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HETEROTIC EXPRESSION FOR YIELD AND QUALITY IN CHILLI (*CAPSICUM ANNUUM* L.) OF HIMACHAL PRADESH, INDIA

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Abstract

The experiment was carried out at the experimental farm, Department of Vegetable Science, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India during 2022 and 2023 to study the mean performance, heterotic expression for yield and quality traits in chilli. The experimental material comprised of eight diverse chilli genotypes, crossed in half-diallel mating design during 2022 to obtain 28 cross combinations. The 28 F_1 crosses along with 8 parental genotypes and 1 check DKC-8 were evaluated in RCBD during 2023. Surajmukhi, Punjab Guchhedar and Arka Lohit among parents and cross combinations viz. Surajmukhi × Punjab Tej, Surajmukhi × Arka Lohit, Kashmir long-1 × Surajmukhi and Punjab Guchhedar × Arka Lohit performed best for dry fruit yield per plant. The top three cross combinations for dry fruit yield per plant showing significant positive heterosis over better parent were Punjab Tej × Pusa Jwala, Punjab Guchhedar × Arka Lohit and Kashmir long -1 × Punjab Tej.

Introduction

Chilli (*Capsicum annuum* L.) belongs to Solanaceae across the tropical world. Capsaicin is not only responsible for the spicy sensation but has been studied for effects on metabolism, pain-perception and lipid profiles and it may also support immune function and lower cholesterol levels (Chapa-oliver and Mejia-Tenieute 2016, Bogusz *et al.* 2018, Civan and Kumcuoglu 2019). In traditional Indian cuisine, red chilli powder is a staple ingredient that adds vibrant color to a wide variety of dishes (Brar *et al.* 2025). Chillies are also a rich source of vitamin C which are essential antioxidants that have numerous health benefits (Azlan *et al.* 2022).

India is the largest producer of chilli globally. Chilli has seen a surge in demand in the consumer market, leading to an increase in its cultivation and commercialization in recent years (Nascimento *et al.* 2014). However, there is still a growing demand in India for new cultivars that offer higher yields, better quality and greater resistance to pests and diseases (Kaur *et al.* 2025). Achieving these desired traits can be accomplished through breeding programs. Breeding programs can help to develop new varieties of chilli that are better adapted to local growing conditions and have improved resistance to pests and diseases. Heterosis breeding is a method used to improve the quality traits of vegetable crops, including chillies. Diallel analysis is a statistical tool used in heterosis breeding to identify superior hybrids in different genotypes of chilli. The aim of the current study was to investigate the heterotic effect of twenty-eight developed F_1 hybrids in terms of their agronomic traits.

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Materials and Methods

The experiment was carried out in the experimental farm, Department of Vegetable Science, College of Horticulture, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Himachal Pradesh, India, during the 2022-2023. The study employed a half diallel mating design, using eight homozygous inbred lines as parent plants. The selection of parents was based on their distinct genetic makeup, and the resulting 28 hybrids were expected to exhibit a range of agronomic traits, providing valuable insights into the genetic basis of hybrid vigor. The data collection process was designed to ensure scientific rigor and accuracy and the results are expected to provide valuable insights into the genetic basis of important agronomic traits in hot pepper crops. The observation of two quality characters were recorded from each hybrids and parents. The ascorbic acid content of hot pepper pod was estimated as per the standard procedure of Ranganna (1986) and expressed in mg/100 g. The capsaicin content (%) of dry pod was estimated adopting the procedure given by Thimmaiah (1999).

The statistical parameters like mean and range were calculated as per the standard methods of analysis. The value of F_1 averaged over replications was used for estimating heterosis. The magnitude of heterosis was calculated as percentage increase or decrease was measured as the proportion of deviation of F_1 over better parent (heterobeltiosis) and standard check.

Result and Discussion

According to the analysis of variance, the observed characteristics exhibited significant differences among the genotypes. Moreover, the significant differences among the entries indicate that the parents and their offspring were distinctly disparate from each other in these characteristics (Table 1). The exceedingly significant mean sum of squares of parental plant genotypes for all characters was indicative of a substantial amount of variation among the genotypes. The selection of appropriate parental plants with strong per se performance was a critical aspect of crop breeding programs. This process was essential for producing the best-performing hybrids, which possess the desired traits and characteristics. The number of days required for 50% flowering and days to red-ripe maturity were among the most crucial traits that were evaluated during the selection process. In this regard, Kashmir long-1 emerged as the top-performing parent in terms of flowering and maturity, with the earliest flowering (42.33 days) and

Table 1. Analysis of variance for randomized block design for different characters in chilli.

Source of Variation	DF	DF	DRRM	PH	NFP	ADFW	DFY	AAC	CC
Replication	2	8.69	6.67	244.95*	145.99*	0.01	33.33	12.55*	0.01*
Genotypes	35	94.25*	125.03*	767.09*	1716.65*	0.09*	2191.59*	2455.08*	0.19*
Error	70	2.91	4.35	9.31	18.25	0.01	47.18	1.46	0.01
Total	107								

DF: Days to 50% flowering, DRRM: Days to red ripe maturity, PH: Plant height, NFP: Number of fruits per plant, ADFW: Average dry fruit weight, DFY: Dry fruit yield per plant, AAC: Ascorbic acid content and CC: Capsaicin content.

maturity (97.67 days) observed in 50% of the plants (Table 2). Moreover, among the hybrids, Kashmir long-1 x Punjab Tej exhibited the shortest duration for 50% flowering (38.67 days) and red-ripe maturity (94.33 days), which was found to be statistically at par with Kashmir long-1 x Punjab Guchhedar (40.67, 96.33 days) in terms of flowering and maturity. The findings indicate a positive correlation between the duration for 50% flowering and the duration for red-ripe fruit,

which was similar with the results reported in prior research conducted by Rohini and Lakshmana (2017). The parents Arka Lohit, Pusa Sadabahar and Kashmir long-1 exhibited superior values of plant height, with Arka Lohit being the tallest (94.39 cm). Among the cross combinations, the crosses Kashmir long-1 × Pusa Sadabahar, Kashmir long-1 × Punjab Tej, and Surajmukhi × Pusa Sadabahar showed better values of plant height, with Kashmir long-1 × Pusa Sadabahar being the tallest (101.75 cm). The hybrids involving Kashmir long-1 as the female parent demonstrated higher plant height in general.

Table 2. Mean performance of parents and hybrids for quantitative and quality traits in chilli.

Parents and Hybrids	DF	DRRM	PH	NFP	ADFW	DFY	AAC	CC
Kashmir long 1	42.33	97.67	83.09	65.36	1.04	97.21	181.07	0.21
Kashi Anmol	53.67	108.67	54.42	73.99	0.56	62.96	153.43	0.17
Surajmukhi	58.33	116.33	76.49	108.80	0.74	133.14	172.63	0.33
Punjab Guchhedar	46.00	103.67	72.72	118.03	0.59	116.10	149.32	0.34
Punjab Tej	48.33	105.33	73.34	87.87	0.64	76.39	115.32	0.56
Pusa Jwala	56.00	111.00	75.54	101.97	0.52	74.69	223.46	0.26
Pusa Sadabahar	61.33	121.33	86.42	82.00	0.68	78.70	187.37	0.27
Arka Lohit	56.67	110.33	94.39	97.73	0.79	118.50	130.89	0.41
Kashmir long -1 × Kashi Anmol	45.67	99.33	73.81	72.67	0.77	78.55	168.87	0.22
Kashmir long -1 × Surajmukhi	47.67	101.00	88.72	97.00	0.88	150.74	193.51	0.26
Kashmir long -1 × Punjab Guchhedar	40.67	96.33	69.73	124.17	0.86	119.80	173.10	0.28
Kashmir long -1 × Punjab Tej	38.67	94.33	97.03	92.03	1.14	114.84	148.22	0.38
Kashmir long -1 × Pusa jwala	47.00	101.33	81.36	82.97	0.71	90.56	193.39	0.21
Kashmir long -1 × Pusa Sadabahar	53.67	109.67	101.75	69.40	1.24	76.78	199.62	0.26
Kashmir long -1 × Arka Lohit	45.67	98.00	76.11	92.53	0.60	114.78	132.83	0.42
Kashi Anmol × Surajmukhi	54.33	107.67	58.56	81.80	0.63	70.49	162.44	0.20
Kashi Anmol × Punjab Guchhedar	52.67	108.67	45.04	93.50	0.57	74.37	158.29	0.23
Kashi Anmol × Punjab Tej	51.00	106.33	58.00	64.43	0.71	63.71	125.51	0.29
Kashi Anmol × Pusa jwala	54.67	107.33	40.47	84.80	0.64	76.99	161.91	0.19
Kashi Anmol × Pusa Sadabahar	56.00	111.00	56.49	72.83	0.71	71.92	176.88	0.23
Kashi Anmol × Arka Lohit	53.33	106.67	43.17	93.50	0.56	76.48	140.47	0.26
Surajmukhi × Punjab Guchhedar	57.33	112.00	84.35	153.67	0.69	135.84	137.40	0.35
Surajmukhi × Punjab Tej	54.33	109.33	93.54	104.13	1.09	156.31	166.34	0.37
Surajmukhi × Pusa jwala	58.33	115.33	93.97	123.27	0.49	91.75	183.06	0.26
Surajmukhi × Pusa Sadabahar	61.33	119.67	95.15	93.10	0.95	114.89	191.36	0.34
Surajmukhi × Arka Lohit	57.33	112.33	94.74	124.07	0.60	151.63	155.32	0.37
Punjab Guchhedar × Punjab Tej	47.00	104.67	73.07	126.50	0.70	122.52	154.15	0.45
Punjab Guchhedar × Pusa jwala	53.00	107.33	64.65	153.27	0.63	125.49	226.15	0.31
Punjab Guchhedar × Pusa Sadabahar	54.67	107.33	75.54	148.43	0.58	111.07	168.64	0.32
Punjab Guchhedar × Arka Lohit	50.67	102.33	84.22	126.23	0.89	140.01	147.03	0.37
Punjab Tej × Pusa jwala	52.67	106.33	75.58	130.25	0.60	96.91	126.55	0.61
Punjab Tej × Pusa Sadabahar	55.00	108.00	64.58	106.83	0.83	74.64	147.55	0.37
Punjab Tej × Arka Lohit	50.33	103.67	64.04	115.33	0.66	110.99	113.00	0.63
Pusa jwala × Pusa Sadabahar	58.00	116.67	54.76	100.67	0.56	76.40	220.55	0.24
Pusa jwala × Arka Lohit	54.00	108.67	78.92	116.17	0.68	96.70	176.15	0.46
Pusa Sadabahar × Arka Lohit	59.33	117.67	81.89	98.37	0.82	108.25	172.14	0.31
DKC-8	57.67	114.67	71.25	68.33	0.63	72.85	180.55	0.47
P. mean	52.56	107.78	74.51	101.24	0.73	100.65	165.26	0.33
Min	38.67	94.33	40.47	64.43	0.49	62.96	113.00	0.19
Max	61.33	121.33	101.75	153.67	1.24	156.31	226.15	0.63
SE±	0.98	1.20	1.77	2.46	0.04	3.97	0.69	0.01
CD (0.05)	2.77	3.39	5.00	6.94	0.10	11.20	1.94	0.03

DF: Days to 50% flowering, DRRM: Days to red ripe maturity, PH: Plant height, NFP: Number of fruits per plant, ADFW: Average dry fruit weight, DFY: Dry fruit yield per plant, AAC: Ascorbic acid content and CC: Capsaicin content.

Identifying hybrids with improved growth habit and spreading nature is beneficial as they enhance fruit yield through continuous flowering truss production at each node. Such information on differences in plant height was noted to be available from the studies of Rani *et al.* (2021). Among eight parents Punjab Guchhedar, Surajmukhi and Pusa Jwala recorded a higher number of fruits per plant with values of 118.03, 108.80 and 101.97, respectively. The present study evaluated various hybrids and found that Surajmukhi x Punjab Guchhedar, Punjab Guchhedar × Pusa Jwala, Punjab Guchhedar × Pusa Sadabahar and Punjab Tej × Pusa Jwala had higher values for this trait with 153.67, 153.27, 148.43 and 130.25 fruits per plant, respectively. The observed variation in the number of fruits per plant could be attributed to factors such as fruit set percentage, genetic nature and environmental conditions. Fruit weight is considered a crucial parameter that directly determines the yield. According to a study involving eight parents, Kashmir long-1 and Arka Lohit exhibited the highest dry fruit weight values, 1.04 g and 0.79 g, respectively. Moving on to the hybrids, the crosses Kashmir long-1 × Pusa Sadabahar, Kashmir long-1 × Punjab Tej, Surajmukhi × Punjab Tej, Surajmukhi × Pusa Sadabahar, and Kashmir long-1 × Surajmukhi demonstrated superior performance in terms of dry fruit weight, with 1.24, 1.41, 1.09, 0.95 and 0.88 g, respectively. The observed highest fruit weight in the aforementioned crosses could potentially be attributed to their hybrid vigor, as suggested by prior research conducted by Rohini and Lakshmanan (2017), Rani *et al*. (2021), Thakur *et al.* (2022) and Thakur *et al.* (2025).

The capsaicin content is a crucial factor for both processing and dry market cultivars in the chilli industry. In this regard, Punjab Tej and Arka Lohit, which are the parent cultivars, have recorded higher capsaicin content values. The hybrid cultivars Punjab Tej × Arka Lohit, Punjab Tej × Pusa Jwala, and Pusa Jwala × Arka Lohit have shown even higher values than their parent cultivars. These results are consistent with the findings of Sreenivas *et al.* (2020), indicating the significance of capsaicin content in the chilli industry. The ascorbic acid content in chilli is directly associated with the Vitamin C content. Among the parents in the study, Pusa Jwala, Pusa Sadabahar, and Kashmir long-1 recorded the highest ascorbic acid content. The hybrid cultivars Punjab Guchhedar × Pusa Jwala, Pusa Jwala × Pusa Sadabahar, and Kashmir long-1 × Pusa Sadabahar exhibited even higher values of ascorbic acid content. These results are consistent with the findings of Jindal *et al.* (2015).

Based on their average performance, the hybrid cultivars Surajmukhi × Punjab Tej, Surajmukhi × Arka Lohit and Kashmir long -1 × Surajmukhi have been identified as the best F_1 cross combinations in the study, with the highest fruit yield. The parents Surajmukhi, Punjab Guchhedar, and Kashmir long-1 have contributed significantly as both female and male parents in developing better hybrids with higher fruit yield. Specifically, the parent Surajmukhi has demonstrated superior performance as the best female parent, producing high-yielding hybrid combinations. The variation in fruit yield per plant in the study could be due to the percentage of fruit set, the number of fruits per plant, genetic nature, environmental factors, and vigor of the crop.

The increased fruit yield of the first-generation hybrids obtained in the study is consistent with the findings of Rohini and Lakshmanan (2017), and Rani *et al.* (2021). Based on their per se performance, Surajmukhi, Punjab Guchhedar, and Arka Lohit were identified as the best parents for further exploitation in the breeding program. Among the hybrids, Surajmukhi × Punjab Guchhedar, Punjab Guchhedar × Arka Lohit, Punjab Guchhedar × Punjab Tej, Surajmukhi × Punjab Tej, and Kashmir long-1 × Punjab Guchhedar were selected as the most promising hybrids. These decisions were based on their per se performance, indicating their potential for contributing to the development of better cultivars through future breeding programs.

Table 3 presents the range of heterosis, desirable significant heterotic crosses, and the best heterotic crosses over the better parent and standard variety for eight traits. For days to fifty percent flowering and days to red ripe maturity, heterotic effects in the negative direction are desirable. Among the hybrids, Kashmir long-1 × Punjab Tej (-8.66 and -3.41%) and Kashmir long-1 × Punjab Tej (-32 and - 6.94%) demonstrated significant and the highest negative heterobeltiosis (HB) and standard heterosis (SH), respectively, for days to fifty percent flowering and days to red ripe maturity. Among the crosses studied, Surajmukhi × Pusa Jwala and Kashmir long-1 × Pusa Sadabahar exhibited the maximum significant heterobeltiosis (HB) and standard heterosis (SH) for plant height, with values of 22.85 and 42.81%, respectively. These findings suggest that the hybrids resulting from these crosses may have the potential to perform better than

Table 3. Heterotic expression of hybrids for quantitative and quality traits in chilli.

Parameters	Range	Best heterotic hybrid	Significant positive	Significant negative
DF	BP- -8.66 – 26.77	Kashmir long -1 × Punjab Tej	BP- 14	BP-01
	SH- -32.95 – 6.36	Kashmir long -1 × Punjab Tej	SH- 01	SH- 20
DRRM	BP- -3.41 – 12.29	Kashmir long -1 × Punjab Tej	BP- 12	BP-01
	SH- -17.73 – 4.36	Kashmir long -1 × Punjab Tej	SH- 01	SH- 22
PH	BP- -54.26 – 22.85	Surajmukhi × Pusa Jwala	BP- 07	BP-17
	SH- -43.20 – 42.81	Kashmir long -1 × Pusa Sadabahar	SH- 12	SH- 10
NFP	BP- -26.67 – 30.19	Surajmukhi × Punjab Guchhedar	BP- 11	BP-09
	SH- -5.71 – 124.88	Surajmukhi × Punjab Guchhedar	SH- 24	SH- 00
ADFW	BP- -42.17 – 47.51	Surajmukhi × Punjab Tej	BP- 06	BP-13
	SH- -21.81 – 97.87	Kashmir long -1 × Pusa Sadabahar	SH- 10	SH- 01
DFY	BP- -47.06 – 26.87	Punjab Tej × Pusa Jwala	BP- 06	BP-09
	SH- -12.55 – 114.56	Surajmukhi × Punjab Tej	SH- 18	SH- 00
AAC	BP- -43.37 – 6.87	Kashmir long -1 × Surajmukhi	BP- 06	BP-22
	SH- -37.41 – 25.26	Punjab Guchhedar × Pusa Jwala	SH- 07	SH- 21
CC	BP- -47.25 – 13.17	Punjab Tej × Arka Lohit	BP- 03	BP-17
	SH- -60.00 – 35.00	Punjab Tej × Arka Lohit	SH- 02	SH- 24

their parents and standard variety for these traits. In the study, Surajumukhi × Punjab Guchhedar exhibited the maximum significant heterobeltiosis (HB) for number of fruits per plant (30.19%). Moreover, Kashmir long-1 × Surajmukhi and Punjab Tej × Arka Lohit displayed the maximum significant HB for ascorbic acid (6.87%) and capsaicin content (13.17%), respectively. For dry fruit yield per plant, Punjab Guchhedar × Arka Lohit (34.34%) and Punjab Tej × Pusa Jwala (26.87%) exhibited the maximum significant HB. These findings suggest that the hybrids resulting from these crosses may have the potential to perform better than their parents and standard variety for the respective traits. Similar findings have been reported in other studies (Rao *et al.* 2017, Rohini and Lakshmana 2017 and Rani *et al.* 2021). The study investigated the comparative performance of five heterotic crosses for dry yield per plant and yield components (Table 4). The estimates and magnitude of various effects were found to vary with cross combinations and characters. Results indicated that crosses Punjab Guchhedar × Arka Lohit, Punjab Tej × Pusa Sadabahar, Kashmir long-1 × Punjab Tej, Surajmukhi × Punjab Guchhedar, and Punjab Tej × Pusa Jwala exhibited higher percentages of heterobeltiosis. For standard heterosis, the cross Surajmukhi × Punjab Guchhedar, Punjab Guchhedar × Arka Lohit, Punjab Guchhedar × Punjab Tej,

Surajmukhi × Punjab Tej, and Kashmir long-1 × Punjab Guchhedar demonstrated high heterotic effects. The study revealed that the heterotic effects for dry pod yield were attributed to the direct effects of the number of fruits per plant and could potentially be the result of interaction effects of other yield attributes such as dry fruit weight. The results indicated that there was a reasonable basis to suggest that the heterotic expression for fruit yield per plant in all five cross combinations was due to additive and additive-additive type of gene effects since one parent with the best general combining ability was involved in the crosses. Understanding the nature and magnitude of better parent heterosis can help identify superior cross combinations and their potential for generating transgressive segregants. In the context of utilizing hybrid vigor in commercial crops, only the vigor in excess of the better parent is of significance. Therefore, it is crucial to carefully evaluate and select cross combinations based on their potential for generating transgressive segregants and optimizing hybrid vigor.

Table 4 . Top five performing hybrids over heterobeltiosis for quantitative and quality traits in chilli.

Hybrids Over Heterobeltiosis	DF	DRRM	PH	NFP	ADFW	DFY	AAC	CC
Punjab Guchhedar × Arka Lohit	10.14*	-1.29	-10.77*	6.95*	13.56*	18.15*	-1.54*	-1.54*
Punjab Tej × Pusa Sadabahar	13.79*	2.53	-25.27*	21.59*	22.55*	-5.16	-21.25*	-21.25*
Kashmir long -1 × Punjab Tej	-8.66*	-3.41*	16.79*	4.74	9.58	18.13*	-18.14*	-18.14*
Surajmukhi × Punjab Guchhedar	24.64*	8.04*	10.29*	30.19*	-6.79	2.03	-20.41*	-20.41*
Punjab Tej × Pusa Jwala	8.97*	0.95	0.05	27.74*	-5.76	26.87*	-43.37*	-43.37
Hybrids Over Stand Check								
Surajmukhi × Punjab Guchhedar	-0.58	-2.33	18.39*	124.88*	9.57	86.47*	-23.90*	59.75*
Punjab Guchhedar × Arka Lohit	-12.14*	-10.76*	18.20*	84.73*	42.55*	92.18*	-18.57*	22.64*
Punjab Guchhedar × Punjab Tej	-18.50*	-8.72*	2.55	85.12*	12.23	68.18*	-14.62*	94.34*
Surajmukhi × Punjab Tej	-5.78*	-4.65*	31.27*	52.39*	73.40*	114.56*	-7.87*	83.02*
Kashmir long -1 × Punjab Guchhedar	-29.48*	-15.99*	-2.13	81.71*	36.70*	64.45*	-4.12*	45.28*

DF: Days to 50% flowering, DRRM: Days to red ripe maturity, PH: Plant height, NFP: Number of fruits per plant, ADFW: Average dry fruit weight, DFY: Dry fruit yield per plant, AAC: Ascorbic acid content and CC: Capsaicin content.

Research has shown that the heterosis for fruit yield is achieved through components heterosis and even the slightest hybrid vigor for individual yield components may have a considerable additive effect on yield. The superiority of the hybrid Punjab Guchhedar × Arka Lohit for fruit yield and its component traits was observed during the present evaluation; however, the performance data are based on a single season. Since heterosis expression can be influenced by environmental conditions, evaluation over multiple years and locations is essential to confirm the stability and consistency of the observed hybrid vigor. Therefore, although the results indicate strong potential for commercial exploitation, further multi-environment and multi-season trials are necessary before drawing definitive conclusions regarding its superiority over open-pollinated cultivars.

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