006	-0.011	-0.062	-0.244	0.291	0.306	-0.011	-0.060	-0.020	0.014	0.001	0.001	0.188
Plant height	P	0.008	-0.001	-0.001	0.047	0.009	0.000	0.001	0.169	0.019	-0.212	0.047	0.081	-0.016	0.000	-0.001	-0.008	0.000	0.144
	G	0.136	0.003	0.002	-0.085	0.007	0.007	0.026	0.216	0.119	-0.438	0.067	0.154	-0.025	0.003	-0.045	-0.008	0.000	0.138
Fruit length	P	0.001	0.002	-0.002	0.006	0.075	0.000	0.001	0.428	0.046	-0.285	-0.087	0.094	0.002	0.000	-0.001	0.011	-0.003	0.287*
	G	0.020	-0.005	-0.005	-0.010	0.054	-0.011	0.017	0.521	0.256	-0.546	-0.120	0.171	0.005	-0.005	-0.061	0.010	-0.001	0.291*
Pedicel length	P	0.007	0.003	-0.011	-0.008	0.028	-0.001	0.000	0.082	0.005	-0.111	0.082	-0.008	0.003	0.000	-0.001	0.004	0.000	0.074
	G	0.113	-0.008	-0.021	0.022	0.022	-0.027	-0.002	0.093	0.027	-0.237	0.126	-0.017	0.006	0.015	-0.037	0.004	0.000	0.079
Fruit girth	P	0.000	0.000	0.008	0.017	0.018	0.000	0.003	0.335	0.065	-0.392	-0.154	0.086	0.028	-0.001	-0.001	-0.008	-0.003	0.003
	G	-0.002	0.000	0.015	-0.033	0.014	0.001	0.068	0.400	0.357	-0.727	-0.207	0.154	0.046	-0.011	-0.060	-0.007	-0.001	0.007
Av. red ripe fruit weight	P	-0.001	0.001	0.005	0.012	0.050	0.000	0.002	0.642	0.076	-0.516	-0.117	0.102	0.030	0.000	-0.001	0.006	-0.002	0.290*
	G	-0.015	-0.003	0.008	-0.025	0.038	-0.003	0.036	0.748	0.407	-0.946	-0.152	0.189	0.045	0.007	-0.044	0.005	-0.001	0.294*
Marketable red ripe fruits	P	0.001	0.001	-0.015	-0.006	-0.021	0.000	-0.001	-0.293	-0.166	0.880	0.500	-0.039	-0.145	0.000	0.000	-0.012	0.003	0.687*
	G	0.016	-0.002	-0.026	0.011	-0.015	0.001	-0.027	-0.338	-0.901	1.622	0.661	-0.071	-0.234	-0.002	0.008	-0.011	0.001	0.693*
Total red ripe fruit/ plant	P	-0.002	0.000	-0.009	-0.011	-0.023	0.000	-0.001	-0.352	-0.156	0.939	0.344	-0.062	-0.125	0.000	0.000	-0.008	0.002	0.537*
	G	-0.042	0.000	-0.016	0.022	-0.017	0.004	-0.029	-0.410	-0.847	1.727	0.462	-0.113	-0.202	0.000	0.011	-0.007	0.001	0.544*
% Marketable red ripe fruits	P	0.007	0.002	-0.020	0.004	-0.010	0.000	-0.001	-0.120	-0.133	0.516	0.626	0.007	-0.134	0.000	0.000	-0.017	0.003	0.729*
	G	0.111	-0.004	-0.036	-0.007	-0.008	-0.004	-0.017	-0.138	-0.724	0.968	0.823	0.013	-0.218	-0.007	-0.002	-0.015	0.001	0.736*
Av. dry fruit weight	P	-0.001	-0.003	0.002	0.017	0.031	0.000	0.001	0.287	0.028	-0.254	0.020	0.228	-0.056	-0.002	-0.001	-0.009	-0.002	0.287*
	G	-0.010	0.005	0.003	-0.033	0.023	0.001	0.026	0.354	0.159	-0.487	0.027	0.400	-0.086	-0.036	-0.040	-0.008	-0.001	0.296*
Dry fruit yield/ plant	P	0.001	0.000	-0.012	0.005	-0.001	0.000	-0.001	-0.114	-0.143	0.694	0.496	0.076	-0.169	-0.001	0.000	-0.010	0.002	0.822*
	G	0.018	0.001	-0.022	-0.008	-0.001	0.001	-0.012	-0.124	-0.779	1.285	0.661	0.127	-0.271	-0.014	-0.019	-0.009	0.001	0.834*
Harvest durations	P	-0.001	-0.001	-0.008	-0.002	0.004	0.000	0.000	-0.039	-0.004	0.012	0.035	0.068	-0.021	-0.007	0.000	-0.015	-0.001	0.020
	G	-0.026	0.003	-0.031	0.004	0.004	0.007	0.012	-0.085	-0.031	0.000	0.098	0.229	-0.061	-0.063	-0.015	-0.024	0.000	0.019
Number of seeds/fruits	P	0.005	0.001	0.005	0.017	0.036	0.000	0.001	0.221	0.010	-0.074	0.018	0.072	-0.028	-0.001	-0.003	0.003	-0.002	0.282*
	G	0.087	-0.003	0.012	-0.034	0.029	-0.009	0.036	0.287	0.066	-0.168	0.017	0.140	-0.046	-0.008	-0.115	0.002	-0.001	0.290*
Capsaicin content (%)	P	-0.001	0.001	0.000	0.005	-0.011	0.000	0.000	-0.054	-0.028	0.101	0.148	0.029	-0.024	-0.001	0.000	-0.071	0.000	0.094
	G	0.004	0.000	0.002	-0.012	-0.009	0.002	0.009	-0.065	-0.171	0.209	0.218	0.060	-0.046	-0.027	0.004	-0.056	0.000	0.121
Oleoresin content	P	0.003	0.001	-0.018	0.002	-0.019	0.000	-0.001	-0.154	-0.052	0.225	0.190	-0.036	-0.030	0.000	0.001	0.002	0.010	0.127
	G	0.064	-0.003	-0.031	-0.004	-0.014	0.001	-0.018	-0.182	-0.291	0.429	0.260	-0.061	-0.052	0.004	0.027	0.003	0.004	0.136

Residual effect at phenotypic level (P) =0.02580, and genotypic level (G) = - 0.00088. Significant at P ≤0.05; bold values indicate direct effects; r correlation coefficient with red ripe fruit yield per plant

1-Days to flowering; 2-Primary branches/plant; 3-Secondary branches/ plant; 4-Plant height (cm); 5-Fruit length (cm); 6-Pedicel length (cm); 7-Fruit girth (cm); 8-Av. red ripe fruit weight; 9-Marketable red ripe fruits/ plant; 10-Total red ripe fruits/ plant; 11-% Marketable red ripe fruit; 12-Av. dry fruit weight (g); 13-Dry fruit yield/ plant; 14-Harvest duration; 15-Seeds/ fruits; 16-Capsaicin content (%); 17-Oleoresin content.

a positive and significant correlation of dry fruit yield/plant with secondary branches/plant (Farhad *et al*., 2008) and total red fruits/plant (Negi and Sharma, 2019). Selection based on these features may result in increased yield, and these traits should be given specific attention for improving red and dry fruit output. Amongst the component traits, a positive and significant correlation at both phenotypic and genotypic levels was observed for primary branches/plants with pedicel length and secondary branches; secondary branches/plants with percent marketable red fruits/plant, oleoresin content and marketable red fruits/plant; plant height with number of seeds, fruit girth, average dry fruit weight and average red fruit weight; average red fruit weight with average dry fruit weight and number of seeds/fruits.

Path analysis (Table 4) exposed that total red ripe fruits/plant followed by percent marketable red ripe fruits/plant, average red ripe fruit weight and average dry fruit weight had the highest positive and direct effect on the red ripe fruit yield/plant both at phenotypic and genotypic levels suggesting the importance of these traits in selection program for improving yield. Further, partitioning of the total association of red ripe fruit yield/plant with other traits revealed that positive indirect effect via marketable red ripe fruits/plant, total red ripe fruits/plant, percent marketable red ripe fruits/plants and average dry fruit weight were the main contributors to the correlation of fruit length, average red ripe fruit weight, marketable red fruits/plants, total red ripe fruits/plant, percent marketable red ripe fruits/plant, average dry fruit weight, dry fruit yield/plant, seeds/fruit with red ripe fruit yield/plant.

Based on overall results, high PCV, GCV, heritability, and genetic advance as a percentage of mean were noted for dry fruit yield/plant followed by marketable red ripe fruits/plant, red ripe fruit yield/plant, and total red ripe fruits/plant along with fruit length, average red ripe fruit weight, and secondary branches/plants. The correlation coefficients and direct and indirect effects suggested focusing on total red ripe fruits/plants, average red ripe fruit weight, percent marketable red ripe fruits/plant, fruit girth, and fruit length to frame a profitable strategy for creating high-producing chili genotypes.

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सारांश

गर्मी-बरसात के मौसम 2020 के दौरान बत्तीस किस्मों के मूल्यांकन के आधार पर आनुवंषिक परिवर्तनषीलता की डिग्री, विभिन्न लक्षणों के बीच संबंध, मिर्च के लाल पके फल की उपज पर घटक लक्षणों के प्रत्यक्ष और अप्रत्यक्ष प्रभावों को निर्धारित करने का प्रयास किया गया था। विचरण के विष्लेशण से पता चला कि सभी लक्षणों के लिए प्रजातियां आपस में काफी भिन्न थे। लाल मिर्ची फल औसत उपज के आधार पर नौ किस्मों ने अनुषंसित किस्म 'हिम पालम मिर्च-2' से अधिक उपज प्राप्त की, जबकि केवल तीन किस्मों यानि, 'डीपीसीएच-32-11' (96.16 ग्राम), 'डीपीसीएच-40-2' (87.32 ग्राम) और 'डीपीसीएच-38-121' (75.75 ग्राम) ने 'हिम पालम मिर्च-2' की तुलना में अधिक सूखे मिर्ची फल की पैदावार दर्ज की। उच्च फिनोटाइपिक, विविधता के जीनोटाइपिक गुणांक और उच्च आनुवंषिकता के साथ उच्च आनुवंषिकता के लिए प्रति पौधे सूखे फल उपज, प्रति पौधे लाल पके फल और प्रति पौधे लाल पके फल उपज के लिए दर्ज किया गया था, यह दर्षाता है कि इन गुणों के प्रभावी चयन से मिर्ची की अनुवंषिक सुधार के लिए मजबूत क्षमता है। प्रति पौधे लाल पके फल की उपज का प्रति पौधा सूखे फल की उपज, प्रति पौधा विपणन योग्य प्रतिषत लाल फल, प्रति पौधा विपणन योग्य लाल फल, प्रति पौधा कुल लाल फल, औसत लाल फल वजन, औसत सूखे फल वजन, प्रति फल संख्या बीज और फल की लम्बाई के साथ सकारात्मक और महत्वपूर्ण संबंध था, जिससे उपज में सुधार के लिए इन लक्षणों पर विषेश ध्यान दिया जाना चाहिए। घटक लक्षणों के प्रत्यक्ष और अप्रत्यक्ष योगदान को देखते हुए, कुल लाल पके फल, औसत लाल पके फल का वजन और औसत सूखे फल का वजन के आधार पर चयन उच्च उपज वाले किस्म विकसित करने के लिए महत्वपूर्ण होगा।