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Combining ability analysis for morphological, biochemical and yield traits in chilli (*capsicum annuum* l.) using line × tester design

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ABSTRACT

Chilli (Capsicum annuum L.) is an economically important spice and vegetable crop grown widely across tropical and subtropical regions. It is valued not only for its pungency and flavour but also for its nutritional and therapeutic properties. For enhancing its productivity and quality it requires systematic breeding strategies, however, breeding efforts are often challenged by the complex inheritance of yield and quality traits, genotype x environment interactions, and the limited availability of elite parental lines. The present investigation entitled "Combining Ability Analysis for Morphological, Biochemical and Yield Traits in Chilli (Capsicum annuum L.) Using Line × Tester Design" was conducted at the Vegetable Research Farm, SKUAST-Jammu using 8 lines and 3 testers in a Line × Tester mating design, generating 24 hybrids. The experiment was laid out in a Randomized Complete Block Design with three replications during Kharif 2023–24. Observations were recorded for 15 morphological, yield and quality traits to assess the general combining ability (gca) of 8 lines and 3 testers in chilli (Capsicum annuum L.). Combining ability plays a crucial role in identifying promising parents for hybrid breeding. Results revealed significant gca effects, indicating the importance of additive gene action for several traits. Parents L_4(DKC-8), L_3(Pusa Sadabahar), L_5(SJC-1) and T_2(Surai mukhi) emerged as superior general combiners for yield and yield attributing traits, while L_2(TNAU-9), L_4(DKC-8), L_6(Hot Queen) and T_3(TNAU-6) were identified as promising general combiners for the majority of quality and growth-related traits. These findings offer valuable insights for selecting parents in future chilli improvement programs.

Keywords: *Chilli, hybrid, breeding, combining ability, lines, testers, traits, yield.*

Introduction

Chilli (*Capsicum annuum* L., 2n = 2x = 24), a member of the Solanaceae family and genus *Capsicum*, comprises over 30 species, of which only five—*C. annuum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L., and *C. pubescens*—have been domesticated and are widely cultivated. The genus name "Capsicum" originates from the Greek word *kapto*, meaning "to bite" or "to swallow," referring to the distinctive pungent sensation produced by chili peppers. Chilli is primarily cultivated for two commercially valuable compounds: capsaicin ($C_{18}H_{27}NO_3$), a crystalline alkaloid responsible for its pungency, and capsanthin ($C_{40}H_{56}O_3$), a pigment contributing to its red color. Capsanthin is a blend of various carotenoids, including capsorubin, zeaxanthin, cryptoxanthin, and their esters. Nutritionally, green chilli fruits serve as a rich source of essential minerals like potassium, calcium, magnesium, and iron [1], along with vital vitamins such as A, C, E and P [2]. Globally, *Capsicum annuum* is recognized as an economically important vegetable and spice crop. In India, it plays a crucial role in both domestic culinary applications and international trade due to its export potential. Chilli is valued not only for its culinary attributes but also for its high content of capsaicin, vitamin C, phenolic compounds, and color pigments like capsanthin, all of which contribute to its nutritional and therapeutic significance. To enhance its genetic potential, it is essential to identify promising parental lines capable of transmitting favourable alleles for growth, yield and quality traits. The line × tester mating design, introduced by [3], is a widely used method for assessing the genetic worth of parental genotypes. This design allows for the estimation of general combining ability (GCA), which reflects additive genetic effects that are heritable, fixable and crucial for parent selection in breeding programs. The present study aims to evaluate the general combining ability effects of 8 lines and 3 testers for a set of fifteen agro-morphological, biochemical and yield-related traits in chilli.

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Material and Methods

The proposed investigation on "Combining Ability Analysis for Morphological, Biochemical and Yield Traits in Chilli (*Capsicum annuum* L.) Using Line × Tester Design was carried out at Vegetable Experimental Farm, Division of Vegetable Science, SKUAST-Jammu, Chatha during Kharif season 2023-24 to generate crosses using eleven diverse genotypes. The Vegetable Experimental Farm was located at the main campus, SKUAST, Jammu which is 14 km away from Jammu city. The experimental farm is situated at a latitude of approximately 32.68°N and a longitude of 74.82°E, with an elevation of about 281 meters above mean sea level. The average temperature during the growing season is 38.7 °C for day and 26 °C for night. Eight diverse lines (L_1 to L_8) were crossed with three testers (T_1 to T_3) in a line × tester mating design, generating 24 F_1 hybrids. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

The observations were recorded on following fifteen morphological (days to 50% flowering, plant height, plant spread, number of primary branches per plant, fruit length and fruit diameter), biochemical (ascorbic acid, total phenol content, capsaicin content, capsanthin content and dry matter content) and yield components (green fruit yield per plant, red fruit yield per plant, number of fruits per plant and total fruit yield). The Combining ability analysis was carried out following Kempthornes method. The GCA effects were computed and tested for significance using the appropriate standard errors (S.E. ± gi). Critical Difference (CD) values at 5% significance were used for interpretation.

Results and Discussion

GCA for Morphological Traits:

The genotypes L_3 (Pusa Sadabahar = -1.881), L_5 (SJC-1 = -1.681) and T_3 (TNAU-6 = -1.264) showed highly significant negative GCA effects for days to 50% flowering and were discovered to be good general combiners for days to 50% flowering. For plant height, L_5 (SJC-1 = 12.634), L_3 (Pusa sadabahar = 7.103) and L_6 (Hot Queen = 3.349) were superior and were found to be good general combiners for plant height. L_1 (TNAU-8 = 2.818), T_3 (TNAU-6 = 2.353) and L_8 (Pusa Jwala = 1.992) recorded positive GCA for plant spread. The number of primary branches per plant was highly significant in T_2 (Suraj mukhi = 0.417), L_6 (Hot Queen = 0.393) and L_4 (DKC-8 = 0.356). Fruit length was best in L_4 (DKC-8 = 0.569) and T_3 (TNAU-6 = 0.437). The fruit diameter was significant in L_6 (Hot Queen = 0.227), L_1 (TNAU-8 = 0.064) and T_1 (TNAU-3 = 0.039) and were found to be good general combiners for this trait. Similar findings with respect to GCA effects were also reported by [4], [5].

GCA for Quality Traits:

The genotypes L_1 (TNAU-8 = 6.771), L_4 (DKC–8 = 5.821) and L_2 (TNAU-9 = 5.742) had high ascorbic acid. It was found that the capsanthin content was highest in parent L_4 (DKC–8 = 20.280) followed by L_6 (Hot Queen = 19.630) and T_3 (TNAU-6 = 6.990). where as the capsaicin content was highest in L_8 (Pusa Jwala = 0.125) followed by L_6 (Hot Queen = 0.108) and L_1 (TNAU-8 = 0.089). Also the phenol content was found to be highest in L_2 (TNAU-9 = 2.200), L_4 (DKC-8 0.493) and T_1 (TNAU-3 = 0.164) and the dry matter content was observed to be highest in parent L_2 (TNAU-9 = 2.069), L_3 (Pusa sadabahar = 1.889) and L_8 (Pusa Jwala = 1.728). Similar findings were also reported by [6], [7].

GCA for Yield Traits:

The analysis of general combining ability (GCA) for yield-related traits revealed significant positive effects in several parental lines. For green fruit yield per plant, the highest significant GCA effects were observed in L_4 (DKC-8 = 164.039), followed by L_3 (Pusa sadabahar = 130.307) and L_5 (SJC-1 = 80.075), indicating their strong potential as donors for enhancing green fruit productivity. In terms of red fruit yield per plant, L_4 (DKC-8 = 106.614) again emerged as the best general combiner, followed by L_3 (Pusa sadabahar = 98.918) and L_5 (SJC-1 = 42.439), suggesting their suitability for improving red fruit yield. With respect to the number of fruits per plant, L4 (DKC-8 = 45.353) recorded the highest GCA effect, followed by L_3 (Pusa sadabahar = 34.975) and L_5 (SJC-1 = 18.150), indicating their additive genetic contribution towards fruit number. Additionally, the total fruit yield per hectare was significantly influenced by L_4 (DKC-8 = 100.241), L_3 (Pusa sadabahar = 84.897), and L_5 (SJC-1 = 45.376), confirming their superior general combining ability for yield performance at the field level. The significant GCA effects across these traits underscore the predominance of additive gene action in their inheritance. These findings highlight the potential of (DKC-8), (Pusa sadabahar), and (SJC-1) as elite parents in hybrid breeding programs aiming to enhance yield traits in chilli. The results align with earlier reports by [8], [9], [10] & [11] , who also emphasized the importance of additive gene effects and superior GCA performance for yield traits in chilli breeding.

Table 1: Estimation of general combining ability effects of parents for different morphological traits in chilli (Capsicum annuum L.)

Parents	Days to 50% flowering	Plant height (cm)	Plant Spread (cm)	Number of primary branches per plant	Fruit length (cm)	Fruit Diameter (cm)
L_1	0.319	-5.141 *	2.818 *	0.321	0.178	0.064 *
L_2	-1.125 *	-4.005 *	-0.036	0.098	0.286	-0.059 *
L_3	-1.881 *	7.103 *	-2.687 *	-0.386 *	-0.038	0.028
L_4	-0.681	-1.576 *	1.12	0.356 *	0.569 *	-0.060 *
L_5	-1.681 *	12.634 *	-3.665 *	-0.347 *	-0.572 *	-0.057 *
L_6	3.542 *	3.349 *	-0.378	0.393 *	-0.307 *	0.227 *
L_7	2.319 *	-10.260 *	0.836	-0.458 *	0.163	-0.02
L_8	-1.014 *	-2.105 *	1.992 *	0.023	-0.278	-0.122 *
S.E±(gi) line	0.38	0.71	0.78	0.16	0.15	0.02
S.E±(gi-gj) line	0.54	1.00	1.10	0.23	0.21	0.03
T_1	1.403 *	1.222 *	-3.699 *	0.096	-0.469 *	0.039 *
T_2	-0.139	1.178 *	1.346 *	0.417 *	0.032	-0.026 *
T_3	-1.264 *	-2.400 *	2.353 *	-0.513 *	0.437 *	-0.013
S.E±(gi) tester	0.23	0.43	0.48	0.09	0.09	0.01
S.E±(gi-gj) tester	0.33	0.61	0.67	0.14	0.13	0.02
$CD_{(0.05)}$ (Line)	0.764	1.425	1.573	0.324	0.3	0.039
$CD_{(0.05)}$ (Tester)	0.468	0.873	0.963	0.199	0.184	0.024

Table 2: Estimation of general combining ability effects of parents for different quality traits in chilli (Capsicum annuum L.)

Parents	Ascorbic acid (mg/100g)	Capsanthin content (ASTA) units	Capsaicin Content (%)	Phenol Content(mg/100g)	Dry matter content (%)
L_1	6.771 *	-19.556 *	0.089 *	0.320 *	-1.440 *
L_2	5.742 *	3.532	-0.072 *	2.200 *	2.069 *
L_3	-1.152	-5.106	0.01	0.071	1.889 *
L_4	5.821 *	20.280 *	0.044 *	0.493 *	0.707
L_5	-0.302	4.281	-0.205 *	-0.495 *	-0.388
L_6	4.957	19.630 *	0.108 *	-1.798 *	-1.181 *
L_7	-14.193 *	-14.517 *	-0.100 *	-0.047	-3.382 *
L_8	-7.645 *	-8.544 *	0.125 *	-0.745 *	1.728 *
S.E±(gi) line	2.57	3.71	0.01	0.11	0.49
S.E±(gi-gj) line	3.64	5.24	0.02	0.15	0.70
T_1	-3.531 *	-9.017 *	0.007	0.164 *	-0.634 *
T_2	5.010 *	2.027	-0.042 *	-0.217 *	1.334 *
T_3	-1.48	6.990 *	0.036 *	0.052	-0.700 *
S.E±(gi) tester	1.57	2.27	0.01	0.06	0.30
S.E±(gi-gj) tester	2.22	3.21	0.01	0.09	0.43
$CD_{(0.05)}$ (Line)	5.183	7.468	0.023	0.212	0.995
$CD_{(0.05)}$ (Tester)	3.174	4.573	0.014	0.13	0.609

Table 3: Estimation of general combining ability effects of parents for different yield and yield attributing traits in chilli (Capsicum annuum L.)

Parents	Green fruit yield per plant (g/plant)	Red fruit yield per plant (g/plant)	Number of fruits per plant	Fruit yield (q/ ha)
L_1	-75.500 *	-55.858 *	-15.855 *	-48.652 *
L_2	-64.965 *	-54.291 *	-25.273 *	-44.169 *
L_3	130.307 *	98.918 *	34.975 *	84.897 *
L_4	164.039 *	106.614 *	45.353 *	100.241 *
L_5	80.075 *	42.439 *	18.150 *	45.376 *
L_6	13.524 *	-7.046 *	-16.655 *	2.400 *
L_7	-135.429 *	-68.776 *	-15.699 *	-75.631 *
L_8	-112.051*	-61.999 *	-24.997 *	-64.462 *
S.E±(gi) line	0.47	0.33	0.45	0.21
S.E±(gi-gj) line	0.41	0.46	0.64	0.29
T_1	-30.399*	-27.852 *	-8.221 *	-21.574 *
T_2	5.077 *	24.091 *	3.626 *	10.803 *
T_3	25.322 *	3.760 *	4.595 *	10.771 *
S.E±(gi) tester	0.28	0.20	0.28	0.13
S.E±(gi-gj) tester	0.40	0.29	0.39	0.18
$CD_{(0.05)}$ (Line)	0.943	0.656	0.917	0.415
$CD_{(0.05)}$ (Tester)	0.578	0.402	0.562	0.254

Conclusion

The present investigation successfully identified promising parental lines and testers in chilli (*Capsicum annuum* L.) based on their general combining ability (GCA) effects for morphological, biochemical, and yield-related traits using a line × tester mating design. The significant GCA variances observed for most traits underscore the predominance of additive gene action, reaffirming the effectiveness of selection-based breeding strategies in chilli improvement programs. Among the lines, $\mathbf{L_4}$, $\mathbf{L_3}$, and $\mathbf{L_5}$ consistently exhibited high GCA effects across key yield parameters such as green and red fruit yield per plant, number of fruits per plant, and total fruit yield per hectare. This highlights their strong potential as parental lines for developing high-yielding hybrids. In terms of quality traits, $\mathbf{L_2}$, $\mathbf{L_4}$, and $\mathbf{L_6}$ showed notable GCA effects for biochemical attributes like ascorbic acid, capsanthin, capsaicin, phenol, and dry matter content-suggesting their usefulness in enhancing the nutritional and processing value of chilli. For morphological attributes, $\mathbf{L_3}$, $\mathbf{L_5}$, and $\mathbf{L_6}$ were superior general combiners, especially for traits such as earliness (days to 50% flowering), plant height, and number of primary branches per plant , which are essential for agronomic performance and adaptability. Among testers, $\mathbf{T_3}$ and $\mathbf{T_2}$ emerged as highly suitable for quality and yield-related improvements, respectively, showing desirable GCA for multiple traits. Overall, the study provides a comprehensive genetic appraisal of elite parental combinations with a high potential for hybrid development. The identified parents particularly $\mathbf{L_4}$ (DKC-8), $\mathbf{L_3}$ (Pusa sadabahar) $\mathbf{L_5}$ (SJC-1), $\mathbf{T_2}$ (Suraj mukhi) and $\mathbf{T_3}$ (TNAU-6) can serve as valuable genetic resources in future breeding programs focused on developing superior chilli hybrids with enhanced yield potential, quality attributes, and adaptability to agro-climatic challenges.

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