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RESEARCH ARTICLE

Estimation of combining ability effect in bottle gourd (*Lagineria siceraria* (Molina) Standl.) for yield and attributing characters for thirty - six hybrids through line x tester design

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Abstract

General and specific combining ability effects were studied for 15 characters in line x tester design were studied in bottle gourd - 12 lines, 3 testers and 36 hybrids. The effective hybrid combination identified was Subam x Punjab Komal in terms of days to first harvest, fruit length and number of fruits and number of fruits vine^{-1}. Among the lines, Subam (L3), Mysore Local (L9) and Manadipet Local (L4) and the testers Punjab Komal (T3) and Arka Bahar (T2) looked as best general combiners for quality and yield traits. Accordingly, analysis of the general combining ability effects and average performance of the parents showed that the lines Subam (L3), Mysore Local (L9) and Manadipet Local (L4) were the best parents for increasing productivity, while the testers Punjab Komal (T3) and Arka Bahar (T2) were found to be good parents for enhancing earliness. Subam x Punjab Komal (L3 x T3) was identified as the result of hybrid selection based on specific combining ability effects. This hybrid showed more specific combining ability effects for sex ratio, number of fruits vine^{-1}, days to first female flower anthesis, days to first harvest and node of first female flower appearance, fruit length which are the yield attributing characters in addition to high per se performance. This hybrid can be utilized in either heterosis breeding or cross breeding programmes for good quality and quantity yield in bottle gourd. Combining ability analysis helps the breeders to identify the gene of interact and use that in improving yield.

Keywords: general combining ability; heterosis; line x tester; specific combining ability

Introduction

Bottle gourd (*Lagenaria siceraria* (Molina) Standl.) (2n = 2x = 22) is a significant horticulture crop grown in subtropical and tropical areas globally and holds a prominent position among cucurbits (vine crops). *L. siceraria* is the single cultivated species among the 6 species of *Lagenaria* recognized. It is widely cultivated in the winter but is currently cultivating throughout summer and drizzling season (1). Bottle gourd is esteemed for its nutritional and therapeutic attributes. The fruit contains 0.2 g of protein, 96.1 g of moisture, 2.5 g of carbohydrates and trace amounts of minerals comprised 0.7 g of Fe, 10 mg of P and 20 mg of Ca per 100 g (2). The plant extract is used as a cathartic and seeds are used in dropsy. Kofta is most popular medicinal syrup preparation from bottle gourd, which is prescribed for people suffering from biliousness and indigestion (3). Bottle gourd is a low-calorie vegetable packed with nutrients. It is highly cross pollinated and has wide genetic diversity. It is important to develop better varieties for obtaining higher yield. It is an important vegetable crop and improvement of yield with superior traits is very significant. Despite its significant economic value and the variety in its plant and fruit characteristics, the genetic potential of bottle gourd remains largely unexamined, with minimal efforts directed towards its genetic enhancement (4). To identify parents with superior characters and use those parents to produce hybrids with good yield combining ability analysis is useful. Combining ability (CA) analysis is crucial for plant breeders as it elucidates the nature of gene activity influencing the expression of specific traits, hence informing future breeding strategies. The advancement of the idea of combining ability (CA) has facilitated the selection of optimal combiners capable of demonstrating greater hybrid vigour in the F_1 generation. General combining ability (GCA) and Specific combining ability (SCA) of parents and crosses and its impact on bottle gourd was assessed in this study. GCA denotes the mean performance of lines in hybrid combinations, whereas SCA indicates the departure of particular crosses from anticipated outcomes based on the average performance of the derived line (5). In a recent year bottle gourd breeding has been concentrated towards increased yield, earliness, quality, disease and pest resistance. In bottle gourd, various biometrical techniques namely line (L) x tester (T), diallel and half diallel analysis are commonly used for the analysis of CA, heterosis and gene action. The L x T analysis, as proposed in a previous study, is the most prevalent, preferred and has proven to be more appropriate in various aspects (6). It facilitates the evaluation of several genotypes to determine CA, heterosis and gene action. The selection of parent genotypes is an essential factor in any hybridisation work and plant breeders must ensure that the chosen genotypes are viable and compatible with the environments in which they will be cultivated. Not all selected parents will yield desirable hybrids due to their varying compatibility with different partners. These factors compel plant breeders to acknowledge the significance of examining the SCA and GCA of both the hybrids and parents. Recently molecular markers assisted selected are used in combing analysis studies to identify superior combiners for breeding. This can be combined with conventional combing ability studies. In light of this, the main aim of the current study is to identify the best hybrids and parent varieties to be used in the production of this crop to promoting sustainable farming practices and meeting the growing demand. The current study also aims to learn more about the CA in Line x Tester crosses in bottle gourd traits associated with yield.

Material and Methods

The current experiment on estimation of CA on L x T analysis in bottle gourd (*Lagenaria siceraria* (Molina) Standl.) was performed during 2020 - 2021. For this investigation, 35 bottle gourd genotypes were obtained from various geographic areas. Seed materials were from IIHR, Bengaluru, IARI, New Delhi, local types and land races collected from different parts of Tamil Nadu and Northern part of India. The growth, yield and quality of each genotype were assessed. Out of the 35 genotypes, 15 were chosen as lines (female parents) based on their market preference and yield potential, specifically on size of the fruits, number of fruits vine^{-1}, fruit length (FL) and the earliness of the female flowers. They are Uttam (L1), Angad (L2), Subam (L3), Manadipet Local (L4), Karnal Local (L5), Ajmer Local (L6), Akkampally Local (L7), Angul Local (L8), Mysore Local (L9), Dharwad Local (L10), Nellore Local (L11) and Paravai Local (L12). Three high yielding varieties resistant to pest and diseases were used as testers *viz.,* Pusa Naveen (T1), Arka Bahar (T2), Punjab Komal (T3). Thirty six hybrids were created by using the L x T mating programme to cross the chosen lines and testers.

Crossing programme and production of F_1 seeds

All the parental seeds were sowed in the crossing block by adopting L x T method with a spacing of 2 × 2 m. To maintain a consistent plant population, seeds were SCAttered in pits and then gap-filling and thinning were carried out (one seedling per pit). The suggested package of recommendations and crop protection approaches were adopted uniformly as per the Tamil Nadu Agricultural University (TNAU) plant development model. This study was carried out during July 2022 to November 2022.

Crossing technique

Fully developed female flower buds from the seed parent and male flower buds from the male parent were protected with butter paper a day prior to anthesis or the day before anthesis. The following day at 6 - 9 a.m., the male parent's pollen grains were obtained and dusted on the female plant's stigmatic surface of the flowers. There was a butter paper cover (40 GSM) with the crossing details on it for the pollinated flowers.

Evaluation of F_1 hybrids and their parents

A randomised block design with 3 replications was used to grow 36 hybrids and 15 parents from January - May of 2023. The seeds were sowed in the pits with 2 x 2 m spacing. Every parent and hybrid followed the same recommended cultural practices. Ten plants were chosen at random for each replication, including parents and hybrids and observations were made. Results were observed in 10 randomly picked plants in every replicate in parents and hybrids. Observations recorded were Ascorbic acid content (mg 100 g^{-1}), Days to first female flower anthesis (DFFA), Days to first harvest (FH), Days to first male flower anthesis (DFMA), Fruit flesh thickness (cm) (FFT), Fruit length (cm) (FL), Fruit weight (kg) (FW), Fruit width (cm) (FWD), Fruit yield vine^{-1} (kg) (FYV), Node of first female flower appearance (NFFA), Node of first male flower appearance (NFMA), Number of fruits vine^{-1} (FV), Number of primary branches (PB), Sex ratio (SR), Total soluble solids (^{o}Brix) (TSS) and Vine length (VL).

Conventional methods of analysis were used to calculate the statistical parameters, such as the mean, standard error and coefficient of variation (7).

$$\text{General mean (GM)} = \frac{\text{Total of all values}}{n},$$

where, n - number of observations

$$\text{Standard Error (SE)} = \frac{SD}{n}$$

$$\text{Coefficient of variation (CV)} = \frac{SD}{\text{Variental mean}} \times 100$$

The standard analysis of variance method was applied to the data derived from the mean of each genotype. This was also carried out in accordance with earlier study (7). The significance tests were performed using the table provided in previous report to determine the F value (8).

The SCA and GCA of the hybrids and parents were tested using L x T analysis respectively. The L x T study of CA clarifies the type and quantity of different forms of gene effect for the manifestation of productivity and its attributing features and provides helpful information about the choice of parents. According to the information in earlier report, the null hypothesis was checked for variations between the genotypes (7). As indicated in a previous study, the GCA impacts of the parents and SCA impacts of the crosses were calculated (6).

Results

Assessment of analysis of variance, GCA of 15 parents, mean performance of all the hybrids and SCA influence of 36 hybrids with respect to all the traits tested are displayed in

Table 1 - 4 (Specific and general combining ability effects for lines, testers and hybrids and mean per se performance). The GCA tests of the parents in the present inquiry showed the following assessments. The line Subam (L3) recorded maximum value for FYV, FV and FL. The line Mysore Local (L9) had higher GCA value for productive traits for fruit weight (FW) and FYV. Manadipet Local (L4) registered low GCA value for SR, DFFA and FH. Quality characters were observed to be good in Angad (L2). Among the testers, Punjab Komal (T3) and Arka Bahar (T2) showed maximum VL with a greater PB and it also registered desirable value for DFFA and early harvest. FV and FYV were observed to be high in Arka Bahar (T2).

Accordingly, an analysis of the GCA effects and average performance of the parents showed that the lines Subam (L3), Mysore Local (L9) and Manadipet Local (L4) were the best parents for increasing productivity, while the testers Punjab Komal (T3) and Arka Bahar (T2) were found to be good parents for enhancing earliness. These are the best combiners for quality and yield traits. This allowed for further breeding programs to take advantage of growth and high yield.

Mean performance is a key parameter for the assessment of hybrids. The hybrids Subam x Punjab Komal (L3 x T3) reported improved mean performance for VL, a bigger number of PB, NFFA, early harvest, FV, FL and FYV. Mysore Local x Arka Bahar (L9 x T2) achieved greater mean value for VL, FW, TSS and FYV. Manadipet Local x Arka Bahar (L4 x T2) registered low value for DMFA, SR, FH and highest value for a greater PB.

Significant negative SCA effect for earliness and high positive SCA effects for productive traits are desirable. In the present investigation, the hybrids Subam x Punjab Komal (L3 x T3) showed low GCA effect for node of DMFA, DMFA and FH, whereas it registered highest SCA effects for FL, FW, FV and FYV. Manadipet Local x Pujab Komal (L4 x T3) showed high GCA effects for VL PB and FW. Based on *per se* performance, SCA effects the hybrids Subam x Punjab Komal (L3 x T3), Mysore Local x Arka Bahar (L9 x T2) and Manadipet Local x Arka Bahar (L4 x T2) were observed to be suitable for heterosis breeding.

Discussion

The current experiment on estimation of combining ability on L x T analysis in bottle gourd (*Lagenaria siceraria* (Molina) Standl.) was performed in the farmers field at Karaikal in Puducherry District during 2020 - 2021. For this investigation, 35 bottle gourd genotypes were obtained from various geographic areas. All genotypes were assessed for growth, yield and quality. Out of 35 genotypes, 15 were chosen for their potential yield and market desirability. Three high producing types resistant to pest and diseases were employed as testers. In order to create 36 hybrids, the chosen L and T were crossed using the L x T design of mating.

Combining ability analysis can greatly assist a plant breeder in choosing optimal parents in a successful breeding work. It also underlines the relevance of gene action in trait inheritance. In the current experiment, the average performance and GCA impacts of parents exhibited that the lines Subam (L3), Mysore Local (L9) and Manadipet Local (L4) as best parents for improving productivity whereas the testers, Punjab Komal (T3) and Arka Bahar (T2) for improving earliness were identified as good parents. Assessment of parents depends on average and GCA effects together resulted in the identification of various sets of parents as good performers. GCA values are the effective tool in selecting the parents based on their performance. As the means are realized values and GCA effects are estimated values, evaluation based on these values considered together gives reliable result. According to earlier report, if a favorable GCA effect in a genotype corresponds with matching favorable *per se* performance, additive gene action is operative for the trait concerned in those genotypes (9). If that genotype is used as a parent in hybridization programme, it is expected to develop transgressive segregants for the concerned trait. Therefore, selection of parents based on GCA combined with *per se* performance together would be of desirable value in hybridization programmes.

The present investigation demonstrated that the variations owing to SCA were of greater significance than that of GCA for each trait tested, indicating the prevalence of non-additive gene action in control of these traits. This was addition supported by the proportion of SCA and GCA variations of various characteristics. This is against the findings of earlier reports, which found the prevalence of additive gene for the production of characteristics under study and observed that the presence of both additive and non-additive gene activity are involved in the inheritance of all the traits examined (10 – 13).

The genetic construction of offsprings could be enhanced through efficient parental recombination in a crossover approach. To produce optimal recombinants in a

Table 1. Analysis of variance for combining ability of parents and hybrids in bottle gourd

Characters	GCA	SCA	GCA/SCA	Gene Action
Vine length	8.1716	4324.95	0.0018	Non - additive
Number of primary branches	0.0216	0.9212	0.0234	Non - additive
Node of first male flower appearance	0.0037	0.4931	0.0075	Non - additive
Node of first female flower appearance	0.009	0.9498	0.0094	Non - additive
Days to first male flower anthesis	0.0594	11.6472	0.0299	Non - additive
Days to first female flower anthesis	0.056	2.1252	0.0263	Non - additive
Sex ratio	0.0003	0.0202	0.0148	Non - additive
Days to first harvest	0.0432	1.8482	0.0233	Non - additive
Fruit length	-0.0055	10.3738	-0.0005	Non - additive
Fruit width	0.0028	0.7294	0.0038	Non - additive
Fruit weight	0.0011	0.0322	0.0341	Non - additive
Number of fruits per vine	0.0171	0.8066	0.0212	Non - additive
Total soluble solids	0.0001	0.0238	0.0042	Non - additive
Ascorbic acid	0.0014	0.0356	0.0393	Non –additive
Fruit yield vine^{-1}	0.0233	2.1925	0.0106	Non - additive

Table 2. General combining ability (GCA) effects of lines and testers for growth, yield and quality characters in bottle gourd

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L1	429.31	7.07	6.56*	8.73**	46.82	48.67*	0.33**	58.18**	36.68	21.11	1.31	6.51	1.83	9.72**	8.44
L2	530	7.68	8.77	11.56	46.29	47.37**	0.33**	60.44	38.5	21.47	1.27	7.47	2.09	8.88	9.75
L3	651.91**	10.25*	7.71	10.04	41.62**	43.50**	0.23**	57.93**	42.92**	20.4	0.59	13.28**	2.14	9.18	15.34*
L4	523.91	8.38	8.59	11.54	50.94	53.08	0.19**	60.67	41.46**	21.17	1.04	11.67*	1.63	8.17	12.12
L5	410.36	7.33	8.25	11.31	47.86	51.08	0.43	61.61	37.89	21.76	1.26	10.38	1.91	8.42	12.77
L6	522.76	8.41	8.86	11.59	46.17	50.53	0.35*	61.53	41.84**	22.71	1.15	9.16	1.87	8.47	10.57
L7	409.37	7.36	6.75*	10.76	52.26	55.33	0.46	65.67	38.68	23.1	1.16	11.35*	1.96	8.54	13.14
L8	561.08*	9.54	9.32	13.23	49.58	53.62	0.72	64.13	36.11	22.75	1.26	10.72	1.97	8.53	13.5
L9	604.23**	11.08**	9.81	13.3	46.99	50.73	0.56	61.37	38.01	22.03	1.84**	8.16	1.8	8.44	14.91*
L10	433.03	7.3	8.35	13.24	49.35	51.67	0.48	62.07	38.11	23.02	1.22	10.32	2.27	8.45	12.55
L11	574.94**	8.47	7.47	11.72	47.88	49.79	0.47	61.61	37.56	23.88	1.33	9.84	1.91	7.89	13.11
L12	486.22	9.27	8.3	12.54	47.77	51.22	0.57	60.94	36.66	23.14	1.86**	8.25	2.11	7.51	7.83
T 1	513.48	9.16	8.49	12.39	45.76*	49.78	0.56*	61.57	34.73	21.92	1.26	8.97	1.87	8.15	10.31
T2	482.54	7.35	8.69	12.65	46.68	50.06	0.73	62.35	38.1	24.03	1.34	9.73	2.29	8.73	11.26
T3	532.61	9.85	8.31	13.14	49.51	50.9	0.54*	62.27	36.21	22.9	0.86	12.06*	2.09	8.44	12.93

*Significant at 5 % level ** Significant at 1 % level

1.Vine length
2.Number of primary branches
3.Node of first male flower appearance
4.Node of first female flower appearance
5.Days to first male flower anthesis
6. Days to first female flower anthesis
7. Sex ratio
8. Days to first harvest
9. Fruit length
10. Fruit width
11. Fruit weight
12. Number of fruits per vine
13. Total soluble solids
14. Ascorbic acid
15. Fruit yield vine^{-1}

Table 3. Mean performance of hybrids for various characters

Hybrids	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L1 x T1	408.95	7.68	8.32	12.08	48.45	52.43	0.91	61.67	38.31	21.48	1.35	8.74	2.09	8.51	11.88
L1 x T2	486.88	7.39	6.97*	9.00**	47.89	52.21	0.6	61.25	40.86*	23.34	1.1	8.89	2.04	8.6	9.75
L1 x T3	522.74	7.19	7.95	10.58	47.94	50.44	0.48	60.7	37.8	22.13	1.28	9.27	2.1	8.59	11.87
L2 x T1	490.25	8.49	7.96	9.38**	46.66	49.91	0.68	60.1	38.18	23.09	1.31	10.91**	2.44	8.7	14.2
L2 x T2	444.05	7.04	8.57	10.53	48.8	51.19	0.23**	61.99	35.17	23.35	1.3	8.76	1.7	8.21	11.44
L2 x T3	513.18	8.38	8.14	11.46	49.78	53.52	0.45	63.42	39.92	22.67	1.45	9.26	2.4	8.95	13.42
L3 x T1	534.52	9.82*	9.15	13.09	48.79	52.62	0.33**	61.29	36.93	22.55	1.43	9.46	2.05	8.57	13.47
L3 x T2	559.04**	9.88*	9.18	14.12	47.04	51.03	0.32**	60.23	38.68	24.46	1.62	8.5	2.42	8.56	13.76
L3 x T3	652.29**	12.20**	5.83**	8.35**	35.78**	47.87**	0.19**	56.11**	53.82**	21.53	0.72	12.65**	2.52	8.63	16.92*
L4 x T1	398.52	6.99	8.6	11.63	42.84**	49.48*	0.26**	59.67	36.57	23.87	1.3	8.96	2.37	8.51	11.68
L4 x T2	635.40**	10.95**	6.45**	12.06	37.50**	46.81**	0.20**	57.23**	38.53	22.75	1.36	9.87	2.12	7.79	13.37
L4 x T3	474.83	7.27	7.45	13.12	49.12	52.27	0.47	61.53	44.11**	24.95*	1.75	9.22	2	8.41	16.21
L5 x T1	521.63	7.32	9.09	12.77	47.68	51.05	0.46	60.68	37.04	21.74	1.59	9.66	1.68	7.78	15.37
L5 x T2	495.57	7.67	8.47	11.05	46.69	50.04	0.53	60.97	35.58	20.17	1.52	9.18	2.09	8.05	13.88
L5 x T3	443.05	6.68	8.93	11.96	48.33	50.97	0.40*	61.26	37.32	22.68	1.87*	6.73	2.2	7.97	12.67
L6 x T1	403.67	8.7	9.09	12.72	47.81	52.03	0.48	61.7	38.1	20.36	1.86*	8.38	2.07	8.28	15.44
L6 x T2	488.6	9.49	9.18	12.7	49.63	51.29	0.27**	61.92	41.09*	22.61	1.97**	8.22	2.18	8.48	16.2
L6 x T3	493.84	7.68	9.15	12.31	48.78	51.29	0.44	62.92	40.59	22.78	1.52	6.39	1.96	8.47	9.72
L7 x T1	413.24	6.96	7.91	12.33	44.78**	49.72*	0.47	61.24	39.82	21.25	1.55	7.46	1.82	8.46	11.58
L7 x T2	422.97	8.37	9.22	12.51	46.31	49.84	0.48	61.59	35.21	23.82	1.81*	8.22	2.15	7.66	14.88
L7 x T3	501.45	6.88	8.6	12.05	47.29	50.75	0.47	61.3	35.69	23.12	1.77	8.17	1.86	8.5	14.44
L8 x T1	534.36	7.32	8.72	13.39	48.18	51.77	0.38**	62.11	38.01	22.75	1.64	8.12	2.04	8.34	13.33
L8 x T2	434.85	7.04	9.2	11.02	49.68	53.45	0.38**	63.24	39.91	23.21	1.52	9.06	2.28	7.69	13.76
L8 x T3	586.63**	9.95*	8.97	11.94	50.9	54.96	0.47	64.08	36.7	23.89	1.52	8.37	2.18	8.62	12.73
L9 x T1	458.51	7.85	8.67	13.1	49.64	53.54	0.61	63.56	38.31	23.71	1.96**	8.23	1.73	8.42	16.13
L9 x T2	640.90**	10.55**	9	12.83	37.06**	48.83**	0.22**	58.83**	35.08	23.32	1.98**	8.57	2.48	7.99	16.71*
L9 x T3	393.37	8.2	10.16	13.06	48.39	52.45	0.78	62.37	37.52	23.05	1.79	7.55	2.13	7.8	13.53
L10 x T1	443.46	7.87	8.48	12.58	49.21	53.07	0.74	62.96	37.14	23.28	1.59	7.8	1.61	8.38	12.42
L10 x T2	373.81	7.29	8.15	12.38	48.56	51.76	0.63	61.27	40.5	22.16	1.49	7.73	2.15	8.29	11.46
L10 x T3	495.54	7.75	8.73	12.89	49.7	52.8	0.41	62.73	39.07	23.05	1.53	8.31	2.06	8.32	12.67
L11 x T1	550.64*	7.56	8.2	13.66	50.52	53.72	0.47	63.98	40.53	25.00*	1.52	8.3	1.99	8.64	12.63
L11 x T2	549.80*	7.87	7.77	11.97	50.52	54.57	0.47	64.69	37.55	22.82	1.61	8.33	2.15	8.48	13.46
L11 x T3	532.74	7.13	8.03	12.35	50.14	54.38	0.61	64.18	37.39	22.95	1.51	8.58	2.3	8.39	12.93
L12 x T1	464.17	7.7	9.2	13.18	52.33	55.57	0.38**	64.96	40.27	23.38	1.63	10.23*	1.85	8.49	9.09
L12 x T2	470.99	8.47	8.57	13.4	48.88	51.42	0.47	61.23	39.68	23.28	1.41	10.58*	1.82	8.25	14.97
L12 x T3	480.12	7.9	8.13	12.05	50.13	52.79	0.47	62.62	40.64	23.05	1.49	9.27	2.05	7.83	14.52

*Significant at 5 % level ** Significant at 1 % level

1.Vine length
2.Number of primary branches
3.Node of first male flower appearance
4.Node of first female flower appearance
5.Days to first male flower anthesis
6. Days to first female flower anthesis
7. Sex ratio
8. Days to first harvest
9. Fruit length
10. Fruit width
11. Fruit weight
12. Number of fruits per vine
13. Total soluble solids
14. Ascorbic acid
15. Fruit yield vine^{-1}

Table 4. Specific combining ability (SCA) effects of lines and testers for growth, yield and quality characters in bottle gourd

Hybrids	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L1 x T1	-40.33*	0.56	0.41	1.13	-0.04	0.38	0.19**	0.22	-0.13	-0.67	0.09	-0.29	0.12	-0.16	0.38
L1 x T2	5.85	-0.37	-0.72*	-1.41*	0.73	1.2	0.01	0.48	2.54**	0.96	-0.16	-0.12	-0.08	0.19	-1.67
L1 x T3	34.47*	-0.18	0.31	0.28	-0.7	-1.58*	-0.18**	-0.7	-2.41**	-0.29	0.07	0.41	-0.04	-0.03	1.29
L2 x T1	31.33	0.82	-0.43	-1.47*	-2.15*	-1.99**	0.17**	-1.98**	0.98	0.22	-0.06	1.20**	**0.37***	-0.02	0.85
L2 x T2	-46.61**	-1.28*	0.4	0.21	1.32	0.33	-0.16**	0.59	-1.92**	0.25	-0.06	-0.92*	-0.53**	-0.26	-1.83
L2 x T3	15.28	0.47	0.03	1.26	0.83	1.66*	-0.01	1.39	0.94	-0.47	0.12	-0.28	0.16	0.28	0.98
L3 x T1	-23.85	-0.52	0.93*	0.84	4.53**	1.76**	-0.01	1.84*	-5.66**	-0.12	0.16	-0.81	-0.17	-0.12	1.03
L3 x T2	-31.08	-1.10*	**1.18****	**2.40****	4.11**	1.2	0.10**	1.45*	-3.79**	**1.55****	**0.35****	-1.74**	0.04	0.12	1.4
L3 x T3	54.93**	1.62**	-2.12**	-3.25**	-8.63**	-2.96**	-0.10**	-3.29**	**9.45****	-1.43*	-0.51**	**2.55****	0.13	0	**3.04****
L4 x T1	-80.82**	-1.12*	0.92*	-1.03	-0.71	-0.4	-0.10**	-0.05	-2.61**	0.19	-0.19*	-0.46	0.31	0.17	-2.41*
L4 x T2	124.32**	**2.20****	-1.00**	-0.07	-4.71**	-2.03**	-0.05*	-1.81*	-0.54	-1.17*	-0.13	0.48	-0.09	-0.29	-0.64
L4 x T3	-43.50*	-1.08*	0.06	1.11	**5.43****	**2.43****	0.15**	**1.86***	3.15**	0.98	0.31**	-0.03	-0.23	0.13	-2.43*
L5 x T1	58.46**	0.39	0.09	0.45	-0.28	0.01	-0.06*	-0.54	0.95	0.38	-0.08	1.07*	-0.21	-0.26	1.06
L5 x T2	0.65	0.1	-0.31	-0.74	0.06	0.04	0.13**	0.43	-0.4	-1.43*	0.15	0.62	0.06	0.27	-0.35
L5 x T3	-59.11**	-0.49	0.21	0.29	0.22	-0.04	-0.07**	0.1	-0.55	1.04	0.24*	-1.69**	0.15	-0.01	-0.72
L6 x T1	-34.79*	0.37	-0.21	-0.25	-1.33	0.13	0.03	-0.72	-1.27*	-1.38*	0.06	0.65	0.11	-0.23	1.32
L6 x T2	18.4	0.52	0.09	0.26	1.83*	0.44	-0.07**	0.17	1.84**	0.63	0.18	0.52	0.06	0.22	2.16*
L6 x T3	16.39	-0.89	0.12	-0.01	-0.5	-0.57	0.03	0.55	-0.56	0.76	-0.24*	-1.17**	-0.17	0.01	-3.48**
L7 x T1	-9.07	-0.15	-0.83*	-0.36	-1.75*	-0.74	-0.05*	-0.38	3.47**	-1.31*	-0.17	-0.56	-0.01	0.15	-2.39*
L7 x T2	-31.08	0.62	0.7	0.35	1.12	0.42	0.06**	0.65	-1.03	1.03	0.09	0.23	0.16	-0.39*	1
L7 x T3	40.15*	-0.47	0.13	0.01	0.63	0.32	-0.01	-0.26	-2.44**	0.28	0.09	0.33	-0.14	0.24	1.39
L8 x T1	39.33*	-0.48	-0.41	0.88	-1.80*	-1.98**	-0.08**	-0.83	0.36	-0.36	0.07	-0.46	-0.02	0.02	-0.28
L8 x T2	-91.93**	1.41**	0.29	-0.96	1.03	0.74	0.03	0.97	2.37**	-0.13	-0.06	0.51	0.07	-0.37	0.24
L8 x T3	52.60**	1.90**	0.11	0.08	0.77	1.24	0.05*	-0.14	-2.73**	0.49	-0.01	-0.05	-0.05	**0.35**	0.04
L9 x T1	-15.51	-0.72	-0.78*	-0.29	4.22**	1.58*	0.02	1.72*	1.90**	0.52	0.03	0.05	-0.28	0.25	0.27
L9 x T2	**135.14****	1.33*	-0.22	-0.03	-7.03**	-2.10**	-0.26**	-2.32**	-1.22*	-0.1	0.06	0.42	0.32	0.07	1.14
L9 x T3	-119.63**	-0.62	0.99**	0.32	2.82**	0.52	**0.24****	0.6	-0.68	-0.42	-0.09	-0.46	-0.04	-0.32	-1.41
L10 x T1	29.43	0.53	-0.14	-0.43	0.35	0.16	0.10**	0.4	-1.21*	0.62	0.04	-0.22	-0.22	-0.05	-0.1
L10 x T2	-71.96**	-0.69	-0.25	-0.1	0.34	-0.1	0.10**	-0.62	2.26**	-0.73	-0.06	-0.25	0.16	0.11	-0.97
L10 x T3	42.53*	0.17	0.39	0.53	0.01	-0.06	-0.19**	0.22	-1.06	0.11	0.02	0.47	0.06	-0.06	1.07
L11 x T1	29.83	0.34	0.03	0.61	-1.83*	-0.86	-0.10**	-1.44*	2.59**	1.54**	-0.05	-0.17	-0.05	0.04	-0.71
L11 x T2	-2.76	0.02	-0.18	-0.56	1.84*	1.03	0.01	1.29	-0.27	-0.83	0.05	-0.11	-0.04	0.13	0.2
L11 x T3	-27.07	-0.34	0.14	-0.05	-0.01	-0.16	0.09	0.16	-2.32**	-0.75	-0.01	0.28	0.09	-0.17	0.51
L12 x T1	15.99	-0.03	0.4	-0.09	1.49	1.95**	-0.11**	1.78*	0.63	0.32	0.1	-0.01	0.05	0.2	0.97
L12 x T2	-8.94	0.1	-0.01	0.66	-0.63	-1.16	0.09**	-1.27	0.16	-0.02	-0.11	0.37	-0.13	0.21	-0.68
L12 x T3	-7.05	-0.07	-0.39	-0.57	-.0.86	-0.79	0.02	-0.51	-0.79	-0.3	0.01	-0.36	0.09	-0.41*	-0.29

Significant at 5 % level** * Significant at 1 % level**

1.Vine length
2.Number of primary branches
3.Node of first male flower appearance
4.Node of first female flower appearance
5.Days to first male flower anthesis
6. Days to first female flower anthesis
7. Sex ratio
8. Days to first harvest
9. Fruit length
10. Fruit width
11. Fruit weight
12. Number of fruits per vine
13. Total soluble solids
14. Ascorbic acid
15. Fruit yield vine^{-1}

segregating generation, the hybrid's progenitors must have superior GCA for the traits targeted for enhancement. Selection in the early segregating generation of hybrids with strong SCA effects is likely to be ineffective, as the SCA effects mask the true performance of the plants chosen. Recombination breeding is expected to provide segregants possessing beneficial genes from both progenitors, hence it is advisable to select hybrids that include parents exhibiting substantial GCA effects and negligible SCA effects (14 – 16). The *per se* performance and GCA impacts of hybrids may be the greatest indicators of hybrid vigour exploitation (17). Therefore, in the current study, the hybrids produced from L x T mating were assessed to determine their suitability for both heterosis and recombination breeding. Additionally, another study described the generation of hybrids in crosses involving both the parents with average and GCA impacts for productivity and its components features in pumpkin (18).

The hybrids from L x T were evaluated for their mean performances. The hybrids Subam x Punjab Komal (L3 x T3) recorded better mean performance for VL, more PB, node of first female flower appearance, early harvest, FV, FL and FYV. Mysore Local x Arka Bahar (L9 x T2) recorded higher mean value for VL, FW, total soluble solids and FYV. Manadipet Local x Arka Bahar (L4 x T2) registered low value for DFMA, SR, FH and highest value for more PB. The increase in FW might be attributed to increased mineral nutrition of plants associated with acceleration of metabolic activity, photosynthesis and greater diversion of food material to fruits as mentioned in bitter gourd (19). This observation aligns with the earlier findings such as PB and FL, VL, FW and fruit girth, node of DFMA, node of NFFA, days to DMFA, FW, FV, fruits flesh thickness and FYV in bottle gourd (20 – 23). The F_2 hybrids of bottle gourd emerged as a specific combiner for yield (24). This was in accordance with the current study. In previous study, it was reported that the production of hybrids in crosses involving both the parents with mean and GCA effects for yield and its components traits in pumpkin (18).

Standard heterosis, SCA effects and hybrid performance could be the strongest indicators of hybrid vigor exploitation. For this reason, the hybrids produced in the current study through Line x Tester mating were assessed to determine their suitability for both heterosis and recombination breeding (17). A polygenically regulated trait, grain yield is dependent on numerous related traits. Selection based just on grain yield is typically ineffective; however, selection based on its constituent characteristics may be more dependable and effective.

It is well evident that the mean performance reflects only the phenotypic expression and therefore, this parameter could not be fully relied upon to decide the hybrids for heterosis breeding. Heterosis is mostly decided by the non - additive portion of genetic variance constituting dominance and epistatic interactions. This non - additive genetic variance of hybrids could be estimated in terms of SCA effects (25). Hence, evaluation of hybrids for heterosis breeding based on their SCA effects would be more desirable. SCA effects are generally of great importance for commercial exploitation of heterosis in bottle gourd (26).

The present study revealed that the variances due to SCA were of higher magnitude than that of GCA for all characters studied, indicating the predominance of non-additive gene action in control of these traits. This was further strengthened by the ratio of GCA and SCA variances of different traits. Hence, heterosis breeding could be better exploited for improvement. Grain yield is a quantitative trait which is affected by genotype × environment (G × E) hence combining ability would depend on the set of germplasm and environment where they are tested. In the present study significant interactions were found between GCA and environment.

Combining ability may sometimes result in the narrowing of genetic base and is time consuming and requires expertise. This may be overcome by the use of molecular methods. The ability to predict optimal genotype combinations for various goals in plant breeding on the basis of molecular-based genetic data would remarkably increase the effectiveness of plant breeding programs. Theoretically, when GCA is considered as a trait, all populations for QTL mapping can be applied to map GCA loci. For a better contribution of marker-QTL associations in plant breeding, their association should be consistent across diverse genetic backgrounds of inbred line testers and across breeding populations within a heterotic group (27).

The combining ability analysis helps not only breeders but also farmers by enabling the identification of superior parental lines for hybrid development, leading to crops with improved yield, quality and other desirable traits, ultimately boosting productivity and market competitiveness. These improved hybrids can lead to higher crop yields and better quality, which translates to increased productivity and profitability for farmers. They also contribute more to sustainable agricultural practices.

Significant adverse SCA effect for earliness and high positive SCA effects for productive traits are desirable. The findings of our present study are in agreement with earlier reports in bottle gourd (28).

The 3 F_1 hybrids, Subam x Punjab Komal (L3 x T3), Mysore Local x Arka Bahar (L9 x T2) and Manadipet Local x Arka Bahar (L4 x T2) produced 8 - 10 % more yield than the standard parent. The hybrids rendered 10 - 12 number of fruits vine^{-1} within 70 - 90 days as compared to 115 days in most commercial cultivars. Close observations less incidence of pest and disease incidence. Since it possessed minimum fruit weight and fruit length and maximum number of fruits vine^{-1}. Total soluble solids and ascorbic acid content were good and therefore possessed the merit to grow in home gardens also. Besides all, they succeeded in market sales gaining good eye appeal by consumers.

Conclusion

The study concludes with the conclusion that significant differences were found in the bottle gourd's general combining ability (GCA) and specific combining ability (SCA) for every parameter that was taken into consideration. The analysis of gene impacts for growth, quality and yield characteristics demonstrated that non-additive action of gene was acting for entire characters tested. Its potential was shown by the early harvest of hybrids from the cros Subam x Punjab Komal (L3 x T3). The testers Punjab Komal (T3) and Arka Bahar (T2), as well as the lines Subam (L3), Mysore Local (L9) and Manadipet Local (L4), were found to be suitable parents for future breeding initiatives that aim to maximize on earliness and high yield. The hybrids L8 x T3 and L5 x T2 were noted to be extremely suited for recombination breeding since these hybrids observed non-significant SCA effect with significantly favorable GCA impact of the parents for the features viz., total soluble solids and ascorbic acid content. Hence, these hybrids could be exploited to get desirable segregants. The study also highlights the importance of combining ability to be used in heterosis breeding and this could be further utilized for molecular research to identify yield attributing traits in these hybrids. By identifying so genetically improved varieties can be produced which is ultimately helpful for the farmers.

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Authors' contributions

JJSI carried out preparation and implementation of research work, field data collection and wrote the manuscript. KSCB assisted in manuscript editing. RS performed statistical analysis, data interpretation. KM helped for grammatical corrections. KS reviewed and edited the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that no conflict of interest exist.

Ethical issues: None

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