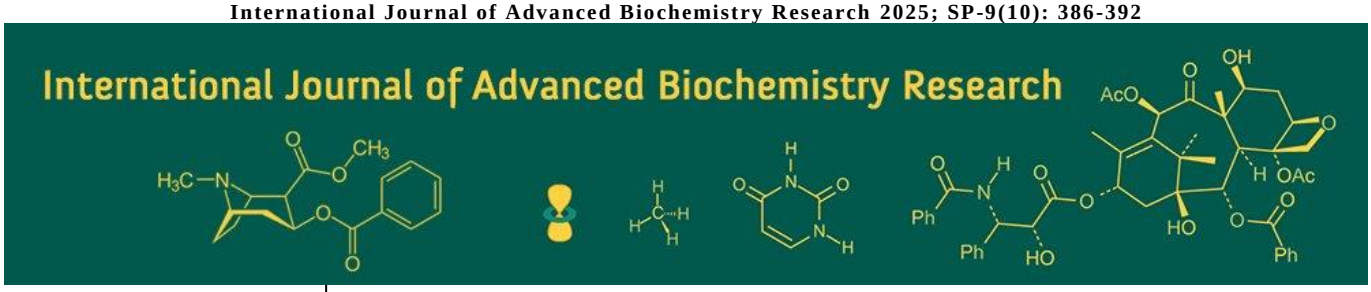

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Heterosis and combining ability studies in sponge gourd (*Luffa cylindrica* L.)

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Abstract
The present investigation entitled "Heterosis and Combining Ability Studies in Sponge Gourd (*Luffa cylindrica* L.)" was carried out at the experimental block, Department of Vegetable Science, College of Horticulture, Mudigere during 2024-25. Twenty one F_1 hybrids were developed by crossing 7 lines with 3 testers in a Line × Tester mating design. These hybrids along with their parents were evaluated in a Randomized Complete Block Design (RCBD) with three replications. The mean sum of squares due to different sources of variation showed significant differences for most of the traits studied. Heterosis over the standard check (Kashi Sowmya) was observed desirable and significant for several traits including vine length at 60 DAS (34.57%), Chlorophyll content (37.50%), number of branches per plant at 60 DAS (21.31%), days to first female flower appearance (-20.20%), fruit length (22.94%), number of fruits per vine (20.88%) and fruit yield per plot (20.88%). Among the ten parents studied, KRCCH-6, Pusa Sneha and Pusa Chikni emerged as good general combiners for days to first female flower appearance, fruit length and fruit yield per plot. The hybrids KRCCH-6 × Pusa Chikni and Pusa Sneha × Pusa Chikni were identified as superior specific combiners for vine length at 60 DAS, fruit length, number of fruits per vine and fruit yield per plot. The predominance of additive gene action was evident as variance due to general combining ability (GCA) was greater than that of specific combining ability (SCA). The promising heterotic hybrids identified in this study hold potential for genetic improvement of sponge gourd through the exploitation of transgressive segregants for yield and other economic traits in future generations.

Keywords: Sponge gourd, heterosis, combining ability, Line × Tester, gene action, fruit yield

Introduction
Sponge gourd (*Luffa cylindrica* L.) is an important but underutilized vegetable crop grown in tropical and subtropical regions. It is a diploid species (2n = 26) belonging to the family Cucurbitaceae and is predominantly cross-pollinated. Also known as smooth luffa or climbing okra it is called chikni or turai in Hindi and tuppada heeray kayi in Kannada (Nath and Swamy 2016) [16]. In North India sponge gourd is cultivated both commercially and in kitchen gardens during the spring-summer and rainy seasons whereas in Karnataka it is largely grown in backyard gardens with limited commercial cultivation.

The young tender fruits are cooked as vegetables and used in soups and curries. They are easily digestible stimulate appetite and are suitable for people with digestive problems. Nutritionally sponge gourd is rich in vitamins and minerals especially vitamins A and C which are essential for healthy skin immunity and vision. Per 100 g of edible portion, it contains about 93.2 g of moisture 1.2 g of protein 0.2 g of fat 2.9 g of carbohydrates and 0.20 g of dietary fiber along with thiamine (0.02 mg) and riboflavin (0.06 mg) (More and Shinde 2001) [14]. Compared to ridge gourd it has higher protein and carotene content making it a more nutritious alternative.

The vine is a perennial climber with branched tendrils that help it spread. It is monoecious bearing both male and female flowers on the same plant with occasional hermaphrodite flowers. Large bright yellow flowers open between 4:00 to 7:00 AM when pollen is shed. Pollen remains viable for two to three days in winter but only about one and a half days during the rainy season while the stigma is receptive from six hours before anthesis to 24 hours after ensuring efficient cross-pollination. Understanding these reproductive traits is important for successful hybridization and seed production. Beyond its nutritional value sponge gourd contains bioactive compounds such as alkaloids flavonoids sterols glycosides

and glycoproteins that give it anti-inflammatory antifungal antibacterial and sedative properties. The fruits are used in treating high blood pressure diabetes jaundice and fever while ribosome-inactivating proteins in the seeds have shown anti-HIV potential. The dried mature fruit provides a natural sponge of cellulose fibers used as a cleaning material in bath accessories and for industrial applications. Seed oil is used in cooking and for treating skin disorders and the oil cake serves as fertilizer and animal feed (Kumar *et al*. 2013) [9].

Despite its economic and nutritional importance sponge gourd has received limited attention in crop improvement programs. Heterosis breeding offers a promising approach for enhancing yield earliness and quality. Combining ability analysis particularly through line × tester mating design helps identify superior parents and cross combinations. General combining ability (GCA) reflects additive gene effects while specific combining ability (SCA) measures non-additive effects (Sprague and Tatum 1942) [21]. Studies such as those by Musmade and Kale (1986) have demonstrated significant hybrid vigour in sponge gourd emphasizing the need to identify heterotic crosses and suitable parental lines for the development of high-yielding early maturing hybrids adapted to diverse environments.

Objectives

- To study heterosis in sponge gourd hybrids for growth, yield, and quality traits.
- To assess general and specific combining ability of parental lines and crosses.

Materials and Methods

The experimental material consisted of ten parents (seven lines and three testers) namely BGS-1, Konkan Ghoshali, KRCCH-4, KRCCH-5, KRCCH-6, Pusa Sneha and Sirsi Local as lines and Kashi Divya, Kashi Shreya and Pusa Chikni as testers. Twenty-one F_1 hybrids were developed during 2024 through Line × Tester mating design. These hybrids along with their ten parents were evaluated for growth and yield-related traits in a randomized block design with three replications at the Vegetable Experimental Block, College of Horticulture, Mudigere during Kharif and summer seasons of 2024-25. A spacing of 0.5 m between plants and 1.5 m between rows was maintained. Data were recorded on five randomly selected plants per treatment (hybrids and parents) for seven characters: vine length (m) at 60 DAS, chlorophyll content (mg/g), number of branches per plant at 60 DAS, days to first female flower appearance, fruit length (cm), number of fruits per vine and fruit yield per plot (kg). Heterosis over mid-parent, better parent and the standard check (Kashi Sowmya) was computed for each character. Significance was tested and estimates of general combining ability (GCA) and specific combining ability (SCA) effects were obtained following the procedure outlined by Kempthorne (1957) [5]. For estimation of chlorophyll content, fresh and fully matured leaves from the plant were brought to the laboratory in polyethylene bag from the field and were cut into pieces. The known weight of the sample (100 mg) was incubated in 7.0 ml of Dimethyl Sulfoxide (DMSO) at 65 °C for 120 minutes. After the incubation, supernatant was collected by decanting and leaf tissue was discarded. Then the volume of the supernatant was made up to 10 ml using DMSO.

The absorbance of the extract was measured at 645 nm and 663 nm using Dimethyl Sulfoxide as a blank in spectrophotometer.

The total chlorophyll content was calculated by using the formulae given below.

$$\text{Total Chlorophyll} = [20.2(A_{645}) + 8.02(A_{663})] \times \frac{V}{(1000 \times W \times a)} \text{ (mg/g fr. wt.)}$$

Where,

A = Absorbance at specific wavelength (645 nm and 663 nm)

V = Volume of the extract (10 ml)

W = Fresh weight of the sample (100 mg)

a = length of light in cuvette (1 cm)

Results and Discussion

***Per se* performance and Analysis of variance**

The *Per se* performance of parents and hybrids for different traits is presented in Table 1. Analysis of variance revealed highly significant differences for all traits (Table 2). Variance due to parents was also highly significant for all traits indicating the presence of adequate variability among parents. The parents versus crosses variance were significant for most traits confirming the presence of heterosis. Significant differences were also observed among crosses and line × tester interactions for all traits except vine length @ 60 DAS and fruit length. These results are in agreement with the findings of Kumar and Pandit (2020) [7].

Heterosis

For vine length at 60 DAS Heterosis over the better parent, it ranged from-18.23 percent (Konkan Ghoshali × Pusa Chikni) to 36.73 percent (KRCCH-4 × Kashi Shreya). Over the standard check, the highest significant positive heterosis was exhibited by KRCCH-6 × Pusa Chikni (34.57%) and the highest significant negative heterosis by Konkan Ghoshali × Pusa Chikni (-23.11%) mainly due to complementary gene action and the presence of dominance and over-dominance effects contributing to hybrid vigour. Similar results were also reported by Lakhnotra *et al*. (2019) [11] and Kumar and Pandit (2020) [7] in sponge gourd and Masud *et al*. (2021) [12] in bottle gourd. For chlorophyll content the crosses KRCCH-5 × Kashi Divya (41.82% over mid parent) and Pusa Sneha × Pusa Chikni (35.38% over better parent and 37.50% over standard check) recorded the highest heterosis, indicating greater photosynthetic efficiency and enhanced metabolic activity, which support vigorous growth and higher yield potential. . The magnitude of heterosis was comparable with the findings of Reddy *et al*. (2019) [18], Lakhnotra *et al*. (2019) [11] and Kumar and Pandit (2020) [7] in sponge gourd. For number of branches per vine at 60 DAS, the highest heterosis was recorded in KRCCH-4 × Kashi Divya (30.21% over mid parent) and Pusa Sneha × Pusa Chikni (25.20% over better parent), reflecting the role of non-additive gene action and hybrid vigour in promoting lateral growth and branching, which helps in increasing fruit bearing sites. Similar findings were also reported by Reddy *et al*. (2019) [18] and Kumar *et al*. (2020) [7] in sponge gourd. For days to first female flowering the cross KRCCH-6 × Pusa Chikni exhibited the highest negative heterosis (-21.36% over mid parent), which is desirable for early flowering. This earliness is attributed to favourable gene interactions and faster transition from

vegetative to reproductive growth, an advantage for early market harvests. Comparable findings were reported in ridge gourd by Kumar and Pandit (2020) [7], Kumar and Pandit (2022) [8] and Khairiya *et al*. (2023) [6] in sponge gourd and Mishra *et al*. (2019) [13] and Masud *et al*. (2021) [12] in bottle gourd. For fruit length KRCCH-6 × Pusa Chikni recorded the highest heterosis over the standard check (22.94%), while Pusa Sneha × Kashi Divya was superior over the better parent (8.68%). This improvement reflects hybrid vigour for cell division and elongation, leading to longer fruits. Similar findings in sponge gourd have been reported by Kumar and Pandit (2020) [7], Chauhan *et al*. (2023) [4] and by Khairiya *et al*. (2023) [6] and Kumari *et al*. (2024) [10] in cucumber. For number of fruits per vine KRCCH-4 × Kashi Divya showed the highest heterosis (34.00% over mid parent and 32.69% over better parent), while KRCCH-6 × Pusa Chikni recorded 23.40% over the standard check. This increase results from improved flowering, better fruit set and efficient nutrient partitioning in heterotic hybrids. Similar results in sponge gourd have been reported by Reddy *et al*. (2019) [18], Kumar and Pandit (2020) [7] and Chauhan *et al*. (2023) [4]. For fruit yield per plot the highest heterosis was recorded in KRCCH-6 × Pusa Chikni (30.38% over better parent and 20.88% over standard check). Superior yield performance is mainly due to combined effects of increased vine growth, higher chlorophyll content, more branches and greater fruit number, indicating the predominance of non-additive gene action and the potential for heterosis exploitation. These results are in agreement with the findings of Narasannavar *et al*. (2017) [15] in ridge gourd and Thakur *et al*. (2017) [23] in cucumber and in sponge gourd by Lakhnotra *et al*. (2019) [11], Kumar and Pandit (2022) [8] and Chauhan *et al*. (2023) [4] presented in the Table 3. and Table 4.

Combining ability studies

For vine height at 60 DAS, GCA & SCA: Positive GCA was observed in KRCCH-6 (0.58) and Pusa Sneha (0.39), negative in Konkan Ghoshali (-0.64) and Sirsi Local (-0.43). Among testers, Pusa Chikni (0.20) showed positive GCA. Highest positive SCA was in KRCCH-6 × Pusa Chikni (0.45) and Konkan Ghoshali × Kashi Divya (0.43). Positive GCA indicates additive gene action controlling vine height, making KRCCH-6 and Pusa Sneha reliable parents. High SCA in hybrids shows non-additive gene effects (dominance/epistasis), suggesting these crosses can be exploited for heterosis in vine length. Similar observations were reported by Mishra *et al*. (2019) [13] in bottle gourd Kumari *et al*. (2024) [10] in cucumber and Kumar and Pandit (2022) [8] in sponge gourd. For chlorophyll content, positive GCA effects were recorded in Pusa Sneha (0.20) and KRCCH-5 (0.10); negative in Sirsi Local (-0.17) and Kashi Shreya (-0.10). Among testers, Pusa Chikni (0.08) had positive GCA. Highest SCA was in Konkan Ghoshali × Kashi Shreya (0.12), while Konkan Ghoshali × Kashi Divya (-0.13) had negative SCA. This is due to additive gene effects (GCA) help in consistently improving chlorophyll content. Positive SCA indicates hybrid vigour, allowing specific combinations to produce higher photosynthetic efficiency. Previous studies, including those of Singh *et al*. (2024) [20] in bottle gourd and Kumari *al*. (2024) [10] in cucumber, have similarly shown that chlorophyll content was largely influenced by additive gene action. For number of branches per vine, positive GCA in Pusa Sneha (0.61) and KRCCH-6 (0.48), among testers Pusa Chikni (0.40) was the best combiner. Highest SCA in Sirsi Local × Pusa Chikni (0.37), most negative in KRCCH-5 × Pusa Chikni (-0.50). this is due to additive gene action (GCA) contributes to increased branching, which can be fixed in selection. Significant SCA reflects dominance effects, showing the hybrid potential for more branched plants. Comparable finding was reported by Chauhan *et al*. (2019) [3] and Kumar and Pandit (2022) [8] in sponge gourd. For days to first female flowering, negative GCA desirable for earliness was highest in KRCCH-6 (-3.93) and Pusa Chikni (-1.44). For SCA, KRCCH-6 × Pusa Chikni (-2.74) and KRCCH-5 × Kashi Divya (-1.77) showed the most negative effects. Negative GCA indicates additive gene control for early flowering, enabling selection for earliness. Negative SCA indicates dominance effects, showing specific hybrids can flower earlier than both parents. . Similar findings for days to first male and female flowering in sponge gourd were reported by Chauhan *et al*. (2019) [3] and Kumar and Pandit (2022) [8]. While Ruma *et al*. (2024). For fruit length positive GCA in KRCCH-6 (1.90), Pusa Sneha (0.48), and BGS-1 (0.48); among testers Pusa Chikni (1.07) highest. SCA highest in Pusa Sneha × Kashi Divya (1.29), most negative in Konkan Ghoshali × Kashi Divya (-1.40). Additive effects (GCA) help in improving fruit length through parental selection. High positive SCA indicates non-additive effects, useful in hybrids for longer fruits than either parent. Similar findings in bitter gourd have been reported by Singh *et al*. (2024) [20] and Srinivasulu and Jasmitha (2024) [22] and in sponge gourd by Chauhan *et al*. (2019) [3] and Kumar and Pandit (2022) [8]. Borasulov *et al*. (2024). For number of fruits per vine GCA & SCA: Positive GCA in KRCCH-6 (1.47) and Pusa Sneha (1.42), among testers Pusa Chikni (0.59). SCA highest in Konkan Ghoshali × Kashi Shreya (1.66) and KRCCH-4 × Kashi Divya (1.27). this is due to Additive gene action ensures parents like KRCCH-6 and Pusa Sneha reliably transmit more fruit number. Positive SCA reflects heterosis, indicating hybrid combinations can produce higher fruit set per vine. Similarly, Chauhan *et al*. (2019) [3] and Kumar and Pandit (2022) [8] reported that both additive and non additive gene actions play a role in determining the number of fruits per vine in sponge gourd. For fruit yield per plot, positive GCA in Pusa Sneha (1.67) and KRCCH-6 (1.36); among testers Pusa Chikni (0.95). SCA highest in KRCCH-6 × Pusa Chikni (1.72) and Sirsi Local × Pusa Chikni (1.18). High GCA indicates additive effects contributing to stable, high-yielding parents. Positive SCA shows non-additive gene effects, highlighting hybrids that can exploit heterosis for higher yield. Similar observations were made by Singh *et al*. (2024) [20] in bottle gourd and Chauhan *et al*. (2019) [3] and Kumar and Pandit (2022) [8] in sponge gourd. presented in the Table 5 and Table 6.

Table 1: *Per se* performance of parents, their hybrids for yield and related traits

Parents/Hybrids	Vine length (m) at 60 DAS	Chlorophyll content (mg/g)	Number of branches per plant at 60 DAS	Days to first female flower appearance	Fruit length (cm)	Number of fruits per vine	Fruit yield per plot (kg)
BGS-1	2.65	0.58	5.10	47.40	20.52	11.40	12.89
Konkan Ghoshali	2.25	0.47	4.30	48.15	19.15	9.50	10.95
KRCCH-4	2.45	0.45	4.25	47.15	20.16	9.60	12.25
KRCCH-5	3.06	0.48	5.20	45.50	20.12	10.40	13.01
KRCCH-6	3.43	0.69	6.40	43.90	22.67	12.50	13.81
Pusa Sneha	3.35	0.65	6.35	46.50	20.63	11.60	14.26
Sirsi Local	2.03	0.41	4.15	48.50	19.98	9.60	9.45
Kashi Divya	2.75	0.62	6.20	47.50	20.47	10.40	13.50
Kashi Shreya	2.45	0.63	6.25	49.55	19.30	10.10	10.33
Pusa Chikni	3.20	0.65	6.35	45.50	21.64	11.40	14.00
BGS-1 × Kashi Divya	3.47	0.59	7.10	44.45	20.67	11.50	14.36
BGS-1 × Kashi Shreya	3.36	0.40	6.40	42.90	21.49	10.70	14.19
BGS-1 × Pusa Chikni	3.59	0.70	7.35	42.20	22.58	13.40	14.85
Konkan Ghoshali × Kashi Divya	2.65	0.39	6.20	47.25	18.08	10.60	11.57
Konkan Ghoshali × Kashi Shreya	2.95	0.52	5.75	48.45	20.04	11.80	12.63
Konkan Ghoshali × Pusa Chikni	2.62	0.60	6.60	43.20	21.68	10.30	12.45
KRCCH-4 × Kashi Divya	3.76	0.68	6.80	45.20	20.31	13.40	14.70
KRCCH-4 × Kashi Shreya	2.71	0.48	6.40	43.15	20.11	10.20	14.50
KRCCH-4 × Pusa Chikni	3.53	0.70	6.90	42.30	22.58	12.30	14.75
KRCCH-5 × Kashi Divya	3.88	0.78	7.15	41.05	21.97	13.80	14.60
KRCCH-5 × Kashi Shreya	2.90	0.60	7.05	42.70	20.56	10.40	15.95
KRCCH-5 × Pusa Chikni	3.51	0.79	6.95	42.50	21.44	13.20	15.52
KRCCH-6 × Kashi Divya	3.55	0.72	6.85	41.25	22.47	13.40	14.80
KRCCH-6 × Kashi Shreya	3.75	0.50	7.10	41.60	21.95	12.90	13.72
KRCCH-6 × Pusa Chikni	4.58	0.85	7.85	35.15	24.60	14.50	18.25
Pusa Sneha × Kashi Divya	3.90	0.80	6.95	42.10	22.42	12.85	15.75
Pusa Sneha × Kashi Shreya	3.45	0.79	7.30	41.05	20.01	13.60	15.10
Pusa Sneha × Pusa Chikni	3.95	0.88	7.95	40.45	22.33	14.20	16.85
Sirsi Local × Kashi Divya	2.75	0.52	5.80	46.70	18.61	10.50	10.74
Sirsi Local × Kashi Shreya	2.85	0.41	5.40	47.90	19.25	10.00	9.97
Sirsi Local × Pusa Chikni	3.25	0.44	6.75	46.95	20.02	11.10	13.55

Table 2: Mean sum of squares for ten quantitative characters in L × T analysis in sponge gourd

Characters	Replication	Treatments (genotypes)	Parents	Lines	Tester	Line × Tester	Parents *vs* Cross	Crosses	Error
Degrees of freedom	**2**	**30**	**9**	**6**	**2**	**1**	**1**	**20**	**60**
Vine length (m) at 60 DAS	0.04	1.00**	0.69**	0.89**	0.43**	0.02	7.72**	0.80**	0.07
Chlorophyll content (mg/g)	0.00	0.06**	0.03**	0.04**	0.00	0.07**	0.08**	0.07**	0.00
Number of branches per plant at 60 DAS	0.28	2.86**	2.79**	2.76**	0.02	8.49**	36.23**	1.23**	0.21
Days to first female flower appearance	7.88	30.74**	8.29**	7.69**	12.30**	3.90**	278.56**	28.45**	12.14
Fruit length (cm)	0.13	6.08**	3.27**	3.54**	4.10**	0.00	8.33**	7.22**	2.15
Number of fruits per vine	1.86	6.93**	3.14**	4.24**	1.40**	7.31*	44.25**	6.78**	0.89
Fruit yield per plot (kg)	3.11*	12.25**	8.31**	8.44**	11.90**	0.35**	64.72**	11.41**	0.97

DAS-Days after sowing

Table 3: Heterobeltiosis of the promising crosses in sponge gourd

Crosses	Vine length (m) at 60 DAS	Chlorophyll content (mg/g)	Number of branches per plant at 60 DAS	Days to first female flower appearance	Fruit length (cm)	Number of fruits per vine	Fruit yield per plot (kg)
BGS-1 × Kashi Divya	26.30 **	-4.84	14.52 *	-6.41	0.71	0.88	6.40
BGS-1 × Kashi Shreya	26.67 **	-36.84 **	2.35	-13.42 *	4.71	-6.17	10.09
BGS-1 × Pusa Chikni	12.19	7.69	15.70 *	-10.98	4.38	17.51 *	6.05
Konkan Ghoshali × Kashi Divya	-3.64	-37.10 **	0.00	-1.87	-11.68 **	1.96	-14.30 *
Konkan Ghoshali × Kashi Shreya	20.41 *	-17.37 *	-8.10	-2.22	3.85	16.83 *	15.35
Konkan Ghoshali × Pusa Chikni	-18.23 *	-7.69	3.94	-10.29	0.22	-9.68	-11.07
KRCCH-4 × Kashi Divya	36.73 **	9.68	9.73	-4.84	-0.78	28.85 **	8.89
KRCCH-4 × Kashi Shreya	10.48	-24.21 **	2.35	-12.92 *	-0.23	0.96	18.39 *
KRCCH-4 × Pusa Chikni	10.42	7.69	8.66	-10.29	4.38	7.89	5.36
KRCCH-5 × Kashi Divya	26.66 **	25.81 **	15.32 *	-13.57 *	7.34 **	32.69 **	8.15
KRCCH-5 × Kashi Shreya	-5.22	-5.26	12.79	-13.83 *	2.19	-0.03	22.60 **
KRCCH-5 × Pusa Chikni	9.58	21.54 **	9.45	-6.59	-0.91	15.76 *	10.83
KRCCH-6 × Kashi Divya	3.50	4.35	7.03	-13.14 *	-0.88	7.20	7.17
KRCCH-6 × Kashi Shreya	9.23	-27.05 **	10.89	-16.04 **	-3.19	3.20	-0.68
KRCCH-6 × Pusa Chikni	33.53 **	23.19 **	22.66 **	-22.75 **	8.50 **	16.00 *	30.38 **
Pusa Sneha × Kashi Divya	16.42 *	23.08 **	9.45	-11.36	8.68 **	10.78	10.47
Pusa Sneha × Kashi Shreya	2.99	21.03 **	14.96 *	-17.15 **	-3.01	17.21 *	5.94
Pusa Sneha × Pusa Chikni	17.81 *	35.38 **	25.20 **	-13.00 *	3.19	22.39 **	18.21 **
Sirsi Local × Kashi Divya	0.12	-16.13 *	-6.45	-3.70	-9.07 **	0.96	-20.42 **
Sirsi Local × Kashi Shreya	16.33	-34.74 **	-13.65 *	-3.33	-3.65	-0.99	-3.42
Sirsi Local × Pusa Chikni	1.56	-32.82 **	6.35	-3.19	-7.47 **	0.88	-3.21

DAS-Days after sowing

Table 4: Standard heterosis of the crosses in sponge gourd

Crosses	Vine length (m) at 60 DAS	Chlorophyll content (mg/g)	Number of branches per plant at 60 DAS	Days to first female flower appearance	Fruit length (cm)	Number of fruits per vine	Fruit yield per plot (kg)
BGS-1 × Kashi Divya	2.06	-7.81	8.34	0.92	3.30	-2.13	-4.90
BGS-1 × Kashi Shreya	-1.37	-37.50 **	-2.34	-2.60	7.40	-8.96	-6.03
BGS-1 × Pusa Chikni	5.48	9.37	12.11	-4.19	12.86 *	14.04 *	-1.68
Konkan Ghoshali × Kashi Divya	-22.14 **	-39.06 **	-5.39	7.28 **	-9.65	-9.76	-23.40 **
Konkan Ghoshali × Kashi Shreya	-13.32	-18.23 **	-12.31 **	10.00 **	0.17	0.43	-16.38 **
Konkan Ghoshali × Pusa Chikni	-23.11 **	-6.25	0.71	-1.92	8.36	-12.34	-17.55 **
KRCCH-4 × Kashi Divya	10.48	6.25	3.81	2.62	1.50	14.04 *	-2.67
KRCCH-4 × Kashi Shreya	-20.47 **	-25.00 **	-2.34	-2.04	0.50	-13.22	-3.95
KRCCH-4 × Pusa Chikni	3.82	9.37	5.29	-3.97	12.86 *	4.71	-2.32
KRCCH-5 × Kashi Divya	14.01 *	21.88 **	9.10	-6.80 **	9.81**	17.45 *	-3.33
KRCCH-5 × Kashi Shreya	-14.69 *	-6.25	7.63	-3.06	2.75	-11.52	5.63
KRCCH-5 × Pusa Chikni	3.04	23.44 **	6.05	-3.51	7.15	12.34	2.76
KRCCH-6 × Kashi Divya	4.31	12.50	4.53	-6.34 **	12.31	14.04 *	-1.99
KRCCH-6 × Kashi Shreya	10.09	-21.35 **	8.29 **	-5.55	9.70	9.79	-9.16
KRCCH-6 × Pusa Chikni	34.57 **	32.81 **	19.79 **	-20.20 **	22.94 **	23.40 **	20.88 **
Pusa Sneha × Kashi Divya	14.59 *	25.00 **	6.05	-4.42	12.04**	9.36	4.30
Pusa Sneha × Kashi Shreya	1.37	22.92 **	11.39 **	-6.80 **	0.00	15.72 *	0.02
Pusa Sneha × Pusa Chikni	15.96 *	37.50 **	21.31 **	-8.16 **	11.58**	20.82 **	11.61**
Sirsi Local × Kashi Divya	-19.10 **	-18.75 **	-11.50	6.03	-6.98	-10.64	-28.87 **
Sirsi Local × Kashi Shreya	-16.26 *	-35.42 **	-17.60 **	8.75 **	-3.80	-14.89 *	-33.95 **
Sirsi Local × Pusa Chikni	-4.51	-31.77 **	3.05	6.59	0.05	-2.13	-10.26

DAS-Days after sowing

Table 5: Estimates of general combining ability effects of ten parents for 7 quantitative characters in L × T analysis

Traits/Parents	Vine length (m) at 60 DAS	Chlorophyll content (mg/g)	Number of branches per plant at 60 DAS	Days to first female flower appearance	Fruit length (cm)	Number of fruits per vine	Fruit yield per plot (kg)
Females (Lines)							
BGS-1	0.10	-0.06**	0.16	-0.08	0.48**	-0.26	0.24
Konkan Ghoshali	-0.64**	-0.12**	-0.61**	3.04*	-1.17*	-1.23**	-2.01**
KRCCH-4	-0.05	-0.01	-0.09	0.29	-0.10	-0.16	0.42
KRCCH-5	0.05	0.10**	0.26	-1.18	0.22	0.34	1.13**
KRCCH-6	0.58**	0.07**	0.48**	-3.93**	1.90**	1.47**	1.36**
Pusa Sneha	0.39**	0.20**	0.61**	-2.06	0.48**	1.42**	1.67**
Sirsi Local	-0.43**	-0.17**	-0.81**	3.92**	-1.81**	-1.59**	-2.81**
SEm±	0.13	0.02	0.23	1.63	0.72	0.46	0.51
CD @ 5%	0.40	0.06	0.70	4.91	2.19	1.45	1.55
Males (Testers)							
Kashi Divya	0.05	0.01	-0.10	0.74	-0.46	0.17	-0.44
Kashi Shreya	-0.24**	-0.10**	-0.31**	0.70	-0.62	-0.76**	-0.51*
Pusa Chikni	0.20**	0.08**	0.40**	-1.44**	1.07**	0.59**	0.95**
SEm±	0.09	0.02	0.15	1.07	0.47	0.30	0.33
CD @ 5%	0.29	0.08	0.46	3.25	1.45	1.15	1.25

DAS-Days after sowing

Table 6: Estimates of specific combining ability effects of 21 crosses for 7 quantitative characters in L × T analysis

Traits/Parents	Vine length (m) at 60 DAS	Chlorophyll content (mg/g)	Number of branches per plant at 60 DAS	Days to first female flower appearance	Fruit length (cm)	Number of fruits per vine	Fruit yield per plot (kg)
BGS-1 × Kashi Divya	-0.05	0.01	0.25 *	0.53	-0.46	-0.53 **	0.34
BGS-1 × Kashi Shreya	0.12 *	-0.07 **	-0.24 *	-0.99	0.53	-0.41 *	0.23
BGS-1 × Pusa Chikni	-0.08	0.05 **	-0.01	0.46	-0.07	0.95 ***	-0.57 **
Konkan Ghoshali × Kashi Divya	-0.13 *	-0.13 **	0.12	0.21	-1.40 **	-0.47 *	-0.21
Konkan Ghoshali × Kashi Shreya	0.43 **	0.12 **	-0.13	1.45 *	0.72 *	1.66 **	0.92 **
Konkan Ghoshali × Pusa Chikni	-0.32 **	0.01	0.02	-1.66 *	0.68	-1.19 **	-0.71 **
KRCCH-4 × Kashi Divya	0.38 **	0.05 **	0.20	0.91	-0.24	1.27 **	0.49 *
KRCCH-4 × Kashi Shreya	-0.39 **	-0.04 **	0.00	-1.10	-0.27	-1.01 **	0.36
KRCCH-4 × Pusa Chikni	0.00	-0.00	-0.20	0.19	0.51	-0.25	-0.85 **
KRCCH-5 × Kashi Divya	0.41 **	0.04 **	0.20	-1.77 **	1.11 **	1.17 **	-0.32
KRCCH-5 × Kashi Shreya	-0.29 **	-0.03 *	0.31 *	-0.09	-0.15	-1.31 ***	1.10 **
KRCCH-5 × Pusa Chikni	-0.12 *	-0.02	-0.50 **	1.86 **	-0.96 **	0.15	0.78 **
KRCCH-6 × Kashi Divya	-0.45 **	0.02	-0.32 **	1.18	-0.08	-0.37	-0.35
KRCCH-6 × Kashi Shreya	0.03	-0.09 **	0.14	1.56 *	-0.44	0.06	-1.37 **
KRCCH-6 × Pusa Chikni	0.45 **	0.08 **	0.18	-2.74 **	0.52	0.31	1.72 **
Pusa Sneha × Kashi Divya	0.09	-0.04 **	-0.35 **	0.16	1.29 **	-0.87 **	0.29
Pusa Sneha × Kashi Shreya	-0.07	0.06 **	0.21	-0.85	-0.96 **	0.81 **	-0.29
Pusa Sneha × Pusa Chikni	-0.02	-0.02 *	0.15	0.69	-0.33	0.06	0.01
Sirsi Local ×Kashi Divya	-0.24 **	0.05 **	0.09	-1.22	-0.23	-0.20	-0.24
Sirsi Local ×Kashi Shreya	0.14 *	0.05 **	-0.28 *	0.01	0.57	0.22	-0.94 **
Sirsi Local × Pusa Chikni	0.10	-0.10 **	0.37 **	1.21	-0.35	-0.02	1.18 **
SEm±	0.05	0.01	0.12	0.65	0.35	0.19	0.19
CD @ 5%	0.17	0.03	0.38	1.95	1.08	0.59	0.59

DAS-Days after sowing

Conclusion

The study revealed highly significant differences among parents and hybrids for all traits, confirming the presence of wide genetic variability and scope for heterosis breeding in sponge gourd. Significant parent, cross and parent versus cross variances indicated the expression of heterosis for key traits. Among the hybrids, KRCCH-6 × Pusa Chikni consistently recorded the highest heterosis for vine length, chlorophyll content, number of fruits per vine and fruit yield, while KRCCH-4 × Kashi Divya and Pusa Sneha × Pusa Chikni were superior for branching and chlorophyll content. Earliness was effectively improved by KRCCH-6 × Pusa Chikni, which showed the highest negative heterosis for days to first female flowering. Combining ability analysis revealed the predominance of both additive and non-additive gene actions for most traits. Parents KRCCH-6 and Pusa Sneha, along with tester Pusa Chikni, were identified as good general combiners for yield and its contributing traits. Specific crosses such as KRCCH-6 × Pusa Chikni, KRCCH-4 × Kashi Divya and Sirsi Local × Pusa Chikni exhibited high specific combining ability effects for fruit yield and related traits, highlighting the role of dominance and epistasis in heterosis expression. These results suggest that hybrids like KRCCH-6 × Pusa Chikni have strong potential for commercial exploitation and can serve as valuable genetic material for future breeding programs aimed at developing high-yielding and early sponge gourd hybrids.

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