International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(10): 734-738
www.biochemjournal.com
Received: 15-07-2025
Accepted: 17-08-2025

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Assessment of heterosis for key growth and early harvest traits in okra using line × tester mating design

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DOI: https://www.doi.org/10.33545/26174693.2025.v9.i10Si.5912

Abstract
A field study was conducted during 2024–2025 at the experimental site of the Department of Vegetable Science, College of Horticulture, Hiriyur, Chitradurga district, Karnataka, to evaluate heterosis for key growth and early harvest traits in okra using a line by tester mating design. The experimental material consisted of nine lines, three testers, their twenty-seven F_1 hybrids, and two commercially popular varieties, NS7774 and Arka Nikitha, as standard checks. The per se performance of genotypes and hybrids was assessed for number of branches per plant, plant height, internodal length, stem girth, days to 50 percent flowering, and days taken for first harvest. Significant variation was observed among the genotypes for all traits. Positive heterosis was desirable for plant height and stem girth to improve plant vigor, whereas negative heterosis was preferred for internodal length, days to fifty percent flowering, and days taken for first harvest to facilitate early growth and harvest. Among the hybrids, L5 by T1 exhibited the highest positive heterosis for plant height, whereas L3 by T1 and L3 by T3 recorded maximum negative heterosis for internodal length. Early flowering and reduced days to first harvest were most pronounced in L7 by T3 and L2 by T2, respectively. The results indicate that several hybrids exhibited significant and desirable heterosis for growth and early harvest traits, suggesting their potential for use in breeding programs aimed at developing vigorous and early maturing okra cultivars.

Keywords: Okra, heterosis, growth traits, early harvest, line by tester, F_1 hybrids

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench], a member of the family Malvaceae, is an important vegetable crop cultivated across tropical and subtropical regions. It is widely consumed for its tender green pods, which are rich in vitamins, minerals, mucilage, protein, and edible oil, making it both nutritionally and economically significant (Gopalan *et al.,* 2007; Martin and Rhodes, 1998) [1, 2]. In addition to its dietary role, okra has considerable medicinal importance, as its mucilage exhibits antioxidant, antimicrobial, and antidiabetic properties (Chauhan, 1972; Mehta, 1959) [3, 6]. These diverse uses underline the crop's prominence in agriculture and human health.

Despite its wide adaptability, productivity in okra is limited by insect pests, viral diseases, and the low genetic potential of traditional cultivars. Hybrid development through heterosis breeding has emerged as one of the most effective approaches to address these constraints. Heterosis, or hybrid vigor, refers to the superior performance of hybrids over their parents for traits such as growth, earliness, yield, and stress resistance. In okra, the first evidence of heterosis was reported by Vijayaraghavan and Warier (1946) [4], and since then, significant hybrid advantages have been documented for fruit yield, earliness, and biotic stress resistance (Dhall *et al.,* 2003; Singh *et al.,* 2006) [5, 7].

The line × tester analysis technique has been extensively used to assess the extent of heterosis for yield and its contributing traits. It also provides insights into the nature and magnitude of gene action governing yield and related attributes, which is valuable for designing effective breeding strategies for crop improvement. The ease of emasculation and pollination, high fruit set, and good seed recovery make okra highly suitable for heterosis breeding, allowing commercial exploitation of hybrid vigor in this crop.

Therefore, evaluating the magnitude of heterosis for key growth and early harvest traits is essential for identifying superior hybrids with early maturity, higher yield, and better adaptability.

The present investigation was undertaken to assess heterosis in okra using the line × tester mating design, with the aim of identifying promising parental combinations for hybrid development.

Materials and Methods

The field experiment was conducted at the Department of Vegetable Science, College of Horticulture, Hiriyur, Chitradurga district, Karnataka, during the 2024–2025 growing season. The experimental site experiences semi-arid conditions, with total rainfall of 47.48 mm during the crop period, maximum and minimum temperatures of 30.1 °C and 13.0 °C, respectively, and relative humidity ranging from 25% to 88%.

The genetic material included Nine female lines, three male testers, and two standard checks (NS7774 and Arka Nikitha) were used. A total of 27 F_1 hybrids were developed using a Line × Tester mating design through controlled hand pollination. Emasculation and pollination were carried out under standard protocols, and harvested fruits were stored for seed extraction.

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each plot consisted of 15 plants spaced 45 cm between rows and 30 cm between plants. Replications were separated by 0.5 m and plots were surrounded by 4 m border rows to minimize edge effects. Agronomic practices including irrigation, weeding, and pest management were applied uniformly across all plots. Observations were recorded on growth and early attributes, including plant height, number of branches per plant, internodal length, stem girth, days to 50 percent flowering, days taken for first harvest. Five plants from the central rows of each plot were randomly selected for measurement to avoid border effects.

Statistical analysis

For data analysis, heterosis was estimated in terms of better parent, mid-parent, and standard check. Analysis of variance (ANOVA) was performed according to the randomized complete block design (RCBD). Selection of superior hybrids was based on desirable agronomic traits, adaptability, and performance relative to standard checks.

Table 1: List of the parents used in the study

Parents		Source
Lines (Females)		
L1	F_5-AP-9-2-39	College of Horticulture, Hiriyur
L2	F_5-AP-77-7-29	College of Horticulture, Hiriyur
L3	F_5-AP-2-1-13	College of Horticulture, Hiriyur
L4	F_5-BP-145-13-9	College of Horticulture, Hiriyur
L5	F_5-BP-147-20-11	College of Horticulture, Hiriyur
L6	F_5-BP-145-20-31	College of Horticulture, Hiriyur
L7	F_5-CP-67-3-21	College of Horticulture, Hiriyur
L8	F_5-CP-5-13-13	College of Horticulture, Hiriyur
L9	F_5-CP-104-15-6	College of Horticulture, Hiriyur
Testers (Males)		
T1	Parbhani Kranti	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
T2	Phule Vimuktha	Mahatma Phule Krishi Vidyapeeth, Rahuri
T3	Arka Anamika	Indian Institute of Horticultural Research, Bangalore
Standard check hybrid		
C1	NS7774	Namdhari Seed Company
C2	Arka Nikitha	Indian Institute of Horticultural Research, Bangalore
Total = 41 (27 hybrids+ 9 lines +3 testers+2 checks)		

Results and Discussion

The analysis of variance revealed significant differences among the genotypes for all six traits, indicating the presence of substantial genetic variability and scope for hybrid improvement in okra (Table 2).

None of the hybrids exhibited significant positive heterosis over the mid-parent, better parent, or standard checks (Table 3). This indicates that the trait is predominantly governed by additive gene action with limited influence of non-additive effects. Branching, being a growth parameter, is also highly sensitive to environmental factors and subject to physiological compensation between vegetative and reproductive growth. Similar observations were reported earlier by Ajit *et al.* (2024) [8] and Pithiya *et al.* (2019) [14].

The magnitude of heterosis over the mid-parent, better parent, and standard checks was highly significant in both directions. The cross L5 × T1 recorded the maximum significant positive heterosis (13.21% over mid-parent, 8.51% over better parent), while L4 × T2 and L5 × T2 showed the highest heterosis over standard checks (5.52% and 5.08%, respectively) (Table 3). The predominance of tallness over dwarfness indicates tallness is a dominant character, consistent with earlier findings reported by Mudhe *et al.* (2022) and Chavan *et al.* (2021) [10].

The magnitude of heterosis was significant in both directions, though negative heterosis is desirable for this trait. The cross L3 × T1 recorded the maximum negative heterosis (-9.45% over mid-parent, -20.87% over check 1, and -22.22% over check 2), while L3 × T3 showed maximum reduction over the better parent (-13.39%) (Table 4). These results confirm the importance of non-additive gene action and complementary parental interactions in reducing internodal length. Similar findings were reported by Panchal *et al.* (2021) [11] and Koli *et al.* (2020) [15]. Stem girth showed significant heterosis in both directions, with positive heterosis being desirable. The cross L3 × T1 recorded the maximum heterosis over the mid-parent (14.30%), while L2 × T1 showed the maximum over the better parent (4.35%). L5 × T2 expressed the highest positive heterosis over check 1 (18.37%) and check 2 (19.34%) (Table 4). These results indicate the predominance of non-additive gene action and favorable parental combinations. Similar positive heterosis was reported by Panchal *et al.* (2021) [11].

Significant heterosis was observed in both directions, with negative heterosis being desirable. The cross L7 × T3 showed the maximum reduction (-5.88% over mid-parent and -8.21% over better parent), while L2 × T2, L6 × T1, and L7 × T3 recorded maximum negative heterosis over standard checks (-9.98% and -11.80%) (Table 5). The involvement of non-additive gene action and complementary parental interactions is evident. These findings agree with reports by Shwetha *et al.* (2021) [12] and Rajani *et al.* (2021) [16]. Significant variation was observed among parents and hybrids for this trait. The cross L7 × T3 recorded the highest negative heterosis (-4.18% over mid-parent and -5.87% over better parent), while L2 × T2, L3 × T2, L6 × T1, and L7 × T3 expressed maximum negative heterosis over standard checks (-8.84% and -7.68%) (Table 5). Such negative heterosis is highly desirable, as it shortens crop duration and ensures early maturity. Similar results were reported by Mudhe *et al.* (2022), Shwetha *et al.* (2021) [12], Kerure *et al.* (2019) and Vekariya *et al.* (2019) [17].

Table 2: Analysis of variance (mean sum of squares) of line x tester analysis for various characters in okra

Character	Replication	Genotypes	Parents	Lines	Tester	Line × Tester	Parents vs Crosses	Crosses	Error
Degrees of freedom	2	38	11	8	2	1	1	26	76
Number of branches per plant	0.58**	0.53**	0.22*	0.26*	0.01	0.39	0.02	0.69**	0.10
Plant height (cm)	3.05	248.96**	120.02**	109.17**	205.36**	36.16**	319.63**	300.79**	3.23
Internodal length (cm)	0.06**	4.88**	4.33**	5.07**	1.47*	4.20**	0.09*	5.30**	0.007
Stem girth (mm)	0.13	25.99**	19.47**	19.30**	28.96**	1.81**	0.23	29.74**	0.14
Days to 50% flowering	0.61**	32.79**	27.86**	35.94**	3.10**	12.67**	0.94**	36.11**	0.09
Days taken for first harvest	0.45*	16.45**	9.25**	11.46**	3.00**	4.12**	2.57*	20.02**	0.03

Table 3: Heterosis (%) over mid parent, better parent and standard checks for number of branches per plant and plant height (cm) in okra

Hybrids	Number of branches per plant				Plant height (cm)			
	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)
$L_1 \times T_1$	-23.14 **	-23.14 **	-27.91 **	-31.11 **	-0.38 **	-2.46 **	-9.77 **	-10.14 **
$L_1 \times T_2$	-15.92 *	-16.94 *	-20.16 **	-23.70 **	0.80 **	-2.23 **	-3.78 **	-4.18 **
$L_1 \times T_3$	-24.79 **	-24.79 **	-29.46 **	-32.59 **	-1.31 **	-3.22 **	-6.88 **	-7.26 **
$L_2 \times T_1$	3.50	-2.21	3.10	-1.48	-5.88 **	-10.41 **	-12.13 **	-12.49 **
$L_2 \times T_2$	6.92	2.21	7.75	2.96	6.48 **	6.30 **	4.61 **	4.18 **
$L_2 \times T_3$	5.84	0.00	5.43	0.74	2.23 **	1.26 **	-0.68 **	-1.09 **
$L_3 \times T_1$	5.02	-1.45	5.43	0.74	5.49 **	0.49 **	-1.59 **	-2.00 **
$L_3 \times T_2$	8.40	2.90	10.08	5.19	7.02 **	6.76 **	5.06 **	4.63 **
$L_3 \times T_3$	2.70	-3.62	3.10	-1.48	5.50 **	4.58 **	2.42 **	2.00 **
$L_4 \times T_1$	-1.63	-3.20	-6.20	-10.37	6.81 **	0.91 **	0.56 **	0.14
$L_4 \times T_2$	-0.40	-0.80	-3.88	-8.15	6.55 **	5.89 **	5.52 **	5.08 **
$L_4 \times T_3$	-1.63	-3.20	-6.20	-10.37	4.58 **	2.78 **	2.42 **	2.00 **
$L_5 \times T_1$	3.50	-2.21	3.10	-1.48	13.21 **	8.51 **	4.90 **	4.47 **
$L_5 \times T_2$	6.92	2.21	7.75	2.96	8.18 **	7.22 **	5.52 **	5.08 **
$L_5 \times T_3$	5.84	0.00	5.43	0.74	6.19 **	5.94 **	2.42 **	2.00 **
$L_6 \times T_1$	7.75	1.46	7.75	2.96	5.10 **	0.08	-1.92 **	-2.33 **
$L_6 \times T_2$	4.21	-0.73	5.43	0.74	1.14 **	0.92 **	-0.68 **	-1.09 **
$L_6 \times T_3$	5.43	-0.73	5.43	0.74	1.64 **	0.72 **	-1.30 **	-1.71 **
$L_7 \times T_1$	3.91	-1.48	3.10	-1.48	5.76 **	0.15	-0.68 **	-1.09 **
$L_7 \times T_2$	5.02	0.74	5.43	0.74	1.79 **	1.40 **	0.56 **	0.14
$L_7 \times T_3$	8.59	2.96	7.75	2.96	7.37 **	5.77 **	4.90 **	4.47 **
$L_8 \times T_1$	-14.64 *	-15.70 *	-20.93 **	-24.44 **	-1.93 **	-2.97 **	-12.13 **	-12.49 **
$L_8 \times T_2$	-4.96	-7.26	-10.85	-14.81 *	-1.44 **	-5.37 **	-6.88 **	-7.26 **
$L_8 \times T_3$	1.26	0.00	-6.20	-10.37	-5.60 **	-8.37 **	-11.84 **	-12.20 **
$L_9 \times T_1$	0.84	-0.83	-6.98	-11.11	-0.68 **	-1.51 **	-11.22 **	-11.58 **
$L_9 \times T_2$	7.05	4.03	0.00	-4.44	-6.79 **	-10.71 **	-12.13 **	-12.49 **
$L_9 \times T_3$	6.72	4.96	-1.55	-5.93	-0.07	-3.22 **	-6.88 **	-7.26 **
S.Em ±	0.22	0.25	0.25	0.25	1.27	1.47	1.47	1.47
CD @ 5%	0.44	0.51	0.51	0.51	2.54	2.93	2.93	2.93

Table 4: Heterosis (%) over mid parent, better parent and standard checks for internodal length (cm) and stem girth (mm) in okra

Hybrids	Internodal length (cm)				Stem girth (mm)			
	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)
$L_1 \times T_1$	-2.20 **	-9.02 **	-3.48 **	-5.13 **	-7.04 **	-7.45 **	-15.51 **	-14.81 **
$L_1 \times T_2$	4.55 **	-5.74 **	0.00	-1.71 **	-4.62 **	-15.04 **	-1.63 **	-0.82 *
$L_1 \times T_3$	6.84 **	2.46 **	8.70 **	6.84 **	-8.53 **	-11.96 **	-13.88 **	-13.17 **
$L_2 \times T_1$	-9.36 **	-12.38 **	-20.00 **	-21.37 **	13.82 **	4.35 **	14.29 **	15.23 **
$L_2 \times T_2$	-3.06 **	-3.06 **	-17.39 **	-18.80 **	4.71 **	1.88 **	17.96 **	18.93 **
$L_2 \times T_3$	-6.67 **	-12.50 **	-14.78 **	-16.24 **	-1.18 **	-6.46 **	2.45 **	3.29 **
$L_3 \times T_1$	-9.45 **	-13.33 **	-20.87 **	-22.22 **	14.30 **	3.64 **	16.33 **	17.28 **
$L_3 \times T_2$	-3.09 **	-4.08 **	-18.26 **	-19.66 **	3.10 **	1.53 **	17.55 **	18.52 **
$L_3 \times T_3$	-6.73 **	-13.39 **	-15.65 **	-17.09 **	-4.02 **	-10.18 **	0.82 *	1.65 **
$L_4 \times T_1$	5.22 **	-3.20 **	5.22 **	3.42 **	3.26 **	-1.62 **	-0.82 *	0.00
$L_4 \times T_2$	13.90 **	1.60 **	10.43 **	8.55 **	-2.76 **	-9.05 **	5.31 **	6.17 **
$L_4 \times T_3$	3.80 **	-1.60 **	6.96 **	5.13 **	1.10 **	-0.40	0.41	1.23 **
$L_5 \times T_1$	9.65 **	1.63 **	8.70 **	6.84 **	13.79 **	2.51 **	16.73 **	17.70 **
$L_5 \times T_2$	11.31 **	0.00	6.96 **	5.13 **	3.08 **	2.23 **	18.37 **	19.34 **
$L_5 \times T_3$	2.98 **	-1.63 **	5.22 **	3.42 **	-1.67 **	-8.60 **	4.08 **	4.94 **
$L_6 \times T_1$	-7.92 **	-11.43 **	-19.13 **	-20.51 **	13.33 **	2.92 **	15.10 **	16.05 **
$L_6 \times T_2$	-1.54 *	-2.04 **	-16.52 **	-17.95 **	2.21 **	0.47	16.33 **	17.28 **
$L_6 \times T_3$	-6.22 **	-12.50 **	-14.78 **	-16.24 **	0.84 **	-5.47 **	5.71 **	6.58 **
$L_7 \times T_1$	-1.41 *	-2.78 **	-8.70 **	-10.26 **	14.08 **	3.26 **	16.33 **	17.28 **
$L_7 \times T_2$	4.85 **	0.00	-6.09 **	-7.69 **	3.28 **	1.88 **	17.96 **	18.93 **
$L_7 \times T_3$	0.91	-0.89	-3.48 **	-5.13 **	-4.20 **	-10.51 **	0.82 *	1.65 **
$L_8 \times T_1$	6.49 **	-0.55	4.64 **	2.85 **	-6.31 **	-7.00 **	-15.10 **	-14.40 **
$L_8 \times T_2$	11.42 **	0.83	6.09 **	4.27 **	-4.37 **	-15.04 **	-1.63 **	-0.82 *
$L_8 \times T_3$	7.30 **	3.31 **	8.70 **	6.84 **	-10.43 **	-14.05 **	-15.92 **	-15.23 **
$L_9 \times T_1$	4.76 **	-3.97 **	5.22 **	3.42 **	-9.78 **	-10.31 **	-17.14 **	-16.46 **
$L_9 \times T_2$	12.50 **	0.00	9.57 **	7.69 **	-18.04 **	-26.32 **	-14.69 **	-13.99 **
$L_9 \times T_3$	7.56 **	1.59 **	11.30 **	9.40 **	-9.44 **	-11.96 **	-13.88 **	-13.17 **
S.Em ±	0.06	0.07	0.07	0.07	0.25	0.30	0.30	0.30
CD @ 5%	0.12	0.14	0.14	0.14	0.51	0.59	0.59	0.59

Table 5: Heterosis (%) over mid parent, better parent and standard checks for days to 50% flowering and days taken to first harvest in okra

Hybrids	Days to 50% flowering				Days taken to first harvest			
	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)	Mid	Better	C_1 (NS7774)	C_2 (Arka Nikitha)
$L_1 \times T_1$	2.82 **	-2.37 **	4.26 **	2.15 **	2.58 **	-0.62 **	0.63 **	1.92 **
$L_1 \times T_2$	5.57 **	-0.75 **	5.99 **	3.85 **	5.53 **	1.25 **	2.53 **	3.84 **
$L_1 \times T_3$	5.36 **	1.06 **	7.92 **	5.74 **	6.31 **	3.99 **	5.31 **	6.65 **
$L_2 \times T_1$	-2.71 **	-4.16 **	-7.98 **	-9.84 **	-1.01 **	-2.00 **	-6.95 **	-5.76 **
$L_2 \times T_2$	-3.80 **	-4.25 **	-9.98 **	-11.80 **	-2.04 **	-2.04 **	-8.84 **	-7.68 **
$L_2 \times T_3$	-3.69 **	-6.11 **	-7.92 **	-9.78 **	-2.99 **	-4.89 **	-7.90 **	-6.72 **
$L_3 \times T_1$	-0.84 **	-2.08 **	-5.99 **	-7.89 **	0.50 *	0.00	-5.05 **	-3.84 **
$L_3 \times T_2$	-3.97 **	-4.18 **	-9.91 **	-11.73 **	-2.53 **	-3.02 **	-8.84 **	-7.68 **
$L_3 \times T_3$	0.10	-2.17 **	-4.06 **	-6.00 **	-1.49 **	-2.94 **	-6.00 **	-4.80 **
$L_4 \times T_1$	1.90 **	-0.27 **	0.00	-2.02 **	0.99 **	0.00	-3.16 **	-1.92 **
$L_4 \times T_2$	5.07 **	1.79 **	2.06 **	0.00	3.99 **	1.96 **	-1.26 **	0.00
$L_4 \times T_3$	0.84 **	-0.27 **	0.00	-2.02 **	0.98 **	0.98 **	-2.21 **	-0.96 **
$L_5 \times T_1$	-1.37 **	-2.70 **	-6.59 **	-8.47 **	-1.21 **	-2.00 **	-6.95 **	-5.76 **
$L_5 \times T_2$	-0.11	-0.42 **	-6.39 **	-8.28 **	-1.83 **	-2.03 **	-8.46 **	-7.29 **
$L_5 \times T_3$	0.28 **	-2.10 **	-3.99 **	-5.93 **	-1.20 **	-2.94 **	-6.00 **	-4.80 **
$L_6 \times T_1$	-4.68 **	-6.24 **	-9.98 **	-11.80 **	-3.51 **	-3.99 **	-8.84 **	-7.68 **
$L_6 \times T_2$	-1.53 **	-2.12 **	-7.98 **	-9.84 **	-0.51 *	-1.01 **	-6.95 **	-5.76 **
$L_6 \times T_3$	-1.53 **	-4.14 **	-5.99 **	-7.89 **	-1.49 **	-2.94 **	-6.00 **	-4.80 **
$L_7 \times T_1$	-0.63 **	-2.08 **	-5.99 **	-7.89 **	-1.21 **	-2.00 **	-6.95 **	-5.76 **
$L_7 \times T_2$	2.63 **	2.19 **	-3.93 **	-5.87 **	1.83 **	1.62 **	-5.05 **	-3.84 **
$L_7 \times T_3$	-5.88 **	-8.21 **	-9.98 **	-11.80 **	-4.18 **	-5.87 **	-8.84 **	-7.68 **
$L_8 \times T_1$	3.78 **	-2.09 **	5.99 **	3.85 **	3.58 **	1.27 **	0.63 **	1.92 **
$L_8 \times T_2$	6.84 **	-0.18 *	8.05 **	5.87 **	6.57 **	3.18 **	2.53 **	3.84 **
$L_8 \times T_3$	6.61 **	1.60 **	9.98 **	7.76 **	6.44 **	5.09 **	4.42 **	5.76 **
$L_9 \times T_1$	2.36 **	-3.04 **	4.06 **	1.96 **	0.03	-3.64 **	-1.26 **	0.00
$L_9 \times T_2$	7.27 **	0.62 **	7.98 **	5.80 **	7.46 **	2.53 **	5.05 **	6.40 **
$L_9 \times T_3$	6.19 **	1.61 **	9.05 **	6.84 **	4.79 **	1.91 **	4.42 **	5.76 **
S.Em ±	0.20	0.24	0.24	0.24	0.20	0.23	0.23	0.23
CD @ 5%	0.41	0.48	0.48	0.48	0.41	0.47	0.47	0.47

Conclusion

The study revealed significant heterotic expression in okra for key traits, with positive heterosis observed for plant height and stem girth, and desirable negative heterosis for days to 50 percent flowering and days taken for first harvest, indicating potential for developing vigorous and early-maturing hybrids. Hybrids such as L5 × T1, L4 × T2, and L5 × T2 were identified as promising for plant vigor, while L7 × T3, L2 × T2, and L6 × T1 were superior for earliness, providing valuable parental combinations for future okra improvement programs.

Acknowledgments

Authors are heartly thankful to the Director of Research, Keladi Shivappa Nayaka University of Agricultural and Horticultural sciences, Shivamogga for providing necessary facilities.

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