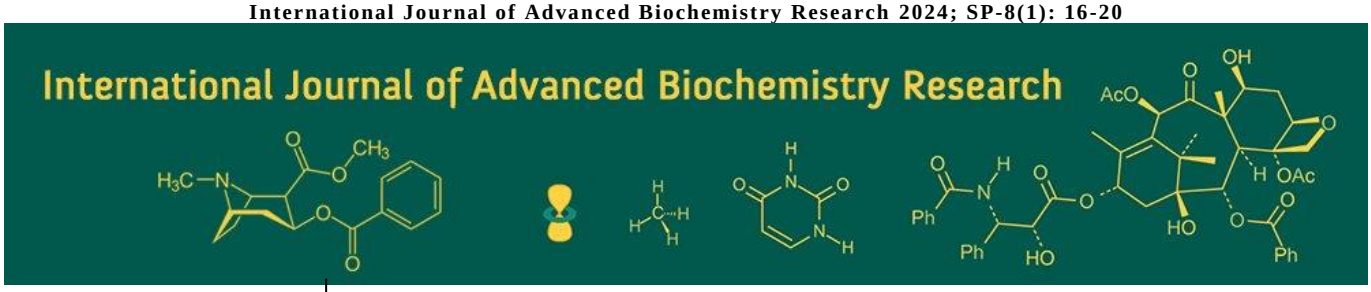

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Studies of heterosis and inbreeding depression for growth parameters in tomato hybrids (*Solanum lycopersicum* L)

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Abstract
The experiment took place over three consecutive Rabi seasons at the Vegetable Research Farm (South Block), Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The experimental material consisted of 13 genotypes, including 10 lines, 3 testers, and one standard check (Pant T_1). These genotypes were chosen based on their performance for various traits. A Line Tester design was used to evolve 30 F1s and 30 F2s from these 13 genotypes. An investigation was conducted on the three growth parameters, specifically Days to 50% flowering, plant height, and number of primary branches per plant, to examine heterosis and inbreeding depression. The cross VRT-18×H-86 exhibited the highest significant negative mid-parent, better parent, and standard heterosis for days to 50% flowering, which is advantageous in terms of early flowering. Additionally, it displayed the lowest level of inbreeding depression. The cross VRT-51×SEL-7 exhibited the highest level of heterosis in terms of plant height, with a significant magnitude of 44.50%. On the other hand, the cross H-24×SEL-7 displayed the lowest level of inbreeding depression, with a magnitude of 17.48%. When examining the number of primary branches per plant, we found that Kashi Aman×SEL-7 exhibited the highest level of heterosis at 48.40%. On the other hand, the cross VRT-01×ToLcv-41 showed the lowest level of inbreeding depression at -35.35%, which is quite desirable. These findings suggest that these specific crosses have the potential for further selection in varietal development programmes.

Keywords: Heterosis, growth parameters, tomato hybrids, *Solanum lycopersicum* L

Introduction
Tomato is an indispensable vegetable in all parts of the world. India is the world's second-largest producer of tomatoes, right after China. According to India's second advance estimate of production figures, over 848560-hectare area, the production of tomato was 20401970 metric tons in 2022–23 (NHB Database, 2023) [1]. Tomatoes are rich in flavonoids, lycopene, beta-carotene, vitamin C, derivatives of hydroxycinnamic acid and it is regarded to be a nutritional powerhouse or protective food when compared to other vegetables (Saleem *et al.*, 2013) [2]. In addition to these, they are an inexpensive and plentiful source of phosphate, iron, protein, iodine, and minerals including calcium and phosphorus. Tomato is a diploid species with 2n = 2x = 24 chromosomes. Considering the breeding behaviour of crop species different breeding methods have been advocated. Breeding hybrids is one of the prominent techniques and is used in vegetable improvement. In tomato breeding, the study of combining ability and heterosis is crucial to produce varieties with high yields that are disease-free, have desirable/attractive fruit form, size and colour along with early bearing. Breeders are helped in selecting the best breeding strategy for crop improvement programs by the estimations of the inbreeding depression. Despite being a bisexual self-pollinating crop, tomatoes does not experience inbreeding depression. It may produce a large number of seeds per fruit at a low cost through heterosis breeding.

Materials and Methods
The study was conducted over three Rabi seasons (2019-20, 2020-21, and 2021-22) at the Vegetable Research Farm (South Block), Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh.

The experimental material comprised 13 diverse genotypes, including 10 lines, 3 testers, and one check variety (Pant T_1), selected based on their individual trait performances.

Utilizing a Line Tester design (Kempthorne, 1957) [3], a total of 30 F1s and 30 F2s were developed. In the initial Rabi season (2019-20), thirteen elite lines, consisting of ten lines and three testers, were sown. These parents underwent self-pollination to ensure pure seed preservation. During the subsequent Rabi season (2020-21), 30 F1s, along with their parents, were cultivated in a randomized block design (RBD) with 3 replications. Each treatment consisted of 30 plants with standard spacing. Information regarding parents and F1 generation was collected, focusing on yield and yield traits.

In the study conducted during Rabi 2021-22, a total of 13 parents (10 lines and 3 testers), along with 30 F1s and 30 F2s, were carefully cultivated in separate plots arranged in an RBD with three replications. The primary objective was to investigate combining ability, heterosis, and inbreeding depression for various yield and quality traits. Data on parents, F1, and F2 generations were collected, emphasizing yield and yield traits. Thorough data analysis has been conducted, and the findings are presented in tables 1, 2, and 3.

Results and Discussion

The significance of variances among replications, genotypes, and other partitioning sources of variation was evaluated by doing an analysis of variance among 43 genotypes (13 parents and 30 hybrids). The findings showed that the genotypes under the investigation revealed significant variations at 5% level of significance, which suggests a high degree of variability. The estimates for the three heterosis measures, namely relative heterosis, heterobeltiosis and standard heterosis over (Pant T_1) as well as inbreeding depression are presented in Tables 1 and 2.

The characteristic of earliness is considered to be an essential requirement in any crop improvement program. It was noted that among the 30 F_1 crosses examined, the hybrid Cross VRT-18×H-86 (-22.09%) demonstrated the least average heterosis followed by VRT-50×H-86 (-15.41) and VRT-01×SEL-7 (-14.80%). The hybrid VRT-18×H-86 demonstrated the lowest level of heterobeltiosis in the desired direction with a magnitude of -26.54% followed by VRT-50×H-86 (-19.42%) and VRT-01×SEL-7 (-18.86%). The cross VRT-18×H-86 exhibited the highest significant negative standard heterosis at -21.50% followed by VRT-50×SEL-7 at -16.53% and VRT-50×H-86 at -13.90%. Negative heterosis for the trait days to 50% flowering is observed by Hannan *et al*. (2007) [4], Islam *et al*. (2010) [5], Ahmad and Quamruzzaman (2011) [6], Kumar *et al*. (2012) [7] Khan and Jindal (2016) [8], Ramana *et al.* (2018) [9] and Sah *et al.* (2020) [10] in tomato.

With regards to plant height, VRT-51×SEL-7 (44.5%) displayed the highest level of significant positive relative heterosis followed by H-24×H-86 (41.63%) and VRT-74×SEL-7 (34.47%) as indicated in Table 1. The hybrid H-24×H-86 exhibited the highest level of significant positive better parent heterosis at 36.09% followed by VRT-74×H-86 at 22.44% and VRT-51×SEL-7 at 17.31%. The VRT-18×H-86 hybrid displayed the highest recorded growth in plant height with a percentage of 28.37%. The findings suggest that the inheritance of plant height in these crosses is influenced by both additive and non-additive genetic factors. Yadav *et al*. (2013) [11], Rajan (2014) [12], Khan and Jindal (2016) [8] and Rehana *et al.* (2019) [13] also discovered the same results in tomato.

Table 1: Heterosis and inbreeding depression for days to 50% flowering

S. No.	Crosses	Days to 50% flowering			
		Mid parent Heterosis	Better parent heterosis	Standard heterosis	Inbreeding depression
1	VRT-01×SEL-7	-14.80 **	-18.86 **	-11.92	-14.82**
2	VRT-01×H-86	-14.65 **	-15.31 **	-8.08	-14.5**
3	VRT-01×ToLcv-41	-12.66 *	-16.44 **	-9.3	-10.46**
4	VRT-06×SEL-7	-0.26	-7.52	6.29	-4.51
5	VRT-06×H-86	-11.43 *	-14.54 **	-1.78	-10.99**
6	VRT-06×ToLcv-41	7.89	0.49	15.49 *	-4.15
7	VRT-18×SEL-7	13.15 *	11.09	9.11	-4.39
8	VRT-18×H-86	-22.09 **	-26.54 **	-21.50 **	-44.14**
9	VRT-18×ToLcv-41	-2.33	-4.55	-5.35	-39.19**
10	VRT- 50×SEL-7	-14.35 *	-15.01 *	-16.53 **	-35.55**
11	VRT- 50×H-86	-15.41 **	-19.42 **	-13.90 *	-26.83**
12	VRT- 50×ToLcv-41	10.83	9.47	8.54	-4.41
13	VRT-74×SEL-7	-5.86	-9.37	-10.99	-33.23**
14	VRT-74×H-86	7.12	-0.88	5.92	-4.52
15	VRT-74×ToLcv-41	-0.99	-5.11	-5.92	-5.09
16	VRT-51×SEL-7	-3.1	-7.48	-0.09	-4.79
17	VRT-51×H-86	-6.82	-7.3	0.09	-18.67**
18	VRT-51×ToLcv-41	7.52	3.13	11.36	-1.26
19	DVRT-2×SEL-7	2.57	-7.07	12.39 *	-12.7**
20	DVRT-2×H-86	-2.56	-8.23	10.99	-4.31
21	DVRT-2×ToLcv-41	9.56	-0.31	20.56 **	-17.06**
22	Kashi Aman×SEL-7	2.57	-1.41	4.98	-10.82**
23	Kashi Aman×H-86	-13.47 **	-13.62 *	-7.7	-35.91**
24	Kashi Aman×ToLcv-41	-2.01	-5.38	0.75	-21.44**
25	Kashi Chayan×SEL-7	-6.65	-9.66	-5.16	-5.05
26	Kashi Chayan×H-86	-1.15	-2.02	4.69	-4.57
27	Kashi Chayan×ToLcv-41	6.62	3.67	8.83	-4.4
28	H-24×SEL-7	0.58	0.19	-1.6	-4.87
29	H-24×H-86	-1.1	-5.45	1.03	-15.52**
30	H-24×ToLcv-41	8.31	7.39	6.48	-15.26**

Table 2: Heterosis and inbreeding depression for plant height (cm)

S. No.	Crosses	Plant height (cm)			
		Mid parent Heterosis	Better parent heterosis	Standard heterosis	Inbreeding depression
1	VRT-01×SEL-7	19.42 **	-5.55 **	2.76	-11.21**
2	VRT-01×H-86	24.02 **	8.37 **	17.90 **	0.03
3	VRT-01×ToLcv-41	-13.00 **	-13.85 **	-6.27 **	8.16*
4	VRT-06×SEL-7	4.58 *	-22.24 **	1.07	1.54
5	VRT-06×H-86	15.14 **	-6.41 **	21.66 **	-3.17
6	VRT-06×ToLcv-41	-8.77 **	-16.95 **	7.95 **	7.61*
7	VRT-18×SEL-7	3.49	-20.83 **	-5.42 **	0.7
8	VRT-18×H-86	27.85 **	7.46 **	28.37 **	7.13*
9	VRT-18×ToLcv-41	-0.33	-5.66 **	12.69 **	-3.46
10	VRT- 50×SEL-7	18.80 **	-6.55 **	3.2	1.51
11	VRT- 50×H-86	26.03 **	9.43 **	20.84 **	1.29
12	VRT- 50×ToLcv-41	5.38 **	3.59 *	14.39 **	1.36
13	VRT-74×SEL-7	34.47 **	15.39 **	1.99	1.53
14	VRT-74×H-86	27.53 **	22.44 **	8.23 **	-5.5
15	VRT-74×ToLcv-41	7.48 **	-1.73	4.83 *	1.49
16	VRT-51×SEL-7	44.50 **	17.31 **	19.07 **	1.31
17	VRT-51×H-86	21.06 **	9.04 **	10.67 **	1.41
18	VRT-51×ToLcv-41	-0.85	-3.25	3.2	1.51
19	DVRT-2×SEL-7	26.63 **	-0.35	9.93 **	0.42
20	DVRT-2×H-86	-1.4	-14.35 **	-5.52 **	-7.69*
21	DVRT-2×ToLcv-41	1.71	0.03	10.36 **	-2.73
22	Kashi Aman×SEL-7	16.06 **	-4.96 *	-5.66 **	-2.1
23	Kashi Aman×H-86	10.20 **	0.25	-0.49	-3.2
24	Kashi Aman×ToLcv-41	13.37 **	9.43 **	16.73 **	0.12
25	Kashi Chayan×SEL-7	30.30 **	0.98	16.24 **	1.34
26	Kashi Chayan×H-86	7.34 **	-8.40 **	5.43 **	-0.97
27	Kashi Chayan×ToLcv-41	10.96 **	6.89 **	23.04 **	0.23
28	H-24×SEL-7	24.87 **	7.23 **	-5.37 **	-17.48**
29	H-24×H-86	41.63 **	36.09 **	20.10 **	1.3
30	H-24×ToLcv-41	17.16 **	7.05 **	14.19 **	-0.49

Table 3: Heterosis and inbreeding depression for number of primary branches per plant

S. No.	Crosses	Number of primary branch			
		Mid parent Heterosis	Better parent heterosis	Standard heterosis	Inbreeding depression
1	VRT-01×SEL-7	5.96	-4.41	5.48	-1.01
2	VRT-01×H-86	12.21	4.93	7	8.25*
3	VRT-01×ToLcv-41	-22.13 *	-23.33 *	-31.96 **	-35.35**
4	VRT-06×SEL-7	24.92 **	19.92 **	43.84 **	10.58**
5	VRT-06×H-86	15.23 *	6.6	27.85 **	10.12**
6	VRT-06×ToLcv-41	-3.62	-17.26 *	-0.76	-9.66**
7	VRT-18×SEL-7	6.53	-2.62	7.46	0.14
8	VRT-18×H-86	4.13	-1.27	0.68	-2.04
9	VRT-18×ToLcv-41	-1.67	-4.58	-12.79	-9.95**
10	VRT- 50×SEL-7	10.26	-8.14	1.37	-2.1
11	VRT- 50×H-86	11.88	-3.73	-1.83	12.4**
12	VRT- 50×ToLcv-41	-10.31	-16.81	-28.46 **	-17.45**
13	VRT-74×SEL-7	16.32 *	4.97	15.83	6.04
14	VRT-74×H-86	3.95	-2.76	-0.84	1
15	VRT-74×ToLcv-41	-8.05	-9.51	-19.63 *	-11.74**
16	VRT-51×SEL-7	20.30 *	0.55	10.96	-2.19
17	VRT-51×H-86	25.41 **	8.28	10.43	19.37**
18	VRT-51×ToLcv-41	-2.19	-8.94	-21.69 *	-8.84**
19	DVRT-2×SEL-7	10.25	7.59	18.72 *	10.26**
20	DVRT-2×H-86	8.09	6.52	11.87	11.56**
21	DVRT-2×ToLcv-41	6.61	-3.04	1.83	5.83
22	Kashi Aman×SEL-7	21.53 **	10.86	48.40 **	6.67*
23	Kashi Aman×H-86	16.17 *	2.33	36.99 **	8.33*
24	Kashi Aman×ToLcv-41	-11.18	-27.06 **	-2.36	-22.37**
25	Kashi Chayan×SEL-7	16.91 *	15.86 *	27.85 **	8.93**
26	Kashi Chayan×H-86	-7.74	-10.46	-2.97	-12.55**
27	Kashi Chayan×ToLcv-41	-3.45	-13.41	-6.16	-7.06*
28	H-24×SEL-7	0.73	-5.31	4.49	-4.88
29	H-24×H-86	-4.05	-6.34	-4.49	-9.16**
30	H-24×ToLcv-41	9.39	3.13	0.15	1.22

Regarding the number of primary branches per plant, among the hybrids tested, VRT-51×H-86 (25.41%) displayed the highest level of significant positive relative heterosis followed by VRT-06×SEL-7 (24.92%) and Kashi Aman×SEL-7 (21.53%). Out of the 30 crosses examined, only two crosses, namely VRT-06×SEL-7 (19.92%) and Kashi Chayan×SEL-7 (15.86%) exhibited notable positive heterosis. The highest percentage of standard heterosis was observed in the cross Kashi Aman×SEL-7 (48.40%) followed by VRT-06×SEL-7 (43.84%) and Kashi Aman×H-86 (36.99%). The similar findings were also observed by Droka *et al.* (2012) [15], Shalaby (2013) [15], Amin *et al.* (2017) [16], Hamisu (2018) [17] and Mishra *et al.* (2021) [18] in tomato.

The hybrid vigour displayed in F1 generally breaks down in F2 and subsequent generations owing to segregation of the favourable genes that regulate the development of the vigour. Consequently, there is often a reduction in the yield. In order to assess the decrease in hybrid performance, the researchers measured the level of inbreeding depression for several traits. The table provided (Table 3) displays the top three crossings that exhibited the highest degree of inbreeding depression across all traits in this study. The study evaluated the highest levels of negative and statistically significant inbreeding depression in specific cross combinations were VRT-18×H-86, which exhibited an inbreeding depression of -44.14% followed by VRT-18×ToLcv-41 (-39.19%) and Kashi Aman×H-86 with a inbreeding depression of -35.91%. Similarly, in case of plant height, the study observed the most significant manifestation of inbreeding depression in the cross VRT-01 ×ToLcv-41 with a value of 8.16% followed by VRT-01 × ToLcv-41(7.61%) and VRT-18 × H-86 (7.13%). Similar results were observed by Sharma and Thakur (2008) [19] and Solieman *et al.* (2013) [2] in tomato. For the number of primary branches per plant, out of a total of thirty F_2 crosses, the cross VRT-51 × H-86 exhibited the most pronounced positive inbreeding depression with a value of 19.37% followed by VRT-50 × H-86 (12.40%) and DVRT-2 × H-86 (11.56%), respectively. This might be attributed to the existence of non-additive gene activity for the traits being examined. Nevertheless, several hybrids exhibited significant heterosis while displaying little inbreeding depression. This might be attributed to the abundance of transgressive segregants in the F2 generation. These findings are consistent with the findings of Nnungu and Uguru (2014) [21], Kumar and Paliwal (2016) [22], Shakil *et al.* (2017) [23] and Tamta and Singh (2018) [24] in the context of tomato.

Conclusion

The hybridization of VRT-18×H-86 demonstrated significant and statistically negative mid-parent, better parent, and standard heterosis for days to 50% blooming, showing a considerable enhancement in early flowering. This trait is very beneficial for attaining an early stage of blossoming. On the other hand, the cross VRT-51×SEL-7 exhibited the highest level of heterosis for plant height, achieving a remarkable 44.50%. The cross Kashi Aman×SEL-7 exhibited the greatest heterosis in terms of the number of main branches per plant, with a notable increase of 48.40%. These results emphasise the favourable prospects of these particular hybrids, indicating their beneficial influence on characteristics related to the timing of blooming, height of the plant, and growth of branches. The presence of heterosis in these crosses indicates the potential for improved agricultural performance and productivity, highlighting their importance in breeding programmes focused on enhancing critical features in crop production.

Future scope

The presence of heterosis in the attributes of blooming time, plant height, and branch growth highlights the possibility of using focused breeding techniques to further improve these characteristics. Further investigation may delve into the molecular pathways that underlie heterosis in these crosses, which would allow for precise breeding methods to enhance the speed of blooming and enhance the structure of the plants. Furthermore, exploring the genetic foundation of these characteristics might provide guidance for the development of sophisticated breeding methods to enhance crop performance. This research provides opportunities for optimising hybrid combinations to achieve the highest possible agricultural production and adaptability.

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