Journal of Advances in Biology & Biotechnology

Volume 28, Issue 1, Page 112-120, 2025; Article no.JABB.129492
ISSN: 2394-1081

Combining Ability Studies for Flower Yield and Its Contributing Traits in Gaillardia (*Gaillardia pulchella* L. Foug.) in the Northern Dry Zone of Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SB designed the experiment and conducted study, outline of manuscript and prepared first draft. Author SP and BK helped in collection of germplasm and crossing. 'Author SD contributed germplasm for the study. Authors Venkateshalu, Thammaiah and ASH suggested the technical corrections of the study and analysed the data. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2025/v28i11865

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/129492

Original Research Article

Received: 04/11/2024
Accepted: 06/01/2025
Published: 09/01/2025

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Cite as: *Badiger, Shreedevi, Balaji Kulkarni, Sateesh Patil, Sathish, D, Venkateshalu, Thammaiah, N, and Anasubai S Hosgoudar. 2025. "Combining Ability Studies for Flower Yield and Its Contributing Traits in Gaillardia (Gaillardia Pulchella L. Foug.) in the Northern Dry Zone of Karnataka, India". Journal of Advances in Biology & Biotechnology 28 (1):112-20. https://doi.org/10.9734/jabb/2025/v28i11865.*

ABSTRACT

The present study was carried out at Department of Floriculture and landscape Architecture, UHS, Bagalkot, Karnataka. With the aim to elucidate the combining ability variances and effects of parents (7 lines and 3 testers) crossed in Line x Tester mating design that resulted in 21 F_1s which is found to be play pivotal role in selection of parental genotypes for hybridization and also to select best specific combination for specific trait among the F_1s. The elucidation of general and specific combining ability variances and effects were done upon 09 different traits that included, growth, earliness, yield and quality traits of gaillardia. The results of analysis of variance for combining ability anticipated the presence of both additive and non-additive gene actions which were confirmed by the ratios of combining ability variances as a major role via non-additive gene actions for all the traits studied. The combining ability studies inferred that UHS-BGC 9 (L_4), UHS-BGC 2 (T_1) and UHSBGL-3 (T_2) as good general combiners for most of the traits studied including flower yield per plant, while among the crosses, the cross combination, UHS-BGC 7 × UHSBGL- 12 (L_2 x T_3) was found to be the good specific combination for most of the growth, earliness and yield traits of gaillardia.

Keywords: General combining ability; specific combining ability; additive; non-additive; over-dominance; gaillardia; line x tester.

1. INTRODUCTION

Gaillardia (*Gaillardia pulchella* L. Foug), a member of the Asteraceae family, widely spread over Central and Western United States that attains its generic name Gaillardia in the honour of M. Gaillard, a French patron of botany. It is one of the most important hardiest annual or short-lived perennial growing up to a height of 30 to 150 cm. Amongst 30 species, *Gaillardia pulchella, Gaillardia aristata* and *Gaillardia grandiflora* are of ornamental importance and are available in annual and perennial forms. *Gaillardia pulchella* is reported to be diploid with 2n=36 (Gawade, et al. 2018). This crop is well known for its morphological variability as the leaf shape and size which are highly variable in nature. Leaves may be basal and linear to lanceolate, greyish green and very hirsute. The flowers of gaillardia are small and numerous born in solitary, usually showy heads which is known as capitulum with 4 to 6 cm in diameter. Individual flowers in a capitulum are called as florets. As a member of Asteraceae family, it has both ray and disc florets which are sterile and hermaphrodite in nature, respectively. The flower has a long hairy stalk and single, semidouble and double types with single or multi-coloured heads ranging from yellow, orange, cream, scarlet, bronze, brick-red etc., Gaillardia can be grown throughout year because of its photo-insensitivity (Manokari et al., 2023).

Owing to all these factors the development of hybrids with good yield for prolonged duration seems to be very important. The public sector plays a vital role in developing inter-specific and inter-varietal hybrids in gaillardia by conducting research, running breeding programs and providing resources for genetic studies (Christov, 2013). However, the private sector has been more actively involved in hybrid development, both in India and internationally. The private sector hybrids that heavy cost which makes the Indian farmers to pay higher prices that adversely impact on cost-benefit ratio of the growers. It is well known that the studies regarding the hybrid development with the information of combining ability effects and variances that lacks in gaillardia crop that hinders the evolution of the improved varieties or hybrids in this crop (Thakur et al., 2024).

To evolve at the hybrids with superior yield for longer period the knowledge of the combining ability of the parents and resulting hybrids for various traits including yield and its component traits found necessary. This helps in the selection of parental lines for the development of specific traits of the crop and also aids in the selection of the best cross combinations that yields the desirable outcomes (Kumari et al., 2017). Along with the information of combining ability of parental lines and hybrids, the facts related to gene actions that governs the inheritance of the specific trait which can be elucidated through the ratios of combining ability variances helps in opting the suitable crop improvement programme for the trait of interest. Taking all these facts into consideration the present investigation was planned with the below material and methodologies.

2. MATERIALS AND METHODS

The present study to elucidate the combining ability effects and variances to infer the gene actions and some important aspects of combining ability of the parental lines and hybrids that control expression of various yield and its contributing traits in gaillardia was carried out in experimental farm of Department of Floriculture and Landscape Architecture, UHS, Bagalkot, Karnataka situated at an elevation of about 553.0 m above mean sea level with 16°46' North latitude and 74°59' East longitude, representing northern dry zone of the Karnataka state. The experimental materials of 21 F_1 hybrids developed through Line x Tester mating design involving 7 lines and 3 testers were evaluated in the present study for 09 traits *viz*., plant height (cm), number of primary branches, number of secondary branches, days to 50% flowering, duration of flowering (days), flower diameter (cm), individual flower weight (g), number of flowers per plant and flower yield per plant (g/plant).

All the morphological and yield parameters were recorded by standard scale of measurement using appropriate instruments (scale for plant height, vernier callipers for flower diameter, weighing balance for individual flower weight and flower yield per plant). The data obtained for each character were analysed by following the usual standard statistical procedure and the variation among the hybrids were partitioned further into sources attributed to general combining ability and specific combining ability components in accordance with the procedure suggested by Kempthorne (Kempthorne, 1957).

3. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) for the combining ability of nine traits of the gaillardia is summarized in the Table 1 by portioning the total variance into replications, crosses, line effect, tester effect, line × tester effect and error. The variance due to replications and crosses were found to be significant for all the traits studied at P=0.05 level. While on the other hand the mean sum of square of both the line and tester effects were of non-significant for all traits under investigation. However, there was a significant variance for all the traits regarding the line × tester effect, this inferred the presence of variability in the gene actions (additive and non-additive) in the expression of the traits studied, which demands the further elucidations of variances of components and also their ratios to unfurl the mode of inheritance of the traits as opined by Shweta et al. (Shwetha et al., 2022) in chrysanthemum. The variance component of combining ability (general and specific), the ratio of additive to dominance variance, degree of the dominance and the contribution of lines, testers and their interactions are mentioned in the Table 2, the results highlighted that the ratio of the additive to non-additive variances were found to be less than unity and the degree of the dominance was found to be more than the unity for all the traits under study indicating the predominance of non-additive gene action in the expression of the traits which inferred the importance of hybridization programme over direct selection for the improvement of these traits in the gaillardia crops (Shwetha et al., 2022; Tamut et al., 2014). The contribution of the lines towards the variance was found highest for all the traits viz., number of secondary branches (34.05%), days to 50% flowering (36.0%), duration of flowering (40.97%), flower diameter (49.85 %), individual flower weight (34.78%), plant height (46.17%), number of flowers per plant (44.02%) and flower yield per plant (15.10%) except, for the trait number of primary branches where the testers contributed (24.46%) surpassed the contribution through line. The interaction effect of the lines and testers towards the total variance ranged from 38.04 to 78.53% which was found to be highest for flower yield per plant (78.53%) followed by individual flower weight (60.41%) hence for the respective traits the lines and testers would be considered to bring the combined outcomes (Shwetha et al., 2022; Su et al., 2017).

The average performance of the genotype upon series of crosses which is referred to as general combining ability of a parent. Table 3 represents the results regarding the general combining ability effects of the lines and testers used for crossing in the present investigation for all the traits.

Among the lines the plant height was recorded positive and significant *gca* effect in UHSBGL-14, UHSBGL-13 and UHS-BGC 1, while the lines UHS-BGC 7, UHSBGL-14, UHS-BGC 9, UHS-BGC 1 and UHSBGL-15 whereas, UHS-BGC 9, UHSBGL-13 and UHSBGL-15 were good general combiners for number of primary branches and secondary branches coupled with flower yield per plant, respectively. For days to 50% flowering where the significant negative *gca* effects are more appreciated that were recorded in the lines UHS-BGC 3, UHS-BGC 9, UHS-BGC 1 and UHSBGL-15. For duration of flowering the lines UHSBGL-14, UHS-BGC 9 and UHSBGL-15 were regarded as good general combiners while for flower diameter and number of flowers per plant and the lines, UHS-BGC 3, UHS-BGC 9 and UHSBGL- 15 were best. The significant positive *gca* effects for individual flower weight was exhibited by the lines UHS-BGC 3, UHS-BGC 7 and UHSBGL-13.

Among the testers, UHS-BGC 2 exhibited good general combining abilities for the traits, plant height, number of primary branches, days to 50% flowering and duration of flowering. While, the tester, UHSBGL-3 was reported to be good general combiner for plant height, number of secondary branches, flower diameter, individual flower weight, number of flowers per plant and flower yield per plant. However, the tester UHSBGL-12 was observed as a good general combiner for only number of flowers per plant. The remaining lines that were exhibiting the non-significant positive or negative (average general combiners) and significant positive in case of days to 50% flowering (earliness trait) and significant negative in rest of the traits were regarded to be poor general combiners for the respective traits in the crop. The lines and testers that exhibited the good general combining abilities could be of immense importance in selecting the suitable parents in the hybridization programme to attain desired outputs with respect to traits of interest, the similar reports for the various traits in the flower crops of Asteraceae family were presented in the earlier study of Bhargav et al. (Bhargav et al., 2019) and Kolur et al. (Kolur et al., 2024) in China aster, Singh and Misra (Singh and Misra, 2010) in marigold and Rivera- Colin et al*.* (Rivera-Colín et al., 2019) in gerbera.

Any deviation that is noticed from the particular cross as compared to the general combining ability can be referred as the specific combining ability (Fasahat et al., 2016). The results of *sca* effects for all the traits studied are mentioned in Table 4.

The results of specific combining ability effects highlighted that the crosses, UHS-BGC 3 × UHSBGL- 3 (L_1 x T_2), UHS-BGC 7 × UHSBGL-12 (L_2 x T_3), UHSBGL-14 × UHSBGL- 12 (L_3 x T_3), UHS-BGC 9 × UHS-BGC 2 (L_4 x T_1), UHSBGL-13 × UHSBGL- 3 (L_5 x T_2), UHS-BGC 1 × UHS-BGC 2 (L_6 x T_1), UHSBGL-15 × UHS-BGC 2 (L_7 x T_1) and UHSBGL-15 × UHSBGL- 12 (L_7 x T_3) were good specific combinations for plant height. While, for number of primary branches the cross combinations, UHS-BGC 3 × UHS-BGC 2 (L_1 x T_1), UHS- BGC 7 × UHS-BGC 2 (L_2 x T_1), UHSBGL-14 × UHS-BGC 2 (L_3 x T_1), UHS-BGC 9 × UHSBGL-3 (L_4 x T_2), UHSBGL-13 × UHSBGL- 3 (L_5 x T_2), UHSBGL-13 × UHSBGL-12 (L_5 x T_3), UHS- BGC 1 × UHSBGL- 12 (L_6 x T_3), UHSBGL-15 × UHSBGL- 3 (L_7 x T_2), UHS-BGC 7 × UHSBGL- 12 (L_2 x T_3) and UHS-BGC 9 × UHS- BGC 2 (L_4 x T_1) exhibited significand positive *sca* effects. For number of secondary branches, the crosses, UHS-BGC 3 × UHSBGL-12 (L_1 x T_3), UHS-BGC 7 × UHSBGL- 12 (L_2 x T_3), UHSBGL-14 × UHS-BGC 2 (L_3 x T_1), UHS-BGC 9 × UHSBGL- 3 (L_4 x T_2), UHSBGL-13 × UHS-BGC 2 (L_5 x T_1), UHSBGL-13 × UHSBGL-3 (L_5 x T_2), UHS-BGC 1 × UHS-BGC 2 (L_6 x T_1), UHS-BGC 1 × UHSBGL- 3 (L_6 x T_2), UHSBGL-15 × UHS-BGC 2 (L_7 x T_1) and UHSBGL-15 × UHSBGL- 3 (L_7 x T_2) had the positive significant *sca* effects.

For earliness with respect to days to 50% flowering the cross combinations, UHS-BGC 3 × UHS-BGC 2 (L_1 x T_1), UHS-BGC 7 × UHSBGL- 3 (L_2 x T_2), UHSBGL-14 × UHSBGL- 12 (L_3 x T_3), UHS- BGC 9 × UHSBGL- 3 (L_4 x T_2), UHSBGL-13 × UHSBGL- 12 (L_5 x T_3), UHS-BGC 1 × UHSBGL- 12 (L_6 x T_3), UHSBGL-15 × UHS-BGC 2 (L_7 x T_1) and UHSBGL-15 × UHSBGL- 3 (L_7 x T_2) were found to yield the flowering at 50% earlier that remaining crosses. For duration of flowering the significant positive *sca* effects were recorded in the crosses viz., UHS-BGC 3 × UHSBGL- 3 (L_1 x T_2), UHS-BGC 3 × UHSBGL-12 (L_1 x T_3), UHS-BGC 7 × UHSBGL- 12 (L_2 x T_3), UHSBGL-14 × UHSBGL- 3 (L_3 x T_2), UHSBGL-14 × UHSBGL- 12 (L_3 x T_3), UHS-BGC 9 × UHS-BGC 2 (L_4 x T_1), UHSBGL-13 × UHSBGL- 3 (L_5 x T_2), UHS-BGC 1 × UHS-BGC 2 (L_6 x T_1), UHS-BGC 1 × UHSBGL- 3 (L_6 x T_2) and UHSBGL-15 × UHS-BGC 2 (L_7 x T_1) were found to be significantly positively.

Table 1. Analysis of variance of combining ability (mean sum of squares) for growth yield and quality traits in gaillardia

Sl. No.	Source of variation	Mean sum of squares						
		Replications	**Crosses**	**Line effect**	**Tester effect**	**Line × tester effect**	**Error**	**Total**
	Degrees of freedom	**2**	**20**	**6**	**2**	**12**	**40**	**62**
1	Plant height (cm)	104.19*	176.34*	271.39	143.763	134.24*	0.04	60.27
2	Number of primary branches	2.31*	29.82*	24.10	72.936	25.49*	0.01	9.69
3	Number of secondary branches	42.52*	199.63*	226.61	160.01	192.74*	0.05	65.79
4	Days to 50% flowering	100.64*	234.22*	281.08	103.067	232.65*	0.05	78.83
5	Duration of flowering (days)	156.74*	607.57*	829.64	188.852	566.32*	0.14	201.13
6	Flower diameter (cm)	1.07*	8.10*	13.461	9.80	5.13*	0.01	2.64
7	Individual flower weight (g)	0.33*	3.79*	4.405	1.83	3.82*	0.01	1.23
8	Number of flowers per plant	529.66*	5058.36*	7422.44	657.92	4609.73*	1.18	1649.58
9	Flower yield (g/plant)	12226.89*	304327.60*	153177.00	193956.00	398298.30*	71.01	98610.40

***Significant at 5% probability level*

Table 2. Variance of GCA, SCA, contribution of lines, testers and their interactions to the total variance in gaillardia

Sl. No.	Traits	Additive variance (Var. GCA)	Dominance variance (Var. SCA)	GCA/SCA	Degree of dominance	Line contribution (%)	Tester contribution (%)	Line × Tester contribution (%)
1	Plant height (cm)	27.62	44.61	0.62	1.27	46.17	8.15	45.68
2	Number of primary branches	6.45	8.47	0.76	1.14	24.25	24.46	51.30
3	Number of secondary branches	25.76	64.23	0.40	1.57	34.05	8.02	57.93
4	Days to 50% flowering	25.60	77.52	0.33	1.74	36.00	4.40	59.60
5	Duration of flowering (days)	67.87	188.71	0.36	1.66	40.97	3.11	55.93
6	Flower diameter (cm)	1.55	1.71	0.91	1.05	49.85	12.10	38.04
7	Individual flower weight (g)	0.41	1.27	0.33	1.75	34.78	4.81	60.41
8	Number of flowers per plant	538.50	1536.11	0.35	1.68	44.02	1.30	54.68
9	Flower yield (g/plant)	23126.80	132728.00	0.17	2.39	15.10	6.37	78.53

Table 3. General Combining Ability (GCA) effects of lines and testers for growth, earliness and yield parameters in gaillardia

Code	Parents	Plant height (cm)	Number of primary branches	Number of secondary branches	Days to 50% flowering	Duration of flowering (days)	Flower diameter (cm)	Individual flower weight (g)	Number of flowers per plant	Flower yield per plant (g/plant)
Lines										
L_1	UHS-BGC 3	-0.95*	-0.36*	0.02	-3.48*	-13.60*	0.86*	0.58*	-24.70*	-1.38
L_2	UHS-BGC 7	-2.43*	1.01*	-2.97*	6.31*	-3.95*	-0.87*	0.40*	-38.47*	-104.17*
L_3	UHSBGL-14	0.58*	0.49*	-5.11*	6.06*	8.43*	-1.91*	-1.17*	9.85*	-199.91*
L_4	UHS-BGC 9	-1.71*	0.92*	1.94*	-8.73*	0.54*	0.88*	-0.59*	37.01*	32.01*
L_5	UHSBGL-13	7.85*	-3.56*	9.64*	3.77*	-3.11*	-0.51*	0.83*	-7.31*	158.56*
L_6	UHS-BGC 1	5.53*	0.82*	-4.32*	-1.52*	-4.18*	-0.12*	0.01	-11.19*	-38.81*
L_7	UHSBGL-15	-8.87*	0.67*	0.82*	-2.42*	15.91*	1.65*	-0.05*	34.81*	153.70*
S.E (m) ±		0.22	0.09	0.07	0.09	0.14	0.01	0.01	0.39	3.57
CD at 5%		0.59	0.26	0.20	0.25	0.38	0.04	0.03	1.07	9.67
Testers										
T_1	UHS-BGC 2	1.57*	2.09*	-2.13*	-2.53*	3.42*	-0.38*	-0.13*	-6.45*	-82.01*
T_2	UHSBGL- 3	1.45*	-1.47*	3.11*	0.93*	-2.19*	0.78*	0.33*	2.93*	105.74*
T_3	UHSBGL- 12	-3.02*	-0.62*	-0.98*	1.59*	-1.22*	-0.40*	-0.20*	3.52*	-23.73*
S.E (m) ±		0.14	0.06	0.05	0.06	0.09	0.01	0.01	0.25	2.34
CD at 5%		0.38	0.17	0.13	0.16	0.25	0.03	0.02	0.70	6.33

Significant at 5% probability level

Table 4. Specific combining ability (*sca*) effects of crosses for growth, earliness and yield parameters in gaillardia

Crosses	PH	NPB	NSB	DFF	DOF	FD	FW	FPP	FYP
L_1 x T_1	-2.35*	1.36*	-5.46*	-12.73*	-12.52*	-2.19*	0.49*	-19.26*	-31.93*
L_1 x T_2	4.76*	0.30	-5.14*	6.97*	10.97*	1.50*	1.03*	38.84*	376.18*
L_1 x T_3	-2.41*	-1.67*	10.61*	5.75*	1.54*	0.69*	-1.52*	-19.58*	-344.24*
L_2 x T_1	-7.65*	1.85*	-5.22*	3.00*	-2.36*	-0.13*	0.20*	-15.31*	-46.69*
L_2 x T_2	0.37	-2.21*	-2.66*	-2.69*	-6.53*	-0.36*	-1.26*	-35.00*	-406.57*
L_2 x T_3	7.28*	0.35*	7.88*	-0.31	8.89*	0.50*	1.05*	50.31*	453.26*
L_3 x T_1	-6.50*	3.38*	12.11*	0.33*	-13.50*	2.04*	-0.01	18.32*	99.84*
L_3 x T_2	-1.65*	-2.55*	-9.13*	0.79*	12.75*	-1.39*	0.09*	-33.89*	-137.83*
L_3 x T_3	8.15*	-0.83*	-2.97*	-1.12*	0.74*	-0.65*	-0.08*	15.56*	37.99*
L_4 x T_1	7.95*	0.34*	-7.35*	1.32*	1.39*	0.33*	-0.09*	34.43*	142.05*
L_4 x T_2	-0.45	0.93*	8.32*	-12.91*	-0.04	-0.23*	-0.37*	-15.03*	-160.63*
L_4 x T_3	-7.50*	-1.27*	-0.96*	11.58*	-1.35*	-0.08*	0.47*	-19.40*	18.58*
L_5 x T_1	0.39	-3.16*	1.96*	2.38*	-5.19*	-0.96*	-1.09*	-37.15*	-381.46*
L_5 x T_2	4.73*	1.01*	0.80*	3.13*	4.76*	1.43*	1.87*	37.85*	570.05*
L_5 x T_3	-5.13*	2.15*	-2.76*	-5.52*	0.42	-0.46*	-0.77*	-0.69	-188.59*
L_6 x T_1	1.80*	-1.75*	0.67*	6.93*	3.13*	1.13*	0.99*	33.45*	368.70*
L_6 x T_2	0.07	-2.01*	2.49*	7.16*	1.50*	-1.13*	-1.25*	-38.29*	-424.38*
L_6 x T_3	-1.88*	3.76*	-3.17*	-14.09*	-4.64*	0.01	0.25*	4.83*	55.68*
L_7 x T_1	6.35*	-2.04*	3.29*	-1.25*	29.05*	-0.20*	-0.49*	-14.48*	-150.51*
L_7 x T_2	-7.84*	4.52*	5.32*	-2.45*	-23.43*	0.21*	-0.10*	45.53*	183.19*
L_7 x T_3	1.48*	-2.47*	-8.61*	3.71*	-5.62*	-0.01	0.59*	-31.04*	-32.68*
S. Em ±	0.38	0.16	0.12	0.16	0.24	0.03	0.02	0.68	6.19
CD at 5%	1.03	0.45	0.35	0.43	0.67	0.07	0.06	1.86	16.76

***Significant at 5% probability level; PH: Plant Height (cm); NPB: Number of primary branches; NSB: Number of secondary branches; DFF: Days to 50% flowering; DOF: Duration of flowering; FD: Flower diameter (cm); FW: Flower weight (g); FPP: Number of flowers per plant; FYP: Flower yield per plant (g/plant)*

Table 5. Top Five significant cross combinations their *gca* effects and *per se* performance for flower yield per plant

Sr. No.	Cross	*sca* effects	*Per se* performance (g/plant)	*gca* status of parents involved in cross
1	UHSBGL-13 x UHSBGL- 3 (L_5 x T_2)	570.06*	1746.38	Good x Good
2	UHS-BGC 7 x UHSBGL- 12 (L_2 x T_3)	453.26*	1237.37	Poor x Poor
3	UHS-BGC 3 x UHSBGL- 3 (L_1 x T_2)	376.18*	1392.55	Average x Good
4	UHS-BGC 1 x UHS-BGC 2 (L_6 x T_1)	368.70*	1159.88	Poor x Poor
5	UHSBGL-15 x UHSBGL- 3 (L_7 x T_2)	183.19*	1354.66	Good x Good

***Significant at 5% probability level*

For yield related traits viz., flower diameter, number of flowers per plant, individual flower weight and flower yield per plant, the crosses, UHS-BGC 3 × UHSBGL- 3 (L_1 x T_2), UHS-BGC 7 × UHSBGL- 8 (L_2 x T_3), UHSBGL-14 × UHS-BGC 2 (L_3 x T_1), UHS-BGC 9 × UHS-BGC 2 (L_4 x T_1), UHSBGL-13 × UHSBGL- 3 (L_5 x T_2), UHS-BGC 1 × UHS-BGC 2 (L_6 x T_1), UHS-BGC 1 × UHSBGL- 12 (L_6 x T_3) and UHSBGL-15 × UHSBGL- 3 (L_7 x T_2) were reported to be best specific combinations as they exhibited significant positive specific combining ability effects. All the crosses exhibiting the good specific combining abilities in all these various traits were found to consisting one of the either parent to persist the high *per se* performance and/or the best *gca* effect that was found to be contributing for the desirable significant *sca* effects. The similar opinions about the specific combining ability effects were put forth in the earlier studies of Veluru et al. (Veluru et al., 2019) and Bhargav et al. (Bhargav et al., 2019) in china aster; Shweta et al. (Shwetha et al., 2022) in chrysanthemum.

Top five cross combinations that exhibited significant positive specific combining ability effects for flower yield per plant are enlisted in Table 5 along with the *per se* performance and the status of the *gca* effects of the parents involved in those specific crosses which upholds the fact that the most of the top specific combiner had either one of the parents exhibiting the good general combining ability for the trait. However, the crosses, UHS-BGC 7 x UHSBGL- 12 (L_2 x T_3) and UHS-BGC 1 x UHS-BGC 2 (L_6 x T_1) though had both the parent involved in crossing contained poor general combining ability possessed significant positive *sca* effects which can be attributed to their highest *per se* performances for flower yield per plant.

4. CONCLUSION

The analysis of variance for combining ability indicated the presence of sufficient variations in all the traits under study, among the 21 crosses developed by crossing 7 lines with 3 testers it was noticed that the effect of non-additive gene action on expression of all the traits had the prominent role which further supported by the ratio of GCA/SCA variance that was less than unity and degree of dominance been more than unity for all the traits studied, hence strengthening the view of predominating non-additive gene action for all the traits and stating hybridization as suitable crop improvement strategy over direct selection. The lines, UHSBGL-15 and UHS-BGC 9 were the good general combiners for growth and earliness traits, while for the yield traits, UHS-BGC 9 alone was found to be the good general combiner line. Likewise, among the three testers, UHS-BGC 2 was the only best general combiner for the growth and earliness and yield related traits, UHSBGL-3 was the best general combiner. Upon hybridization the cross, UHS-BGC 7× UHSBGL-12 was found to be the good specific combination for most of the growth, earliness and yield traits of gaillardia. Additionally, the crosses that exhibited significant specific combining ability does not necessarily contained the parents with significant *gca* effects which inferred the influence of non-additive gene actions over the expression of the traits and enforce the breeders to opt for hybridization for the improvement of gaillardia crop.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/129492