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Thilak B Anand
Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

CN Hanchinamani
Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

Padmanabha K
Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

Meenakshi Sood
Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

Jayappa J
Department of Entomology, University of Horticultural Sciences, Bagalkot, Karnataka, India

Mohan Kumar S
Department of Biotechnology and Crop Improvement, University of Horticultural Sciences, Bagalkot, Karnataka, India

Corresponding Author:
CN Hanchinamani
Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

Exploiting hybrid vigour: An assessment of Heterosis in snake gourd (*Trichosanthes cucumerina* var. *anguina* L.)

Thilak B Anand, CN Hanchinamani, Padmanabha K, Meenakshi Sood, Jayappa J and Mohan Kumar S

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Abstract
Snake gourd (*Trichosanthes cucumerina* var. *anguina* L.) is a diploid, monoecious annual woody climber popularly known as Snake tomato or long tomato belonging to the family Cucurbitaceae. The crop has significant levels of minerals (0.5%), fibre (0.5%), protein (0.5%), fat (0.3%) and carbohydrates (3.3%). Considering the economic significance and medicinal potential of the crop, the present investigation was carried out employing seven lines and two testers to develop 14 hybrids through a Line × Tester mating design. The hybrids Tenali Local × PKM 1, Siddapur Local × PKM 1 and Raikur Local × PKM 1 possessed significantly high standard heterosis, corresponding for earliness, yield and quality parameters resulting as superior hybrids. On the basis of its yield potential and earliness characters, the hybrid Tenali Local × PKM 1 outperformed all other hybrids with a yield of 7.64 kg/plant, the hybrid showed 94.78% standard heterosis over commercial check. The hybrid Tenali Local × CO-2 manifested superior quality parameters like ascorbic acid, fruit protein content and fruit carbohydrate content, which further can be used in breeding programme.

Keywords: Line, tester, commercial check, heterobeltiosis and standard heterosis

1. Introduction
Snake gourd (*Trichosanthes cucumerina* var. *anguina* L.) is an annual, day neutral climbing type herbaceous vegetable crop belonging to the Cucurbitaceae family with chromosome number of 2n = 2x = 22. Snake gourd occurs in the wild form in India, South-East Asia and tropical Australia. Trichosanthes, the largest genus in the Cucurbitaceae family, is found in southern and eastern Asia, including India, Taiwan, Philippines, Japan, Australia, Fiji and the Pacific Islands. Two species, *Trichosanthes cucumerina* and *Trichosanthes dioica*, are cultivated in tropical regions for their immature fruit, which is rich in minerals and dietary fibre. The Indian Archipelago is thought to be its place of origin. (Vavilov, 1935) [14]. It is a nutrient dense plant that could help people in rural areas who can't afford milk or other comparatively costly nutritional supplements (Idowu *et al.*, 2019) [3]. The crop has significant levels of minerals (0.5%), fibre (0.5%), protein (0.5%), fat (0.3%) and carbohydrates (3.3%). As stated by Ojiako and Igwe (2008) [9], the most common mineral elements present are sodium, magnesium, zinc, potassium and phosphorus. Even though the nutritional benefits are high, it is grown as minor vegetable due to lowest global production, marketing facilities and consumption.

While the unripe immature fruits, fresh succulent leaves and stems are consumed as vegetables, the full fruit has a bright red colour and very bright red juice used in soups and stews. It is substituted for tomatoes when they are scarce. There is a wide range of variability in fruit size, shape and colour (Rashid, 2014) [12]. In Bangladesh, vegetable production has increased five times in the past 40 years which has scored third in global vegetable production, next to China and India. Flowers open from bud stage in 8-16 days, with anthesis starting in early evening, between 5 and 7 pm. The stigma remains receptive from 12 hrs before anthesis to 12 hrs after anthesis, but maximum receptivity remains at the time of anthesis. The sex ratio (ratio of staminate to pistillate flowers) in the monoecious species of snake gourd varies from 25:1 to 225:1 (Singh, 1953) [13]. The major pollinators are bees (*Apis florae* and *A. dorsata*) and beetles (*Conpophilus* sp.).

Exploitation of heterosis in crop plants is one of the most attractive achievements in boosting up the production and productivity of snake gourd breaking the present yield barrier. The improvement in the yield and quality can be possible with the heterosis breeding. Heterosis signifies increased or decreased vigour of the F_1 hybrids over the parents. While breeding high-yielding varieties of crop plants, the breeder often deals with the problem of selecting the desirable parents. The improvement in the yield and quality can be possible with the heterosis breeding. Line × Tester (L × T) analysis is an enhanced version of the top cross design, commonly used to identify promising parental lines based on the performance of their hybrids. (Kempthrone, 1957) [4]. So, the present investigation will be undertaken to assess the magnitude of heterosis for fruit yield and yield attributing traits.

2. Materials and Methods

2.1 Experimentation

The experiment was carried out at College of Horticulture, Bengaluru, Karnataka. The study made use of nine inbred lines *viz.* Banswada Local, Siddapur Local, IC212509, IC212416, Raikur Local, Tenali Local and IC202160 along with two testers CO-2 and PKM 1. These genotypes, which represent a wide genetic base, were collected from different regions of Telangana, Kerala, Andhra Pradesh and Tamil Nadu. Selection was done based on their individual performance for yield and fruit related traits. Crosses were carried out using the Line × Tester mating design, producing 14 F_1s. The hybrids, together with commercial check (COVAI 951), were grown in a randomized block design (RBD). Standard cultivation practices were followed throughout and necessary plant protection measures were taken to ensure healthy crop growth.

2.2 Data collection and statistical analysis

Data on earliness, flowering, yield and quality traits were recorded from five plants chosen at random from each replication. The average values were then analysed using INDOSTAT 2.0 software to calculate heterosis for the traits studies. The significance of heterosis estimates was tested using the t-test.

3. Results and Discussion

Heterosis is defined as superiority or inferiority of F_1 performance with respect to its parents. Heterosis can be either positive or negative, depending on whether the F_1 hybrids perform better or worse than their parents. Positive heterosis is usually reflected in traits such as growth and yield, while negative heterosis is often observed in certain early growth parameters (Yadav and Singh, 2024) [16]. The cross between Banswada Local × CO-2 manifested highest levels of significant heterobeltiosis i.e heterosis over better parent (16.43%) and IC212509 × PKM 1 exhibited highest levels of significant standard heterosis (36.29%) for vine length at 60 DAS. Whereas for number of primary branches at 60 DAS, the hybrid Tenali Local × CO-2 exhibited highest standard heterosis (3.76%), none of the hybrid was found significant over better parent. The elevated magnitude of heterosis observed in the present study may be ascribed to the use of diverse genetic shocks in conjunction with environmental influences, surpassing the values (Laxuman *et al.*, 2012) [17]. These results are in line with the results reported by Kumar *et al.* (2024) [6], Devi *et al.* (2017) [1] and Khan *et al.* (2016) [5] in snake gourd.

Table 1: Heterosis (%) over mid parent, better parent and commercial check for growth parameter in snake gourd

Sl. No	Hybrids	Vine length at 60 DAS		Number of primary branches at 60 DAS	
		BTP	CC	BTP	CC
1	BANSWADA LOCAL × CO-2	16.43**	-31.22 **	-5.18**	-1.61 **
2	BANSWADA LOCAL × PKM 1	-49.13**	-37.97 **	-12.44**	-5.38 **
3	SIDDAPUR LOCAL × CO-2	-27.31**	-28.69 **	-0.52	3.76 **
4	SIDDAPUR LOCAL × PKM 1	-0.69*	21.1 **	-5.97**	1.61 **
5	IC212509 × CO-2	-9.62**	-8.86 **	-2.58	1.61 **
6	IC212509 × PKM 1	11.76**	36.29 **	-6.47**	1.08 *
7	IC212416 × CO-2	4.33*	-33.97 **	-3.11	0.54
8	IC212416 × PKM 1	-45.33**	-33.33 **	-6.47**	1.08 *
9	RAIKUR LOCAL × CO-2	16.27**	-18.57 **	-3.11	0.54
10	RAIKUR LOCAL × PKM 1	-30.10**	-14.77 **	-7.96**	-0.54
11	TENALI LOCAL × CO-2	-9.18	-24.89 **	00	3.76 **
12	TENALI LOCAL × PKM 1	-37.37**	-23.63 **	-6.97**	0.54
13	IC202160 × CO-2	5.26*	-32.49 **	-2.59	1.08 *
14	IC202160 × PKM 1	-43.60**	-31.22 **	-8.71**	-1.34 **
	SEm ±	5.64	5.64	0.28	0.28
	CD at 5%	12.19	12.19	0.61	0.61
	CD at 1%	17.00	17.00	0.85	0.85

*and** indicate significance of values at p = 0.05 and p = 0.01, respectively. MP, BTP and CC: Heterosis over Mid parent, better parent and commercial check (COVAI 951), respectively. DAS-Days after sowing

Table 2: Heterosis (%) over mid parent, better parent and commercial check for flowering parameters in snake gourd

Sl. No.	Hybrids	Days to first male flowering		Days to first female flowering		Node at which first female flower appears		Days to first fruit harvest	
		BTP	CC	BTP	CC	BTP	CC	BTP	CC
1	BANSWADA LOCAL × CO-2	-4.27**	3.97 **	-3.70**	3.31 **	-2.16	2.26 **	0.00	1.61 **
2	BANSWADA LOCAL × PKM 1	-2.77	0.88 **	-1.46	0.83 **	2.70*	7.34 **	-1.58**	0
3	SIDDAPUR LOCAL × CO-2	-8.13**	-0.22	-6.17**	0.66 **	-5.08*	5.65 **	-0.74	-0.37 **
4	SIDDAPUR LOCAL × PKM 1	-1.08	0.88 **	-0.66	0.17	-6.60**	3.95 **	-0.99*	-0.62 **
5	IC212509 × CO-2	-6.10**	1.99 **	-5.25**	1.66 **	-2.53	9.04 **	-7.68**	-7.8 **
6	IC212509 × PKM 1	-6.83**	-0.66 **	-0.81	1.32 **	-4.55*	6.78 **	-7.65**	-8.91 **
7	IC212416 × CO-2	-6.50 **	1.55 **	-4.48**	2.48 **	-3.19	2.82 **	1.10*	2.1 **
8	IC212416 × PKM 1	-1.95	-0.22	-0.32	1.99 **	-4.26*	1.69 **	0.86*	1.86 **
9	RAIKUR LOCAL × CO-2	-5.28**	2.87 **	-5.09**	1.82 **	-2.76	-0.56	-0.62	-0.74 **
10	RAIKUR LOCAL × PKM 1	-4.46**	-0.66 **	-2.72**	0.83 **	-0.55	1.69 **	-3.62**	-4.33 **
11	TENALI LOCAL × CO-2	-7.72**	0.22	-6.33**	0.5 **	0.00	5.65 **	0.99*	0.99 **
12	TENALI LOCAL × PKM 1	-0.65	1.1 **	-0.65	0.66 **	-3.21	2.26 **	0.12	0.12
13	IC202160 × CO-2	-6.71**	1.32 **	-5.86**	0.99 **	-1.56	6.78 **	0.74*	0.62 **
14	IC202160 × PKM 1	-0.66**	-0.44 *	-0.99	-0.33 *	-3.13	5.08 **	-3.64**	-4.95 **
	SEm ±	0.63	0.63	0.47	0.47	0.36	0.36	0.36	0.36
	CD at 5%	1.37	1.37	1.03	1.03	0.79	0.79	0.77	0.77
	CD at 1%	1.91	1.91	1.44	1.44	1.10	1.10	0.93	0.93

*and** indicate significance of values at p = 0.05 and p = 0.01, respectively. BTP and CC: Heterosis over mid parent, better parent and commercial check (COVAI 951), respectively.

Table 3: Heterosis (%) over mid parent, better parent and commercial check for yield parameters in snake gourd

Sl. No.	Hybrids	Number of fruits per vine		Fruit length (cm)		Fruit girth (cm)		Average fruit weight (g)		Fruit yield (kg/plant)		Number of seeds per fruit	
		BTP	CC	BTP	CC	BTP	CC	BTP	CC	BTP	CC	BTP	CC
1	BANSWADA LOCAL × CO-2	-11.30**	-32.34 **	-62.73**	28.13 **	-26.20**	-26.93 **	-31.19**	13.67 **	-38.99**	-23.06 **	-46.81**	3.16 **
2	BANSWADA LOCAL × PKM 1	-7.09**	-21.72 **	-33.31**	249.61 **	2.36	-29.89 **	-23.87**	93.93 **	-29.54**	51.34 **	-38.96**	87.63 **
3	SIDDAPUR LOCAL × CO-2	-3.74	-31.67 **	-64.13**	34.38 **	3.08*	2.06	-28.50**	58.26 **	-30.84**	8.28 **	-58.69**	-3.68 **
4	SIDDAPUR LOCAL × PKM 1	-10.24**	-24.38 **	-27.50**	280.08 **	-20.57**	-42.82 **	-43.57**	43.74 **	-49.29**	8.92 **	-22.69**	137.63 **
5	IC212509 × CO-2	-19.78**	-51.58 **	-14.36**	30.47 **	3.81**	2.78	1.98*	34.41 **	1.39	-35.03 **	-45.95**	-3.42 **
6	IC212509 × PKM 1	-39.37**	-48.92 **	-73.17**	40.63 **	-4.58**	-12.01 **	-48.83**	30.34 **	-69.04**	-33.5 **	-67.38**	0.26
7	IC212416 × CO-2	-20.88**	-52.24 **	-0.56	38.67 **	-23.93**	-24.69 **	12.57**	29.69 **	10.25	-38.34 **	24.94**	48.95 **
8	IC212416 × PKM 1	-37.01**	-46.93 **	-70.42**	55.08 **	10.17**	1.17	-51.92**	22.47 **	-69.81**	-35.16 **	-53.00**	44.47 **
9	RAIKUR LOCAL × CO-2	-10.99**	-46.27 **	-2.77	50.78 **	-19.40 **	-20.2 **	12.61 **	23.81 **	18.14**	-33.63 **	-7.44	24.47 **
10	RAIKUR LOCAL × PKM 1	-36.22**	-46.27 **	-49.70**	163.67 **	0.55	-18.4 **	-15.32**	115.71 **	-46.09**	15.8 **	-40.33**	83.42 **
11	TENALI LOCAL × CO-2	4.17	-17.08 **	0.32	21.09 **	-23.03**	-23.79 **	22.24**	15.25 **	27.24**	-4.2	-10.34	-8.68 **
12	TENALI LOCAL × PKM 1	-3.15	-18.41 **	-46.20**	182.03 **	-2.96*	-17.5 **	-6.59**	137.94 **	-9.31**	94.78 **	-57.45**	30.79 **
13	IC202160 × CO-2	-18.69**	-42.29 **	13.13**	31.25 **	11.24**	10.14 **	55.34**	54.15 **	26.13**	-10.83 **	-3.62	-1.84 **
14	IC202160 × PKM 1	-24.41**	-36.32 **	-62.22**	98.05 **	-5.32**	-8.94 **	-30.35**	77.42 **	-46.62**	14.65 **	-55.57**	36.58 **
	SEm ±	0.29	0.29	1.11	1.11	0.05	0.05	3.11	3.11	0.12	0.12	2.06	2.06
	CD at 5%	0.63	0.63	2.40	2.40	0.12	0.12	6.73	6.73	0.26	0.26	4.46	4.46
	CD at 1%	0.88	0.88	3.35	3.35	0.18	0.18	9.39	9.39	0.37	0.37	6.22	6.22

*and** indicate significance of values at p = 0.05 and p = 0.01, respectively. BTP and CC: Heterosis over mid parent, better parent and commercial check (COVAI 951), respectively.

Table 4: Heterosis (%) over mid parent, better parent and commercial check for quality parameters in snake gourd

Sl. No.	Hybrids	Titratable acidity (%)		Ascorbic acid (mg/100g)		Fruit protein content (%)		Fruit carbohydrate content (%)		Fruit fibre content (%)	
		BTP	CC	BTP	CC	BTP	CC	BTP	CC	BTP	CC
1	BANSWADA LOCAL × CO-2	-16.67	0	0.00	0	20.00**	21.88	7.37**	13.93 **	-7.14**	-3.31
2	BANSWADA LOCAL × PKM 1	16.67	40 **	0.00	-10 **	18.31**	31.25	28.55**	33.21 **	-31.75**	-28.93 *
3	SIDDAPUR LOCAL × CO-2	-28.57	0	-30.00	-30 **	-40.00**	-20.31	-2.60	21.56 **	-17.09**	-19.83
4	SIDDAPUR LOCAL × PKM 1	0.00	40 **	-22.22	-30 **	-32.94**	-10.94	-28.13**	-10.31 **	-12.80**	-9.92
5	IC212509 × CO-2	14.29	60 **	0.00	10 **	0.00	3.13	2.88	9.16 *	-35.90**	-38.02 *
6	IC212509 × PKM 1	28.57	80 **	-9.09	0	8.45**	20.31	13.01**	16.03 **	-32.80**	-30.58 *
7	IC212416 × CO-2	14.29	60 **	-30.00	-30 **	-3.61	25	-11.33**	-5.92	35.04**	30.58 *
8	IC212416 × PKM 1	-14.29	20 **	-11.11	-20 **	0.00	29.69	-4.99*	-5.53	15.20**	19.01
9	RAIKUR LOCAL × CO-2	12.50	80 **	-9.09	0	20.00**	12.5	-33.63**	-29.58 **	-19.11**	4.96
10	RAIKUR LOCAL × PKM 1	-12.50	40 **	0.00	10 **	5.63*	17.19	-31.09**	-31.49 **	-29.94**	-9.09
11	TENALI LOCAL × CO-2	28.57	80 **	-30.00	-30 **	17.50**	46.88	1.15	17.94 **	3.20	6.61
12	TENALI LOCAL × PKM 1	-14.29	20 **	0.00	-10 **	-2.50	21.88	8.84**	26.91 **	4.00	7.44
13	IC202160 × CO-2	14.29	60 **	-20.00	-20 **	2.60	23.44	-9.11**	8.59 *	0.00	-3.31
14	IC202160 × PKM 1	14.29	60 **	-22.22	-30 **	7.79**	29.69	-13.58**	3.24	-2.40	0.83
	SEm ±	0.76	0.76	3.43	3.43	0.008	0.008	0.053	0.053	0.014	0.014
	CD at 5%	1.64	1.64	7.42	7.42	0.01	0.01	0.11	0.11	0.03	0.03
	CD at 1%	2.29	2.29	10.35	10.35	0.02	0.02	0.16	0.16	0.04	0.04

*and** indicate significance of values at p = 0.05 and p = 0.01, respectively. BTP and CC: Heterosis over mid parent, better parent and commercial check (COVAI 951), respectively.

Early flowering is an important trait with economic significance, as it enables earlier harvests, thereby improving market timing and profitability. For these characteristics, negative heterosis is desirable, as it indicates earliness. The crosses Raikur Local × PKM 1 and IC212509 × PKM 1 demonstrated the highest significant standard heterosis (-0.66%), with the first male flower appearing at 45 days. Maximum heterosis in the desired negative direction was observed over the better parent (-6.33%) in the cross Tenali Local × CO-2 and highest significant standard heterosis (-0.33%) in the cross IC202160 × PKM 1 for days to first female flower opening. For Node at which first female flower appears the highest negative heterobeltiosis was manifested in the cross Siddapur Local × PKM 1(-6.60%) on par with Siddapur Local × CO-2 (-5.08%). Whereas the highest significant heterobeltiosis was manifested in the cross IC212509 × CO-2 (-7.68%) on par with IC212509 × PKM 1 (-7.65%) and the cross IC212509 × PKM 1 (-8.91%) exhibited highest standard heterosis in negative direction for days to first fruit harvest. These findings align with comparable ranges reported by Kumar *et al.* (2024) [6] in snake gourd (44.30 to 77.63 days), Vidya *et al.* (2024) [15] and Khan *et al.* (2016) [5] (48.90 to 91.00 days), supporting the conclusion that early flowering and fruiting can enhance overall productivity.

In terms of fruit length, the standard heterosis was ranged from 21.09% (Tenali Local × CO-2) to 280.08% (Siddapur Local × PKM 1) (Table 3.). As the market demands short fruit length, lowest standard heterosis is desirable. In the short segments, the cross Tenali Local × CO-2 exhibited least significant heterosis (21.09%). In this study, four hybrids showed positive heterosis over the better parent and only one hybrid demonstrated significant positive heterosis over the standard check. While IC202160 × CO-2 showed the highest positive heterobeltiosis (11.24%) and also exhibited the highest significant standard heterosis (10.14%) with a mean fruit girth of 6.14 cm. This range of values is similar to the findings of Khan *et al.* (2016) [5], Podder *et al.* (2018) [10] and Fathima *et al.* (2023) [2]. For fruit weight IC202160 × CO-2 demonstrated the highest significant heterosis over better parent (55.34%). Meanwhile, Tenali Local × PKM 1 recorded the highest positive significant standard heterosis (137.94%) with a *per se* fruit weight of 619.3 g. Among all the cross combinations evaluated, the cross Tenali Local × CO-2 showed significant heterosis over better parent, with a value of 46.02 per cent, Tenali Local × PKM 1 recorded the highest standard heterosis of 94.78 per cent, with a mean yield of 7.64 kg per plant because it is directly related to the number of fruits per vine and average fruit weight. These results align with those reported by Kumar *et al.* (2024) [6], who observed yields ranging from 2.82 to 11.94 kg per plant in snake gourd and by Rajkumar and Karuppaiah, 2019, who reported yield between 6.94 and 19.75 kg. However, the mean yield observed in this study exceeds the range documented by Khan *et al.* (2016) [5], which was 1.10 to 8.36 kg per plant. The cross IC212416 × CO-2 (24.94%) showed the highest positive significant heterosis over better parent and the cross Siddapur Local × PKM 1 (137.63%) showed the highest significant standard heterosis for number of seeds per fruit.

Snake gourd is a nutrient dense vegetable with quality factors playing a significant role, among the crosses for titratable acidity (%), the highest positive significant standard heterosis was manifested by IC212509 × PKM 1 (80.00%), Raikur Local × CO-2 (80.00%) and Tenali Local × CO-2 (80%) had the highest acidity of 2.79%. The crosses IC212509 × CO-2 and Raikur Local × PKM 1 manifested highest significant standard heterosis (10%) for ascorbic acid content and may be attributed to the catalytic activity of many enzymes involved in the biosynthesis of ascorbic acid and its precursor (Mauriya *et al.*, 2021) (Table .4). The highest significant heterobeltiosis exhibited by Banswada Local × CO-2 and Raikur Local × CO-2 (20.00%) and the cross Tenali Local × CO-2 exhibited highest significant standard heterosis (46.88%). Banswada Local × PKM 1 recorded highest significant standard heterosis (33.21%). The highest magnitude of fruit fibre content was observed in the cross IC212416 × CO-2 which was significant over better parent (35.04%) and commercial check (30.58%).

4. Conclusion

The comprehensive evaluation of 14 hybrids for standard heterosis across 17 quantitative traits revealed considerable variability in the expression of heterosis, with seven were combinations of highly heterotic, 4 were low heterotic and 3 were average heterotic. The identification of highly heterotic hybrids underscores their potential as promising genetic resources for yield enhancement in snake gourd. Nevertheless, heterosis *per se* cannot guarantee commercial success unless accompanied by yield stability and wide adaptability. Hence, these superior hybrids should be subjected to multi-environment testing to ascertain their performance under diverse agro-climatic conditions. Such validation will not only facilitate the identification of stable and high-yielding hybrids but also provide a reliable foundation for their large-scale deployment in commercial cultivation programs.

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