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Research Note

# Combining ability and gene action analysis in okra (*Abelmoschus esculentus* L. Moench)

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**Abstract**
The present research was conducted in Okra to study combining ability and gene action in a set of 28 $F_1$s developed by crossing seven lines and four testers. The experiment was laid out in a Randomized Block Design with three replications and observations were recorded on 12 traits *viz.* days to 50% flowering, days to first picking, number of internodes, number of branches plant$^{-1}$, fruit length at maturity and harvest, number of fruits plant$^{-1}$, number of seeds fruit$^{-1}$, seed index, fruit weight, yield per plant and plant height. The results revealed that two lines *viz.,* VRO-4 and Sel-2 were excellent general combiners for most of the traits in both positive and negative direction as per desirable traits. Cross VRO-6 x Varsha Uphar recorded highly significant SCA effects for eight traits and GAO-5 x GJO-3 for yield trait. Variance due to GCA was less than SCA, and the GCA/SCA ratio was less than unity indicating preponderance of non-additive gene action for all the traits. This suggested the feasibility of exploitation of heterosis.

**Keywords:** Gene action, Fruit yield, Okra, GCA and SCA

Okra (*Abelmoschus esculentus* L. Moench) is a widely cultivated vegetable crop in tropical and subtropical regions, with a chromosome number of 2n=2x=130 (Patil *et al.,* 2015). India is the largest global producer of okra, contributing over 72% (6.47 million tonnes) from an area of 0.5 million hectare (NHB,2022). Okra is a warm-season vegetable crop that is widely grown in tropical and subtropical regions around the world. It is native to Tropical Africa (Benchasri, 2012) and is known for its immature green seed pods, which are consumed as a cooked vegetable, fresh or sundried (Liu *et al*., 2021). It is believed that okra originated from South Africa near Ethiopia as per Vavilov (1951). The origin of okra can be traced back to the Hindustani region, where it was primarily cultivated in India, Pakistan, and Burma (Zeven and Zhukovsky, 1975). Immature okra pods are utilized for making pickles (Hadiya *et al.,* 2018). As per (APEDA, 2021) India's okra production surpassed 6 million tonnes in 2021, with the highest output coming from Gujarat (0.92 tonnes), followed by West Bengal (0.91 tonnes), Bihar (0.78 tonnes), Madhya Pradesh (0.63 tonnes), and Odisha (0.56 tonnes). In Punjab, okra is commercially cultivated in around 4.57 thousand hectare of land and yields an annual production of 47.65 thousand metric tonnes (Verma and Pathania, 2023). Okra has the potential to earn foreign exchange as it plays a significant role in fresh vegetable export, according to the Agricultural and Processed Food Products Export Development Authority (APEDA, 2020).

The cross-pollination tendency of okra contributes significantly to the creation of considerable genetic diversity across various traits. This diversity is crucial for further advancements in genetic improvement, as

highlighted by Mishra *et al*. (2021). It involves assessing the degree of combining ability in both lines and crosses to identify lines with the best general combining ability (GCA) and specific combining ability (SCA) in crosses, as stated by Sprague and Tatum (1942). The GCA provides insights into the additive gene effects, while the SCA reveals both intra-allelic (dominance) and inter-allelic interactions (epistasis). SCA is the deviation in performance of a cross from what is expected based on the GCA of the parents. One of the most popular and systematic approaches for identifying superior parents and crosses is the Line x Tester analysis technique proposed by Kempthrone (1957). This approach is a basic requirement for success in any breeding program. Enhancing the potential for improved crop yields involves identifying optimal combinations of individual lines with high general combining ability, fostering the creation of more favourable recombinants for further crop enhancement.

The present research was conducted at the Genetics and Plant Breeding Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during *Kharif* 2022. A total of 28 $F_1$s developed by crossing 11 genotypes (7 lines and 4 testers) of okra in line x tester mating fashion (**Table 1**) were raised in RBD with three replications. Twelve quantitative traits *viz.* days to 50% flowering, days to first picking, fruit length at maturity and harvest (cm), number of inter-nodes, number of branches, number of fruits plant$^{-1}$, number of seeds fruit$^{-1}$, seed Index (g), fruit weight (g), yield plant$^{-1}$ (g) and plant height (cm), were examined from five randomly selected plants in each of the parent and hybrid. The significance of differences between treatments was assessed by conducting an analysis of variance (ANOVA) for Randomized Block Design (RBD) as per the procedure outlined by Panse and Sukhatme (1985), for all the metric traits studied. ANOVA for Line x Tester analysis for combining ability and test of significance was worked out as per Kempthrone (1957) and Singh and Chaudhary (1985). All the analyses were carried out using TNAUSTAT software.

Estimation of GCA and SCA effects and variances: The individual effects of General Combining Ability (GCA) and Specific Combining Ability (SCA) were estimated by calculating the two-way table of female and male parents, and then summing the values obtained over multiple replications as given by Sprague and Tatum (1942). The significance of GCA effects of lines and testers and SCA effects of crosses were tested as per Singh and Chaudhary, 1977. Estimation of GCA and SCA were calculated by formulae proposed by Singh and Chaudhary, 1977. Proportional contribution of line, testers and their interactions to total variance computed as per (Singh and Chaudhary, 1977)

**Table 1. List of parents used in crossing programme**

| Lines (7) | | Testers (4) | |
|---|---|---|---|
| VRO-6 | $L_1$ | Azad Kranti | $T_1$ |
| VRO-22 | $L_2$ | Azad Ganga | $T_2$ |
| VRO-4 | $L_3$ | GJO-3 | $T_3$ |
| Sel-2 | $L_4$ | Varsha Uphar | $T_4$ |
| HRB-55 | $L_5$ | | |
| GO-2 | $L_6$ | | |
| GAO-5 | $L_7$ | | |

Analysis of variance: Analysis of variance (ANOVA) for yield and its attributing traits (**Table 2**) revealed that there was significant difference among all the crosses for all the traits. Among lines, highly significant difference were recorded for the traits *viz.,* days to 50% flowering, days to first picking, fruit length (harvest) and Yield Plant$^{-1}$. Significant difference was found for number of internodes, fruit length (maturity), number of seeds fruit$^{-1}$, seed index and fruit weight and non-significant for plant height and number of branches. Testers also recorded highly significant differences for traits *viz.* days to 50% flowering, days to first picking, fruit length (harvest), seed index, fruit weight and yield plant$^{-1}$. Significant difference was observed for fruit length (maturity) and number of seeds fruit$^{-1}$ and non-significant for plant height.

GCA and SCA effect: Assessing general combining ability (GCA) and specific combining ability (SCA) is essential for the identification and selection of inbred lines and $F_1$ crosses demonstrating superior performance. GCA estimation indicates whether the parental mean is superior or inferior to the general mean of the parents. The selection of parents with high GCA is instrumental in predicting the performance of their test cross progenies and fostering the development of a superior breeding population through hybridization. GCA may not consistently predict heterotic combinations, underscoring the importance of SCA for identifying non-additive gene interactions in hybrids. Strategic selection of parents with both high GCA and significant SCA in their crosses is valuable for advancing heterosis-breeding programs. The relative performance of a cross is primarily associated with non-additive gene activity, mainly influenced by factors such as dominance, epistasis, or genotype-environment interaction effects.

Estimation of General combing ability (GCA): Estimation of GCA effect (**Table 3**) revealed that two lines VRO-4 and Sel-2 performed as good general combiners with highly significant GCA effects for six and five traits respectively. For earliness traits *i.e.* early flowering and early picking cultivars are preferred, the combining ability in negative direction is desirable for these characters. The line VRO-4 exhibited highest negative significant GCA effect for days to 50 % flowering (-2.75), days to first picking (-2.56) and Sel-2 exhibited high negative significant GCA effect for days to 50 % flowering (-1.33), days to first picking (-1.73). Line VRO-4 exhibited high positive significant

**Table 2. ANOVA for Line x Tester involving parents for yield and its attributing traits**

| Source of Variation | Df | Days to 50% flowering | Days to first picking | Plant height | Number of internodes | Number of branches | Fruit length (maturity) |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.18 | 1.46 | 245.72 | 0.06 | 0.11 | 0.10 |
| Genotypes | 38 | 17.52** | 37.10** | 1370.48** | 9.54** | 2.78* | 4.03* |
| Crosses | 27 | 20.96** | 44.17** | 1223.32** | 8.01** | 2.71* | 4.36* |
| Lines | 6 | 28.75** | 43.99** | 977.88 | 4.06* | 0.35 | 3.66* |
| Testers | 3 | 26.89** | 36.49** | 952.33 | 9.54** | 5.65** | 2.15* |
| L x T | 18 | 17.38** | 45.51** | 1350.29** | 9.08** | 3.01* | 4.97* |
| Parents | 10 | 9.48** | 17.25** | 1904.83** | 11.72** | 3.14* | 3.37* |
| Error | 76 | 0.51 | 0.92 | 2.62 | 0.14 | 0.20 | 0.03 |
| Total | 116 | | | | | | |

| Source of Variation | DF | Fruit length (harvest) | Number of fruits plant$^{-1}$ | Number of seeds fruit$^{-1}$ | Seed index | Fruit weight | Yield plant$^{-1}$ |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.68 | 0.43 | 561.96 | 0.00 | 0.04 | 10.94 |
| Genotypes | 38 | 21.66** | 22.13** | 7.99** | 2.31* | 5.20** | 9291.16** |
| Crosses | 27 | 22.96** | 23.25** | 8.07** | 2.29* | 4.54* | 8930.83** |
| Lines | 6 | 30.11** | 22.9** | 2.63* | 1.15* | 3.69* | 9393.43** |
| Testers | 3 | 34.63** | 9.07** | 2.32* | 9.51** | 10.92** | 18616.94** |
| L x T | 18 | 18.63** | 7.4* | 10.84** | 1.77* | 3.76* | 7162.27** |
| Parents | 10 | 16.76** | 17.45** | 8.32** | 2.54* | 7.42** | 10301.54** |
| Error | 76 | 0.77 | 0.67 | 3.43 | 1.17 | 0.04 | 106.07 |
| Total | 116 | | | | | | |

*, ** denotes significance at 5% and 1% respectively.

**Table 3. Estimates of general combining ability (GCA) of lines and testers for twelve characters in okra**

| S. No. | Genotypes | Days to 50% flowering | Days to first picking | Number of internodes | Number of branches | Fruit length (maturity) | Fruit length (harvest) | Number of fruits plant$^{-1}$ | Number of seeds fruit$^{-1}$ | Seed index | Fruit weight | Yield plant$^{-1}$ | Plant height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LINES** | | | | | | | | | | | | | |
| 1 | VRO-6 | 0.83 ** | 1.69 ** | 0.50 ** | -0.24 ns | -1.03 ** | -2.70 ** | 0.03 ns | -0.13 ns | -0.49 ** | -0.91 ** | 50.46 ** | 10.00 ** |
| 2 | VRO-22 | 1.83 ** | 2.19 ** | -0.33 ** | 0.10 ns | -0.31 ** | -0.95 ** | -0.02 ns | -0.55 ns | 1.16 ** | 0.50 ** | 0.72 ns | -8.28 ** |
| 3 | VRO-4 | -2.75 ** | -2.56 ** | -0.25 * | -0.15 ns | 0.54 ** | 1.71 ** | 1.70 ** | 0.70 ns | -0.67 ** | 0.57 ** | 32.60 ** | -6.33 ** |
| 4 | SEL-2 | -1.33 ** | -1.73 ** | -0.75 ** | 0.26 ns | -0.11 * | -0.87 ** | -0.11 ns | -0.05 ns | 0.06 ** | -0.31 ** | 18.59 ** | 12.61 ** |
| 5 | HRB-55 | 0.92 ** | 1.11 ** | -0.42 ** | 0.10 ns | 0.08 ns | 1.05 ** | 0.10 ns | 0.54 ns | 0.66 ** | 0.51 ** | 23.93 ** | 9.13 ** |
| 6 | GO-2 | 0.33 ns | -1.64 ** | 0.42 ** | -0.07 ns | 0.50 ** | 0.38 ns | 0.17 ns | -0.46 ns | -1.29 ** | -0.25 ** | -1.15 ns | 5.66 ** |
| 7 | GAO-5 | 0.17 ns | 0.94 ** | 0.83 ** | 0.01 ns | 0.33 ** | 1.38 ** | -0.22 ns | -0.05 ns | 0.58 ** | -0.11 ns | 12.95 ** | 2.44 ** |
| **TESTERS** | | | | | | | | | | | | | |
| 8 | Azad Kranti | 0.52 ** | 0.60 ** | 0.12 ns | 0.62 ** | 0.11 ** | 0.48 * | -0.10 ns | -0.48 ns | -0.32 ** | -0.25 ** | 0.08 ns | -0.50 ns |
| 9 | Azad Ganga | 0.00 ns | -0.45 * | -0.98 ** | -0.62 ** | -0.31 ** | 0.52 ** | -0.03 ns | 0.29 ns | -0.34 ** | 0.52 ** | 18.27 ** | -7.40 ** |
| 10 | GJO-3 | 1.05 ** | 1.45 ** | 0.31 ** | 0.14 ns | -0.20 ** | -1.90 ** | -0.06 ns | 0.14 ns | 0.52 ** | -0.91 ** | 42.02 ** | -1.04 ** |
| 11 | Varsha Uphar | -1.57 ** | -1.60 ** | 0.55 ** | -0.14 ns | 0.40 ** | 0.90 ** | 0.19 ns | 0.05 ns | 0.15 ** | 0.64 ** | 23.67 ** | 8.94 ** |
| SE± (Lines) | | 0.30 | 0.38 | 0.17 | 0.19 | 0.07 | 0.37 | 0.22 | 0.83 | 0.00 | 0.08 | 4.55 | 0.67 |
| CD @ 5% (Lines) | | 0.60 | 0.76 | 0.33 | 0.37 | 0.13 | 0.72 | 0.43 | 1.65 | 0.00 | 0.15 | 9.01 | 1.34 |
| CD @ 1% (Lines) | | 0.79 | 1.01 | 0.44 | 0.49 | 0.18 | 0.96 | 0.57 | 2.20 | 0.00 | 0.20 | 11.97 | 1.77 |
| SE± (Testers) | | 0.23 | 0.29 | 0.13 | 0.14 | 0.05 | 0.28 | 0.16 | 0.63 | 0.00 | 0.06 | 3.44 | 0.51 |
| CD @ 5% (Testers) | | 0.45 | 0.57 | 0.25 | 0.28 | 0.10 | 0.55 | 0.32 | 1.25 | 0.00 | 0.11 | 6.81 | 1.01 |
| CD @ 1% (Testers) | | 0.60 | 0.76 | 0.33 | 0.37 | 0.13 | 0.73 | 0.43 | 1.66 | 0.00 | 0.15 | 9.05 | 1.34 |

*, ** denotes significance at 5% and 1% respectively

GCA effect for yield plant$^{-1}$ (32.60) followed by fruit length at harvest and maturity (1.71) and (0.54) respectively and fruit weight (0.57). Similarly, Sel-2 exhibited high positive significant GCA effect for yield plant$^{-1}$ (18.59) followed by plant height (12.61) and seed index (0.06). These lines can be used in developing varieties that meet market demand for okra. For the trait yield plant$^{-1}$, four lines recorded highly significant GCA effects *viz.* VRO-6 (50.46), followed by VRO-4 (32.62), HRB-55 (23.93) and Sel-2 (18.59). Patel *et al*. (2021) also found VRO-6 and HRB-55 as good general combiner, Verma and Sood (2020) for VRO-4 for negative significant GCA effect, Singh *et al.* (2021) and Narkhede *et al.* (2021) also found similar results for earliness *i.e.* negative significant GCA effect in traits *viz.* days to 50 % flowering and days to first picking.

The tester Varsha Uphar recorded highly significant negative GCA effects for the traits like days to 50% flowering (-1.57), days to first picking (-1.60). Similarly, Azad Ganga recorded significant negative GCA effects for days to first picking (-1.60). Varsha Uphar recorded highly significant positive effect for the traits *viz.* yield plant$^{-1}$ (23.67), plant height (8.94), fruit weight (0.64), fruit length at harvest and maturity (0.90) and (0.40), number of internodes (0.5) and seed index (0.15). The Azad Ganga recorded highly significant positive effect for the traits *viz.* yield plant$^{-1}$ (18.27), fruit weight (0.52) and fruit length at harvest (0.52). The high GCA value primarily stemmed from additive variance and the interaction between two additive genes situated in distinct loci. Nevertheless, depending solely on categorizing parents based on GCA effects is not an optimal approach for parental selection. The study results emphasize that none of the parents simultaneously exhibited all desirable traits, a conclusion supported by Silva *et al.* (2021), Kalaiselvan and Anuja (2021), and *Ivin et al.* (2022). The best general combiner for 12 traits, which suggests that additive gene action as a key factor for the expression of traits tabulated in (**Table 5**)

Estimation of Specific combing ability (SCA): Estimation of GCA effect (**Table 4**) revealed that among the hybrids, VRO-6 x Varsha Uphar exhibited highly significant SCA effects for eight traits. Negative and highly significant effect observed for days to first picking (-2.07) and negatively significant for days to 50% flowering (-0.93) and positive and highly significant for yield plant$^{-1}$ (50.59), fruit weight (1.85), seed index (0.58), number of seed fruit$^{-1}$ (2.37), fruit length at harvest and maturity (1.18) and (0.70) respectively. Hybrids VRO-22 x Varsha Uphar and Sel-2 x GJO-3 recorded highly significant SCA effects for seven traits. VRO-22 x Varsha Uphar recorded negative and highly significant SCA for days to 50% flowering (-4.60), days to first picking (-5.90). However, Sel-2 x GJO-3 recorded negative and highly significant SCA for days to 50% flowering (-1.71) and days to first picking (-3.04). The hybrid VRO-22 x Varsha Uphar recorded positive and highly significant effect for yield plant$^{-1}$ (29.77), plant height (14.30), fruit weight (0.67), fruit length at harvest and maturity (1.43) and (1.74) respectively, while, Sel-2 x GJO-3 recorded positive and highly significant effect for yield plant$^{-1}$ (34.77), plant height (21.04), fruit weight (1.03), fruit length at harvest and maturity (1.15) and (0.44) respectively.

The hybrids HRB-55 x Varsha Uphar, GO-2 x GJO-3 and GAO-5 x Azad Ganga recorded highly significant SCA effects for six traits. HRB-55 x Varsha Uphar recorded negative and highly significant for days to 50% flowering (-2.35), days to first picking (-6.15) followed by positive and highly significant for number of internodes (1.70), plant height (18.19) and fruit length at harvest and maturity (2.43) and (1.29) respectively. However GO-2 x GJO-3 recorded negative and highly significant for days to 50% flowering (-1.71). High positive significant effect for number of branches (1.69), fruit length at harvest and maturity (1.24) and (1.10) respectively, fruit weight (0.63) and yield plant$^{-1}$ (27.47) was recorded. Moreover GAO-5 x Azad Ganga recorded negative and highly significant for days to 50% flowering (-1.83) and days to first picking (-4.80) followed by positive and highly significant effect for number of internodes (1.31), number of branches (1.04), plant height (17.12) and fruit length at maturity (1.08).

Hybrids VRO-6 x GJO-3 recorded highly significant SCA effects for four traits. It also recorded negative and highly significant effect for days to 50% flowering (-1.88) and days to first picking (-2.79) and positive highly significant for Seed index (0.81) and number of internodes (0.69). GO-2 x Azad Kranti and GAO-5 x Azad Kranti recorded for highly significant SCA effects for three traits. GO-2 x Azad Kranti recorded negative and highly significant for days to first picking (-4.60) however, GAO-5 x Azad Kranti recorded negative and highly significant for days to 50% flowering (-2.36) and days to first picking (-2.18). GO-2 x Azad Kranti recorded positive and highly significant effect for plant height (21.60) and fruit weight (0.34). However, GAO-5 x Azad Kranti recorded positive and highly significant effect for seed index (0.38) only. The best specific combiners for 12 traits furnished in (**Table 5)**. Simultaneously, crosses resulting from the pairing of effective × effective combiner parents, displaying elevated mean values and substantial SCA effects for specific traits, highlight the cumulative impact of additive and additive × additive gene actions. Shwetha *et al.* (2021), Kharat *et al.* (2022), Shinde *et al.* (2023), Mundhe *et al.* (2023), Tiwari *et al.* (2016) and *Kumar et al.* (2013) reported comparable outcomes. These hybrids could be exploited through heterosis breeding and may give transgressive segregants in subsequent generations and therefore, it would be worthwhile to use them for improvement in fruit yield *per se*.

Estimation of Gene action (GA):The estimates of GCA and SCA variances respectively and gene action furnished in (**Table 6)**. Variance due to GCA is less than variance due to SCA and the ratio of GCA to sca variance will be less

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**Table 4. Estimates of specific combining ability (SCA) of crosses for twelve characters in Okra**

| S. No | Genotypes | Days to 50% flowering | Days to first picking | Number of internodes | Number of branches | Fruit length (maturity) | Fruit length (harvest) | Number of fruits plant$^{-1}$ | Number of seeds fruit$^{-1}$ | Seed Index | Fruit weight | Yield plant$^{-1}$ | Plant height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VRO-6 x Azad Kranti | 0.98 * | 2.40 ** | 0.21 ns | 0.38 ns | 0.46 ** | 1.61 ** | -0.10 ns | -1.11 ns | -0.45 ** | -0.30 ** | 13.58 * | 13.39 ** |
| 2 | VRO-6 x Azad Ganga | 1.83 ** | 2.45 ** | 2.31 ** | -0.71 ** | -1.16 ** | -3.11 ** | 0.03 ns | -0.20 ns | -0.94 ** | -1.72 ** | -73.18 ** | 10.96 ** |
| 3 | VRO-6 x GJO-3 | -1.88 ** | -2.79 ** | 0.69 ** | -0.14 ns | -0.00 ns | 0.32 ns | -0.38 ns | -1.06 ns | 0.81 ** | 0.17 ns | 9.01 ns | -9.97 ** |
| 4 | VRO-6 x Varsha Uphar | -0.93 * | -2.07 ** | -3.21 ** | 0.48 ns | 0.70 ** | 1.18 * | 0.45 ns | 2.37 * | 0.58 ** | 1.85 ** | 50.59 ** | -14.38 ** |
| 5 | VRO-22 x Azad Kranti | 1.64 ** | 3.24 ** | -1.29 ** | 0.38 ns | 0.97 ** | 0.19 ns | 0.29 ns | -0.36 ns | 0.90 ** | -0.21 ns | -3.10 ns | -25.73 ** |
| 6 | VRO-22 x Azad Ganga | 0.83 ns | 1.29 * | 2.48 ** | -0.38 ns | -1.28 ** | 1.14 * | 0.12 ns | -0.12 ns | -0.19 ** | 0.93 ** | 31.60 ** | 21.31 ** |
| 7 | VRO-22 x GJO-3 | 2.12 ** | 1.38 * | -1.14 ** | -0.48 ns | -1.43 ** | -2.76 ** | -0.32 ns | 0.69 ns | -0.44 ** | -1.38 ** | -58.27 ** | -9.89 ** |
| 8 | VRO-22 x Varsha Uphar | -4.60 ** | -5.90 ** | -0.05 ns | 0.48 ns | 1.74 ** | 1.43 ** | -0.09 ns | -0.21 ns | -0.27 ** | 0.67 ** | 29.77 ** | 14.30 ** |
| 9 | VRO-4 x Azad Kranti | -1.44 ** | -1.01 ns | -0.37 ns | -0.70 ** | -0.08 ns | -0.48 ns | -0.22 ns | 1.39 ns | 1.02 ** | -0.05 ns | -5.28 ns | -1.64 ns |
| 10 | VRO-4 x Azad Ganga | -2.58 ** | -3.30 ** | -0.94 ** | 0.20 ns | 1.63 ** | 1.14 * | -0.22 ns | -2.04 ns | -0.96 ** | 0.33 ** | 22.23 ** | -16.40 ** |
| 11 | VRO-4 x GJO-3 | 1.37 ** | 1.80 ** | 0.77 ** | -0.23 ns | -0.64 ** | -0.43 ns | 0.81 ** | 3.11 ** | -0.32 ** | -0.08 ns | -10.15 ns | 39.53 ** |
| 12 | VRO-4 x Varsha Uphar | 2.65 ** | 2.51 ** | 0.54 * | 0.73 ** | -0.91 ** | -0.24 ns | -0.37 ns | -2.46 * | 0.25 ** | -0.20 ns | -6.80 ns | -21.48 ** |
| 13 | SEL-2 x Azad Kranti | 1.14 ** | -0.18 ns | -0.54 * | 1.21 ** | -0.50 ** | 2.11 ** | 0.31 ns | -1.19 ns | -1.50 ** | -0.36 ** | 13.47 * | 0.63 ns |
| 14 | SEL-2 x Azad Ganga | 1.67 ** | 2.54 ** | -1.44 ** | -0.88 ** | -0.48 ** | -2.94 ** | 0.10 ns | 0.05 ns | 0.91 ** | -1.09 ** | -57.86 ** | -8.73 ** |
| 15 | SEL-2 x GJO-3 | -1.71 ** | -3.04 ** | 0.27 ns | -0.31 ns | 0.44 ** | 1.15 * | -0.47 ns | 2.19 ns | -0.84 ** | 1.03 ** | 34.77 ** | 21.04 ** |
| 16 | SEL-2 x Varsha Uphar | -1.10 * | 0.68 ns | 1.70 ** | -0.02 ns | 0.54 ** | -0.32 ns | 0.06 ns | -1.05 ns | 1.43 ** | 0.42 ** | 9.62 ns | -12.94 ** |
| 17 | HRB-55 x Azad Kranti | 0.56 ns | 2.32 ** | 2.13 ** | 1.38 ** | 0.39 ** | 0.19 ns | -0.60 ns | -1.11 ns | 0.30 ** | 1.18 ** | 29.32 ** | 11.73 ** |
| 18 | HRB-55 x Azad Ganga | 0.75 ns | 2.04 ** | -3.44 ** | -0.05 ns | -0.70 ** | 0.81 ns | 0.30 ns | 2.13 ns | 0.41 ** | 0.88 ** | 28.39 ** | -23.23 ** |
| 19 | HRB-55 x GJO-3 | 1.04 * | 1.80 ** | -0.39 ns | -1.14 ** | -0.98 ** | -3.43 ** | 0.19 ns | -0.39 ns | 0.46 ** | -1.23 ** | -65.68 ** | -6.70 ** |
| 20 | HRB-55 x Varsha Uphar | -2.35 ** | -6.15 ** | 1.70 ** | -0.19 ns | 1.29 ** | 2.43 ** | 0.11 ns | -0.63 ns | -1.17 ** | -0.84 ** | 7.97 ns | 18.19 ** |
| 21 | GO-2 x Azad Kranti | -0.52 ns | -4.60 ** | 0.30 ns | -1.45 ** | -0.51 ** | -0.14 ns | 0.37 ns | 2.23 ns | -0.65 ** | 0.34 ** | 5.61 ns | 21.60 ** |
| 22 | GO-2 x Azad Ganga | -0.67 ns | -0.21 ns | -0.27 ns | 0.79 ** | 0.91 ** | 2.81 ** | 0.06 ns | 0.46 ns | 1.26 ** | 0.84 ** | 53.31 ** | -1.03 ns |
| 23 | GO-2 x GJO-3 | -1.71 ** | -0.79 ns | 0.11 ns | 1.69 ** | 1.10 ** | 1.24 * | 0.16 ns | -2.39 * | -0.09 ** | 0.63 ** | 27.47 ** | -19.96 ** |
| 24 | GO-2 x Varsha Uphar | 2.90 ** | 5.60 ** | -0.13 ns | -1.02 ** | -1.50 ** | -3.90 ** | -0.59 ns | -0.30 ns | -0.52 ** | -1.81 ** | -86.38 ** | -0.61 ns |
| 25 | GAO-5 x Azad Kranti | -2.36 ** | -2.18 ** | -0.45 ns | -1.20 ** | -0.73 ** | -3.48 ** | -0.05 ns | 0.14 ns | 0.38 ** | -0.60 ** | -53.60 ** | -19.98 ** |
| 26 | GAO-5 x Azad Ganga | -1.83 ** | -4.80 ** | 1.31 ** | 1.04 ** | 1.08 ** | 0.14 ns | -0.39 ns | -0.29 ns | -0.51 ** | -0.17 ns | -4.50 ns | 17.12 ** |
| 27 | GAO-5 x GJO-3 | 0.79 ns | 1.63 ** | -0.31 ns | 0.61 * | 1.51 ** | 3.90 ** | 0.01 ns | -2.14 ns | 0.43 ** | 0.86 ** | 62.86 ** | -14.05 ** |
| 28 | GAO-5 x Varsha Uphar | 3.40 ** | 5.35 ** | -0.55 * | -0.44 ns | -1.86 ** | -0.57 ns | 0.43 ns | 2.29 ns | -0.30 ** | -0.09 ns | -4.76 ns | 16.91 ** |
| SE± sca) | | 0.60 | 0.77 | 0.34 | **0.38** | **0.14** | **0.73** | **0.43** | **1.67** | **0.00** | **0.15** | **9.11** | **1.35** |
| CD @ 5% (sca) | | 1.19 | 1.52 | 0.67 | **0.74** | **0.27** | **1.45** | **0.85** | **3.31** | **0.00** | **0.30** | **18.03** | **2.67** |
| CD @ 1% (sca) | | 1.59 | 2.02 | 0.88 | **0.99** | **0.36** | **1.92** | **1.14** | **4.39** | **0.00** | **0.40** | **23.95** | **3.55** |

*, ** denotes significance at 5% and 1% respectively

**Table 5. Best general and specific combiners for twelve characters in Line x Tester analysis of okra**

| S. No. | Characters | GCA | SCA |
|---|---|---|---|
| 1 | Days to 50% flowering | VRO-4 | VRO-22 x Varsha Uphar |
| 2 | Days to first picking | VRO-4 | HRB-55 x Varsha Uphar |
| 3 | Plant height | SEL-2 | GO-2 x Azad Kranti |
| 4 | Number of internodes | GAO-5 | VRO-22 x Azad Ganga |
| 5 | Number of branches | Azad Kranti | GO-2 x GJO-3 |
| 6 | Fruit length (maturity) | VRO-4 | VRO-22 x Varsha Uphar |
| 7 | Fruit length (harvest) | VRO-4 | GAO-5 x GJO-3 |
| 8 | Number of fruits plant$^{-1}$ | VRO-4 | VRO-4 x GJO-3 |
| 9 | Number of seeds fruit$^{-1}$ | - | VRO-4 x GJO-3 |
| 10 | Seed index | VRO-22 | SEL-2 x Varsha Uphar |
| 11 | Fruit weight | VRO-4 | VRO-6 x Varsha Uphar |
| 12 | Yield plant$^{-1}$ | VRO-6 | GAO-5 x GJO-3 |

**Table 6. Contribution of Lines, Testers and Line x Testers for gene action**

| S. No. | Characters | Line % | Tester % | Line x Tester % | Var. GCA | Var. SCA | Gene Action |
|---|---|---|---|---|---|---|---|
| 1 | Days to 50% flowering | 30.48 | 14.25 | 55.27 | 0.08 | 5.61 | Non-Additive |
| 2 | Days to first picking | 22.13 | 9.18 | 68.69 | 0.03 | 14.88 | Non-Additive |
| 3 | Plant height | 17.76 | 8.65 | 73.59 | 2.82 | 449.19 | Non-Additive |
| 4 | Number of internodes | 11.25 | 13.23 | 75.52 | 0.02 | 2.97 | Non-Additive |
| 5 | Number of branches | 2.83 | 23.15 | 74.02 | 0.01 | 0.93 | Non-Additive |
| 6 | Fruit length (maturity) | 18.63 | 5.47 | 75.90 | 0.01 | 1.65 | Non-Additive |
| 7 | Fruit length (harvest) | 29.14 | 16.76 | 54.09 | 0.10 | 5.94 | Non-Additive |
| 8 | Number of fruits plant$^{-1}$ | 10.44 | 8.81 | 80.75 | 0.00 | 0.08 | Non-Additive |
| 9 | Number of seeds fruit$^{-1}$ | 7.26 | 3.19 | 89.55 | 0.06 | 2.22 | Non-Additive |
| 10 | 100 seed weight | 47.79 | 9.54 | 42.67 | 0.03 | 0.88 | Non-Additive |
| 11 | Fruit weight | 18.07 | 26.75 | 55.19 | 0.02 | 1.24 | Non-Additive |
| 12 | Yield plant$^{-1}$ | 23.37 | 23.16 | 53.46 | 39.30 | 2345.97 | Non-Additive |

than unity. Therefore, all the traits studied showed non-additive type of gene action. The trait, yield is under the control of multiple genes and is expressed in a complex manner. Understanding the action of genes is essential for breeders to select the optimal breeding techniques and ultimately enhance the crop's yield and yield-contributing characteristics. Three types of gene actions, including additive, dominance and epistasis, determine character expression. In cases where additive gene action is predominant, crop improvement selection methods are recommended. On the other hand, dominance and epistasis gene actions are associated with allelic and non-allelic gene interactions. In such situations, developing composite varieties or exploiting heterosis can prove beneficial. Similar conclusions highlighting the presence of non-additive gene action for most characteristics were also reported by Chaudhary *et al.* (2023), Pithiya *et al.* (2020), Abinaya *et al.* (2020) and Patel *et al.* (2021) regarding the inheritance of major yield and yield-contributing characters. The study emphasizes the predominant role of gene action which suggest the feasibility of exploitation of heterosis as per Kumar *et al.* (2023).

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