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Enhanced growth and yield in semi-indeterminate tomato (*Solanum lycopersicum*): A heterosis study under protected condition

NAYANA K R[1, 2*], SRINIVASA V[1], DEVARAJU[1] and SHRILATHA K A[3]

College of Horticulture Mudigere, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka 577 132, India

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Tomato (*Solanum lycopersicum* L.) stands as one of the important vegetable, classified within the Solanaceae family and characterized by a diploid chromosome count of 2n=2x=24 originated in Peru, South America. Heterosis refers to phenomenon wherein hybrids display greater vigour and adaptability in comparison to parents. Hybrid seed production in tomato has proven to be economically sound, as it contains a greater number of seeds/fruits. Semi-indeterminate tomato has a prolonged harvest period and better resilience to environmental stress, enhancing adaptability in diverse growing conditions (Opena *et al.* 2001). Protected cultivation extends growing conditions enabling year-round production, ensuring higher yields and improved crop quality while minimizing the impact of adverse weather, pests, and diseases (Sotelo-Cardona *et al.* 2021). Hence, an experiment was planned to exploit heterosis in semi-indeterminate tomato for yield and growth under protected conditions.

Genetic variability studies were conducted on 22 semi-indeterminate tomato genotypes under naturally ventilated polyhouse for one year during 2018–19. The characters evaluated are plant height, stem circumference, primary branches/plant, days to first flowering, polar and equatorial diameter, number of locules/fruit, pericarp thickness, average fruit weight, number of fruits/plant, fruit volume and total yield/plant. Exotic collections were collected from National Bureau of Plant Genetic Resources, New Delhi and VRT13 was procured from ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh. For this study, 5 genotypes, viz. EC15127; EC362941; EC521069; VRT13; and EC521061 (Fig. 1) were chosen based on their overall performance. Selected genotypes were crossed in diallel mating fashion (including reciprocals) during rainy (*kharif*) season of the year 2020. Crosses and the parents were examined for heterosis studies under naturally ventilated polyhouse (COH, Mudigere, Karnataka) during *rabi* season of the year 2020–21 for various growth and yield parameters. Agronomic practices like irrigation, weeding, fertilizer application, training and pruning are done as and when required.

Statistical analysis: The extent of heterosis was assessed in reference to the MP and BP by employing Turner's (1953) techniques:

$$\text{Mid parent heterosis (\%)} = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Better parent heterosis (\%)} = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

where MP and BP, Average and better parent between parents involved (Processed by Windostat Version 9.3 from indostat services).

Exotic collections play a crucial role in tomato breeding by offering a rich source of genetic diversity essential for developing improved varieties/hybrids which often carry valuable traits like high yielding, disease resistance, stress tolerance, and distinct flavors. Furthermore, the introduction of novel flavours and textures from exotic tomato caters to a wide range of consumer preferences, enhancing the marketability of the resulting varieties. The examination of variance (ANOVA) indicated that the mean sum of squares (MSS) for parents, hybrids, F_1, and reciprocals was notably significant across all eight characteristics studied. In case of interaction of F_1 vs reciprocals, traits exhibited significant differences except for equatorial fruit diameter.

Growth parameters: Magnitude of heterosis for different growth parameters, viz. plant height, stem circumference and days to first flowering are represented in Table 1. Plant height is one of the significant growth parameters related to

[1]College of Horticulture, Mudigere, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka; [2]Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana; [3]College of Horticulture, University of Horticultural Sciences, Bagalkot, Karnataka. *Corresponding author email: nayanakr203@gmail.com

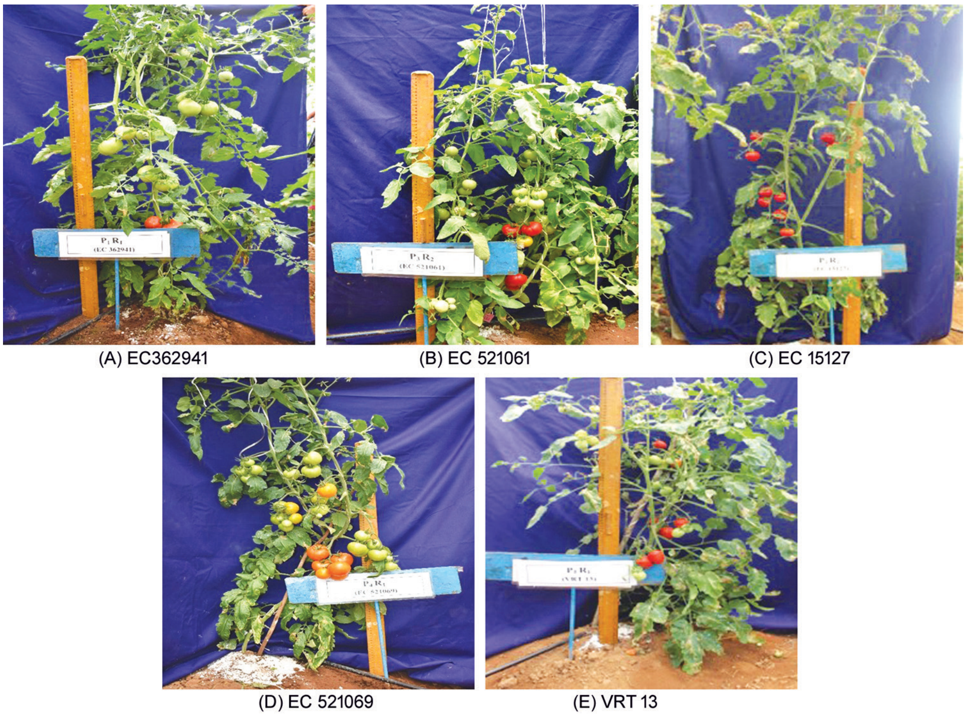

Fig. 1 Parents used for the study.

the strong framework of the plants. Among the hybrids, MP heterosis (%) was maximum for VRT13 × EC362941 (19.24). BP heterosis (%) was maximum in VRT13 × EC521061 (12.96). Out of 20 crosses 7 and 3 outlined positive heterosis over the MP and BP, respectively. Similarly, positive significant heterosis in tomato were reported by Liu *et al.* (2021) and Kumar *et al.* (2023). For stem circumference, the highest MP (5.48%) and BP heterosis (4.15%) values were observed in the cross combination EC15127 × EC362941. Out of 20 hybrids, 4 and 1 crosses exhibited positive heterosis over the MP and BP, respectively. Positive heterosis for stem girth has also been reported by Bdr *et al.* (2020) in tomato and Reddy *et al.* (2020) in brinjal. VRT13 × EC15127 (-14.04 %) and EC521069 × EC362941 (-9.26 %) were noticed for their earliness (minimum days to first flowering) over BP and MP, respectively as they exhibited the negative heterosis. Similarly, negative heterosis in tomato for minimum days taken to flowering which signifies earliness has been noticed by Mishra *et al.* (2021) and Izzo *et al.* (2022). The growth parameters directly enhance crop yield. Taller plants exhibit greater photosynthetic capacity, increased stem girth facilitates improved nutrient transport and early flowering extends the reproductive phase resulting in elevated crop yields.

Yield parameters: Magnitude of heterosis for different yield parameters, viz. fruit yield, fruit weight, fruit length and width are represented in Table 1. VRT13 × EC15127 had the maximum heterosis (%) over MP (47.99) and BP (29.12) for number of fruits/plant (Table 2). It may be due to both the parents having a good number of fruits/plant, where VRT 13 was the parent to give the maximum number of fruits/ plant among the parents. In this study we noticed the positive heterosis over MP and BP. These results are in close conformity i.e. exhibiting positive heterosis has reported by Nevani and Sridevi (2022). Fruit yield is a critical and ultimate trait of significant consideration in hybrid breeding. For fruit yield/plant, maximum positive heterosis for BP and MP was observed in the cross combinations VRT13 × EC15127 (58.19%) and EC15127 × EC362941 (87.41%). Significant positive heterosis in tomato was also noticed by Liu *et al.* (2021) and Javed *et al.* (2022).

Maximum significant positive heterobeltiosis (10.49%) and MP heterosis (15.59%) for fruit polar diameter was observed in the cross-combination EC521069 × EC521061. Positive heterosis for fruit polar diameter is noticed by Javed

Table 1 Magnitude of heterosis per cent over mid and better parent in tomato for yield parameters

Hybrids	Fruit yield		Fruit polar diameter		Fruit equatorial diameter		Fruit weight	
	MP	BP	MP	BP	MP	BP	MP	BP
EC362941 × EC15127	29.45 **	8.35 **	12.20 **	2.48	4.77	-9.01 **	45.19 **	2.22 *
EC362941 × EC521061	24.25 **	11.53 **	10.27 **	0.54	10.61 **	0.73	25.46 **	-9.46 **
EC362941 × EC521069	10.70 **	6.96 *	7.13 **	1.94	13.42 **	6.66 *	30.19 **	-0.93
EC362941 × VRT13	32.68 **	21.87 **	-1.32	-3.44	4.10	-11.44 **	55.37 **	6.71 **
EC15127 × EC362941	87.41 **	56.86 **	4.77 *	-4.31	19.72 **	3.98	44.12 **	1.47
EC15127 × EC521061	27.74 **	18.00 **	-0.59	-0.78	6.46 *	0.99	14.79 **	10.23 **
EC15127 × EC521069	-14.60 **	-26.44 **	-10.14 **	-13.95 **	-3.26	-11.15 **	-8.77 **	-18.72 **
EC15127 × VRT13	-16.05 **	-24.23 **	-10.08 **	-16.20 **	22.35 **	19.38 **	-9.86 **	-13.67 **

Concluded

Table 1 (*Concluded*)

EC521061 × EC362941	12.29 **	0.8	-5.79 **	-14.10 **	-4.46	-12.99 **	-23.44 **	-44.75 **
EC521061 × EC15127	-1.76	-9.25 *	1.24	1.04	2.92	-2.37	0.38	-3.61
EC521061 × EC521069	-7.71 *	-14.50 **	-0.5	-4.89	-15.98 **	-18.80 **	-23.65 **	-29.40 **
EC521061 × VRT13	-7.19 *	-9.50 **	3.02	-4.16	14.39 **	6.03	-12.53 **	-19.42 **
EC521069 × EC362941	61.93 **	56.46 **	0.11	-4.74 *	-0.65	-6.57 *	35.59 **	3.19 **
EC521069 × EC15127	23.51 **	6.4	9.40 **	4.77	8.78 **	-0.09	4.06 *	-7.29 **
EC521069 × EC521061	17.61 **	8.96 **	15.59 **	10.49 **	-0.52	-3.87	1.87	-5.80 **
EC521069 × VRT13	47.19 **	39.66 **	0.12	-2.70	-2.92	-12.81 **	23.11 **	5.61 **
VRT13 × EC362941	55.84 **	43.14 **	2.86	0.65	7.92 **	-8.20 **	47.92 **	1.59
VRT13 × EC15127	75.26 **	58.19 **	7.30 **	0.00	20.99 **	18.06 **	13.61 **	8.81 **
VRT13 × EC521061	54.69 **	50.83 **	5.68 **	-1.69	-7.78 *	-14.53 **	23.54 **	13.82 **
VRT13 × EC521069	0.67	-4.48	0.23	-2.59	-12.06 **	-21.01 **	-2.16	-16.07 **
SEm±	0.06	0.07	0.08	0.09	0.13	0.15	0.98	1.13
CD@5%	0.14	0.16	0.19	0.22	0.30	0.34	2.22	2.56
CD@1%	0.17	0.20	0.23	0.27	0.37	0.43	2.74	3.16

*, Significant at 5% level; **, Significant at 1% level. MP, Mid Parent; BP, Better Parent.

Table 2 Magnitude of heterosis per cent over mid and better parent in tomato for growth parameters

Hybrids	Plant height		Stem circumference		Days to 1st flowering		Fruit numbers/plant	
	MP	BP	MP	BP	MP	BP	MP	BP
EC362941 × EC15127	-14.72 **	-22.15 **	1.28	0.00	-2.65	-3.51	-21.80 **	-36.97 **
EC362941 × EC521061	7.02 **	1.56	-2.60 **	-4.43 **	-1.82	-3.57	-13.27 **	-32.51 **
EC362941 × EC521069	-10.58 **	-15.70 **	0.46	0.00	5.56 **	1.79	-23.16 **	-39.72 **
EC362941 × VRT13	-0.10	-8.71 **	-3.99 **	-7.48 **	3.77 *	-1.79	-28.68 **	-48.08 **
EC15127 × EC362941	-6.16 **	-14.34 **	5.48 **	4.15 **	-6.19 **	-7.02 **	14.85 **	-7.42 **
EC15127 × EC521061	3.10 *	-10.23 **	1.14	-2.00	-2.70	-5.26 **	9.67 **	4.68 *
EC15127 × EC521069	-3.38 **	-6.63 **	-0.35	-2.05	-0.92	-5.26 **	-7.45 **	-10.70 **
EC15127 × VRT13	15.38 **	-2.88 *	-7.97 **	-12.39 **	4.67 **	-1.75	-8.67 **	-20.32 **
EC521061 × EC362941	-4.92 **	-9.77 **	-1.47	-3.33 **	0.00	-1.79	27.43 **	-0.83
EC521061 × EC15127	-13.37 **	-24.56 **	-1.14	-4.21 **	-4.50 **	-7.02 **	-4.18 *	-8.54 **
EC521061 × EC521069	-5.95 **	-15.59 **	-2.36 *	-3.77 **	5.66 **	3.70	12.67 **	11.43 **
EC521061 × VRT13	13.45**	9.01**	-4.24 **	-5.98 **	13.46 **	9.26 **	4.96 **	-4.51 **
EC521069 × EC362941	-2.10	-7.71 **	2.29 *	1.83	-9.26 **	-12.50 **	7.90 **	-15.35 **
EC521069 × EC15127	-8.69 **	-11.77 **	3.60 **	1.83	-2.75	-7.02 **	17.66 **	13.52 **
EC521069 × EC521061	0.74	-9.59 **	-4.61 **	-5.99 **	3.77 *	1.85	12.26 **	11.02 **
EC521069 × VRT13	-3.15 *	-16.09 **	0.88	-2.35 *	-1.96	-3.85	18.42 **	6.66 **
VRT13 × EC362941	19.24 **	8.96 **	-3.33 **	-6.84 **	-3.77 *	-8.93 **	-9.15 **	-33.86 **
VRT13 × EC15127	13.37 **	-4.57 **	3.70 **	-1.28	-8.41 **	-14.04 **	47.99 **	29.12 **
VRT13 × EC521061	17.56 **	12.96 **	-5.77 **	-7.48 **	-1.92	-5.56 **	16.50 **	5.98 **
VRT13 × EC521069	-0.79	-14.05 **	-4.64 **	-7.69 **	1.96	0.00	-1.5	-11.29 **
SEm±	1.98	2.29	0.038	0.044	0.44	0.50	0.62	0.71
CD@5%	4.49	5.18	0.086	0.099	0.99	1.14	1.40	1.61
CD@1%	5.55	6.40	0.106	0.122	1.22	1.41	1.73	1.99

MP, Mid Parent; BP, Better Parent.

Fig. 2 Best performing hybrids for growth and yield characters in semi-indeterminate tomato: (A) EC 15127 × EC 362941; (B) VRT 13 × EC 521061; (C) VRT 13 × EC 15127; (D) VRT13 × EC362941; (E) EC521069 × EC362941.

et al. (2022) and Kumar *et al.* (2023). EC15127 × VRT13 exhibited positive heterosis over both BP (19.38%) and MP (22.35%) for fruit equatorial diameter. Positive significant heterosis for equatorial diameter is observed by Chawsh and Arkwazee (2022). Fruit weight has a direct impact on yield and is a characteristic that attracts consumers. Hence, significant positive heterosis is desirable. The MP and BP heterosis (%) were highest in EC362941 × VRT13 (55.37) and VRT13 × EC521061 (13.82), respectively. Similarly, positive heterosis were reported by Ayenan *et al.* (2022) and Nadjiev *et al.* (2023).

In conclusion, the cross combinations EC15127 × EC362941, VRT13 × EC521061, VRT13 × EC15127, VRT13 × EC362941 and EC521069 × EC362941 were performed best over their parents for growth and yield parameters. Hence, these hybrids can be exploited directly and can be used further for development of improved commercial lines (Fig. 2).

SUMMARY

A diallel design was employed to assess the magnitude of heterosis, aiming to improve growth and yield of semi-indeterminate tomato by identifying the desirable cross-combinations. Five semi-indeterminate tomato genotypes (VRT13, EC15127, EC362941, EC521061 and EC521069) were crossed in diallel mating fashion during rainy (*kharif*) season of 2020. Crosses and the parents were examined for heterosis studies under naturally ventilated polyhouse during winter (*rabi*) season of 2020–21. The results revealed the presence of heterotic vigour in the growth and yield characteristics of the hybrids with significant differences among the traits studied. Hybrids from crosses EC15127 × EC362941 and VRT13 × EC362941 resulted negative heterosis over mid and better parent, respectively for days to first flowering indicating their earliness for flowering. VRT13 × EC15127 and EC15127 × EC362941 noticed heterosis over better and mid parent, respectively for fruit yield. Based on overall performance, the cross combinations EC15127 × EC362941, VRT13 × EC521061, VRT13 × EC15127, VRT13 × EC362941 and EC521069 × EC362941 were performed best over their parents for growth and yield parameters. Hence, these hybrids can be exploited directly or can be used further for development of improved commercial lines

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