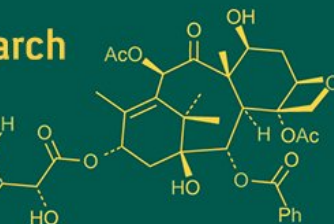
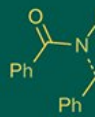


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## Combining ability and gene action analysis for okra fruit yield and its component traits

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### Abstract

The study involved seven female parents and four male parents which were crossed following a line  $\times$  tester mating scheme to produce 28 experimental hybrids. In addition, GJOH-4 was included as the standard check hybrid for comparison. All experimental materials were evaluated during the *kharif* season of 2025 at VRS, JAU, Junagadh. The experiment was conducted using a randomized block design with three replications to determine the combining ability of the parental lines and their respective hybrids in okra.

The analysis of variance for combining ability revealed that the mean squares associated with the lines were significant across all the traits in comparison with the error mean square. Likewise, testers displayed significant mean squares for every character demonstrating that both female and male parents played an important role in generating the observed variability. The line  $\times$  tester interaction was also significant for all the traits indicating the importance of specific parental combinations in trait expression. The ratio of general combining ability (GCA) variance to specific combining ability (SCA) variance indicated that non-additive gene action was predominant for most of the traits. However, additive gene effects appeared to be more important for days to first flowering, days to first picking, days to last picking, number of pickings and total fruit yield per plant. None of the parents showed desirable gca effects consistently across all the traits. For total fruit yield per plant, the female parents JOL-12-13 and JOL-21-106 along with the male parent GJO-3 were identified as promising general combiners. Among the hybrids, JOL-22-17  $\times$  GJO-3 recorded the highest positive sca effect for total fruit yield per plant, followed by AOL-22-16  $\times$  KS-404, JOL-21-106  $\times$  GAO-8 and AOL-22-16  $\times$  Kashi Lalima.

**Keywords:** Okra, Line  $\times$  tester analysis, gene action, combining ability

### Introduction

Okra is an economically important vegetable crop of tropical and subtropical regions and member of the family Malvaceae. India is among the leading countries contributing significantly to worldwide okra production. It is a warm-season annual crop propagated through seeds exhibits an indeterminate growth habit and chromosome number is  $2n = 130$  (Dutta and Naug, 1968) [3]. Okra is primarily cultivated for its tender green fruits, which are consumed as a vegetable and are mainly marketed fresh although they are also processed through canning and dehydration. The characteristic mucilage present in the fruits is valued in various culinary preparations as a natural thickening agent. Owing to its adaptability, high dietary fibre content and favourable seed protein composition, particularly the presence of lysine and tryptophan. okra is often regarded as an ideal vegetable for rural communities. Okra is grown extensively in both the *kharif* and summer seasons. Combining ability analysis serves as an effective approach for evaluating the breeding potential of parental genotypes and selecting promising parents for hybridization programmes. It also helps in identifying superior hybrid combinations that can be utilized for commercial production through heterosis breeding. In addition, knowledge of the type and extent of gene action controlling yield and its associated traits is essential for designing effective breeding strategies aimed at improving productivity and other desirable characteristics in okra.

### Materials and Methods

The study utilized seven female lines JOL-24-108, JOL-24-113, JOL-21-106, JOL-12-13, AOL-22-16, SKNOL-23-03 and JOL-22-17 and four male testers namely GJO-3, Kashi

Lalima, GAO-8 and KS-404. These parents were crossed following a line  $\times$  tester mating design to generate 28  $F_1$  hybrids with GJOH-4 included as the standard check hybrid for comparison. The experimental materials were evaluated during *khariif* 2025 at the VRS, JAU, Junagadh following with three replications in randomized block design (RBD). A spacing of 60 cm between rows and 30 cm between plants was maintained. All recommended agronomic practices suitable for the region were adopted to ensure proper crop growth and development. Data were recorded from five plants selected randomly from each experimental plot except for traits measured on a plot basis. A total of 12 characters were studied, namely nodal position of first flowering, days to first flowering, days to first picking, plant height (cm), number of primary branches per plant, number of fruits per plant, fruit length (cm), fruit girth (cm), average fruit weight (g), days to last picking, number of pickings and total fruit yield per plant (g). The mean values obtained for each trait were subjected to appropriate statistical analysis. The total variation observed among the  $F_1$  hybrids was further partitioned into components attributable to lines, testers, and line  $\times$  tester interactions, which were used for estimating combining ability effects following the procedure described by (Kempthorne, 1957) [3].

## Results and Discussion

The combining ability analysis revealed significant mean square values for lines across all the traits studied. Similarly, significant differences were observed for testers as well as for line  $\times$  tester interactions indicating the presence of substantial variation among the parental components and their hybrid combinations for all the characters evaluated. These results demonstrated that both female and male parents as well as their interactions contributed significantly to the total genetic variation. The GCA to SCA variance ratio suggested that non-additive genetic effects played a major role in controlling the expression of most of the traits evaluated whereas additive effects were relatively more important for days to first flowering, days to first picking, days to last picking, number of pickings and total fruit yield per plant (g). (Table 1)

The parental genotypes were evaluated for their general combining ability to identify those with greater potential to contribute desirable genes to their offspring. However, no single parent showed superior gca effects consistently across all the traits examined. However, among the female parents, JOL-12-13 and JOL-21-106 and among the male parents, GJO-3 were identified as good general combiners for total fruit yield per plant. (Table 2)

Among the parental lines evaluated JOL-12-13 emerged as the most promising general combiner showing favourable gca effects for a number of traits including days to first flowering, days to first picking, plant height (cm), number of fruits per plant, average fruit weight (g), number of pickings and total fruit yield per plant (g). The female line JOL-21-106 demonstrated favourable general combining ability for nodal position of first flowering, fruits per plant, days to last picking, number of pickings and total fruit yield per plant (g). Among the male testers, GJO-3 showed desirable gca effects for nodal position of first flowering, number of primary branches per plant, fruits per plant,

average fruit weight (g), days to last picking, number of pickings and total fruit yield per plant (g) (Table 2). These findings indicate that the parents with superior gca for fruit yield also exhibited favourable combining ability for several important yield-associated traits highlighting their usefulness as promising parents in future hybridization and crop improvement programmes. These results are in agreement with the findings of Lyngdoh *et al.* (2017) [7], Makdooi *et al.* (2018) [8], Padadalli *et al.* (2019) [10], Abinaya *et al.* (2020) [1], Kalaiselvan and Anuja (2021) [4], Subhakar *et al.* (2022) [12], Ranjani *et al.* (2023) [11], Pathania *et al.* (2024) [9] and Keerthana *et al.* (2025) [6] in okra.

Among the 28  $F_1$  combinations assessed, JOL-22-17  $\times$  GJO-3 recorded the most favourable positive sca effect for fruit yield per plant followed by AOL-22-16  $\times$  KS-404, JOL-21-106  $\times$  GAO-8 and AOL-22-16  $\times$  Kashi Lalima. In addition to yield the cross JOL-22-17  $\times$  GJO-3 showed significant and desirable sca effects for nodal position of first flowering, number of fruits per plant, fruit length (cm), average fruit weight (g), days to last picking, number of pickings and total fruit yield per plant (g). The superior performance of this hybrid involved parental lines possessing average to good gca for fruit yield per plant suggesting its potential for further evaluation and utilization in okra breeding.

AOL-22-16  $\times$  KS-404 ranked second for positive sca effects for fruit yield per plant and involved parents with poor gca for this trait. Nevertheless, the hybrid exhibited significant and favourable sca effects for plant height (cm), number of primary branches per plant, number of fruits per plant, fruit length (cm) and total fruit yield per plant (g). This indicates that even parents with low general combining ability can produce superior hybrid combinations through favourable specific combining interactions.

JOL-21-106  $\times$  GAO-8 ranked third for positive sca effect for total fruit yield per plant and represented a good  $\times$  poor gca parental combination. The hybrid also showed significant and desirable sca effects for number of primary branches per plant, number of fruits per plant and total fruit yield per plant (g) indicating its potential for further consideration in okra improvement programmes.

AOL-22-16  $\times$  Kashi Lalima ranked fourth in terms of favourable sca effect for fruit yield per plant and involved two parents with poor gca for the trait. Besides yield the hybrid exhibited significant positive sca effects for fruit girth (cm), average fruit weight (g) and number of pickings. JOL-24-108  $\times$  KS-404 occupied the fifth position for positive sca effect and represented an average  $\times$  poor gca parental combination. This cross also recorded significant and desirable sca effects for number of primary branches per plant, days to last picking, number of pickings and total fruit yield per plant (g). (Table 3).

However, Chaudhary *et al.* (1974) [2] stated that a high sca effect does not necessarily indicate superior hybrid performance suggesting that sca estimates alone may have limited value in identifying promising crosses. Therefore, the choice of parents for future breeding programmes should primarily consider their gca effects. At the same time the actual mean performance of the hybrids should be given appropriate importance when selecting crosses with desirable specific combining ability.

**Table 1:** Analysis of variance presenting mean squares for combining ability and variance components of various traits in okra

| Source                           | d. f. | Nodal position for first flowering | Days to first flowering | Days to first picking | Plant height (cm) | Number of Primary branches per plant | Number of fruits per plant |
|----------------------------------|-------|------------------------------------|-------------------------|-----------------------|-------------------|--------------------------------------|----------------------------|
| Replications                     | 2     | 0.29*                              | 1.15                    | 1.08                  | 8.42              | 0.01                                 | 0.33                       |
| Lines                            | 6     | 4.40** + +                         | 40.72** + +             | 48.52** + +           | 601.07** +        | 0.57**                               | 7.77**                     |
| Testers                          | 3     | 10.33** + +                        | 76.10** + +             | 90.21** + +           | 1095.21** + +     | 3.24** +                             | 55.80** + +                |
| Lines x Testers                  | 18    | 0.46**                             | 5.25*                   | 5.61*                 | 192.97**          | 0.66**                               | 5.87**                     |
| Error                            | 54    | 0.07                               | 2.78                    | 2.63                  | 32.58             | 0.06                                 | 0.80                       |
| $\sigma^2_l$                     | -     | 0.36**                             | 3.16**                  | 3.82**                | 47.37*            | 0.04                                 | 0.58                       |
| $\sigma^2_t$                     | -     | 0.49**                             | 3.49**                  | 4.17**                | 50.60**           | 0.15*                                | 2.62**                     |
| $\sigma^2_{lt} (\sigma^2_{sca})$ | -     | 0.13**                             | 0.82*                   | 1.00*                 | 53.46**           | 0.20**                               | 1.69**                     |
| $\sigma^2_{gca}$                 | -     | 0.44**                             | 3.37**                  | 3.86**                | 49.42**           | 0.11**                               | 1.57*                      |
| $\sigma^2_{gca}/\sigma^2_{sca}$  | -     | 3.39                               | 4.10                    | 3.86                  | 0.92              | 0.55                                 | 0.93                       |

| Source                           | d. f. | Fruit length (cm) | Fruit girth (cm) | Average fruit weight (g) | Days to last picking | Number of pickings | Total fruit yield per plant (g) |
|----------------------------------|-------|-------------------|------------------|--------------------------|----------------------|--------------------|---------------------------------|
| Replications                     | 2     | 0.28              | 0.01             | 196.85                   | 0.37                 | 0.80               | 261.86                          |
| Lines                            | 6     | 1.68**            | 0.22** +         | 802.97**                 | 111.52** + +         | 12.01** +          | 2529.31** +                     |
| Testers                          | 3     | 8.62**            | 0.14**           | 2717.04** + +            | 532.35** + +         | 53.60** + +        | 20625.21** + +                  |
| Lines x Testers                  | 18    | 3.57**            | 0.07**           | 436.56**                 | 22.94**              | 3.96**             | 761.43**                        |
| Error                            | 54    | 0.52              | 0.02             | 95.34                    | 3.52                 | 0.90               | 166.04                          |
| $\sigma^2_l$                     | -     | 0.10              | 0.02*            | 58.97                    | 9.00**               | 0.93*              | 196.94*                         |
| $\sigma^2_t$                     | -     | 0.39              | 0.01             | 124.84**                 | 25.18**              | 2.51**             | 974.25**                        |
| $\sigma^2_{lt} (\sigma^2_{sca})$ | -     | 1.02**            | 0.02**           | 113.74**                 | 6.47**               | 1.02**             | 198.46**                        |
| $\sigma^2_{gca}$                 | -     | 0.10              | 0.01             | 80.21**                  | 18.12**              | 1.75**             | 655.50**                        |
| $\sigma^2_{gca}/\sigma^2_{sca}$  | -     | 0.09              | 0.50             | 0.71                     | 2.80                 | 1.71               | 3.30                            |

\*, \*\* Significant at 5% and 1% levels, respectively, when tested against error mean square.

+, + Significant at 5% and 1% levels, respectively, when tested against lines × testers interaction means, respectively

**Table 2:** Estimation of general combining ability effects of parents for various traits in okra

| Sr. No.        | Parents      | Nodal position for first flowering | Days to first flowering | Days to first picking | Plant height (cm) | Number of Primary branches per plant | Number of fruits per plant | Fruit length (cm) |
|----------------|--------------|------------------------------------|-------------------------|-----------------------|-------------------|--------------------------------------|----------------------------|-------------------|
| <b>Lines</b>   |              |                                    |                         |                       |                   |                                      |                            |                   |
| 1              | JOL-24-108   | -0.03                              | -1.96**                 | -1.45**               | 2.07              | 0.23**                               | -0.68*                     | -0.39             |
| 2              | JOL-24-113   | 0.50**                             | 0.12                    | 0.80                  | 7.08**            | 0.14*                                | 0.06                       | 0.19              |
| 3              | JOL-21-106   | -0.31**                            | 0.70                    | 0.05                  | -8.70**           | -0.06                                | 0.60*                      | 0.41              |
| 4              | JOL-12-13    | 0.64**                             | -2.88**                 | -3.54**               | 9.20**            | 0.03                                 | 1.17**                     | -0.58**           |
| 5              | AOL-22-16    | -1.13**                            | 0.12                    | -0.04                 | -6.82**           | -0.42**                              | -1.27**                    | -0.13             |
| 6              | SKNOL-23-03  | -0.06                              | 2.12**                  | 1.71**                | -5.62**           | -0.07                                | -0.10                      | 0.18              |
| 7              | JOL-22-17    | 0.40**                             | 1.79**                  | 2.46**                | 2.78              | 0.16*                                | 0.22                       | 0.32              |
|                | SE±          | 0.08                               | 0.48                    | 0.47                  | 1.65              | 0.07                                 | 0.26                       | 0.21              |
| <b>Testers</b> |              |                                    |                         |                       |                   |                                      |                            |                   |
| 1              | GJO-3        | -0.47**                            | 1.76**                  | 1.55**                | 0.64              | 0.13*                                | 2.37**                     | -0.05             |
| 2              | Kashi Lalima | 0.82**                             | -2.38**                 | -2.83**               | 8.90**            | 0.40**                               | -0.49*                     | 0.91**            |
| 3              | GAO-8        | 0.34**                             | 1.29**                  | 1.55**                | -0.81             | 0.01                                 | -1.35**                    | -0.30             |
| 4              | KS-404       | -0.69**                            | -0.67                   | -0.26                 | -8.73**           | -0.54**                              | -0.54**                    | -0.56**           |
|                | SE±          | 0.06                               | 0.36                    | 0.35                  | 1.25              | 0.05                                 | 0.20                       | 0.16              |

\*, \*\* significant at 5% and 1% levels, respectively.

| Sr. No.        | Parents      | Fruit length (cm) | Fruit girth (cm) | Average fruit weight (g) | Days to last picking | Number of pickings | Total fruit yield per plant (g) |
|----------------|--------------|-------------------|------------------|--------------------------|----------------------|--------------------|---------------------------------|
| <b>Lines</b>   |              |                   |                  |                          |                      |                    |                                 |
| 1              | JOL-24-108   | -0.39             | -0.08*           | 0.68                     | -1.80**              | -0.10              | -6.74                           |
| 2              | JOL-24-113   | 0.19              | 0.06             | 4.88                     | 0.54                 | -0.35              | 4.70                            |
| 3              | JOL-21-106   | 0.41              | -0.06            | -0.77                    | 5.20**               | 0.90**             | 14.58**                         |
| 4              | JOL-12-13    | -0.58**           | 0.29**           | 14.44**                  | -4.63**              | 1.74**             | 16.57**                         |
| 5              | AOL-22-16    | -0.13             | -0.03            | -8.45**                  | 0.12                 | -1.26**            | -25.92**                        |
| 6              | SKNOL-23-03  | 0.18              | -0.06            | -9.78**                  | 1.62**               | -0.51              | -5.67                           |
| 7              | JOL-22-17    | 0.32              | -0.11**          | -1.01                    | -1.05                | -0.43              | 2.48                            |
|                | SE±          | 0.21              | 0.04             | 2.82                     | 0.54                 | 0.27               | 3.72                            |
| <b>Testers</b> |              |                   |                  |                          |                      |                    |                                 |
| 1              | GJO-3        | -0.05             | 0.08**           | 15.48**                  | 7.05**               | 2.07**             | 46.68**                         |
| 2              | Kashi Lalima | 0.91**            | 0.04             | -11.29**                 | -4.62**              | -1.74**            | -16.75**                        |
| 3              | GAO-8        | -0.30             | -0.10**          | 0.39                     | -0.19                | -0.55**            | -10.53**                        |
| 4              | KS-404       | -0.56**           | -0.02            | -4.58*                   | -2.24**              | 0.21               | -19.40**                        |
|                | SE±          | 0.16              | 0.03             | 2.13                     | 0.41                 | 0.21               | 2.81                            |

\*, \*\* significant at 5% and 1% levels, respectively.

**Table 3:** Top five superior cross combinations based on sca effects for fruit yield per plant along with desirable sca effects for yield contributing traits and gca effects of their parents in okra

| Crosses                  | sca effect for fruit yield per plant | Fruit yield per plant (g) | gca effect for fruit yield per plant |              | Heterosis (%) over |                         | Significant desirable sca effects for component traits |
|--------------------------|--------------------------------------|---------------------------|--------------------------------------|--------------|--------------------|-------------------------|--------------------------------------------------------|
|                          |                                      |                           | Lines                                | Testers      | Better parent      | Standard check (GJOH-4) |                                                        |
| JOL-22-17 × GJO-3        | 24.19**                              | 254.43                    | 2.48(A)                              | 46.68**(G)   | 20.07*             | 45.33**                 | 1, 6, 7, 9, 10, 11, 12                                 |
| AOL-22-16 × KS-404       | 22.29**                              | 158.05                    | -25.92** (P)                         | -19.40** (P) | -10.40             | -9.72                   | 4, 5, 6, 7, 12                                         |
| JOL-21-106 × GAO-8       | 21.27**                              | 206.40                    | 14.58** (G)                          | -10.53** (P) | 11.69*             | 17.90**                 | 5, 6, 10, 11, 12                                       |
| AOL-22-16 × Kashi Lalima | 20.20**                              | 158.61                    | -25.92** (P)                         | -16.75** (P) | 0.94               | -9.40                   | 1, 8, 9, 11, 12                                        |
| JOL-24-108 × KS-404      | 15.16*                               | 170.11                    | -6.74(A)                             | -19.40** (P) | -3.95              | -2.83                   | 5, 10, 11, 12                                          |

\*, \*\* significant at 5% and 1% levels, respectively.

|    |   |                                    |    |   |                               |    |   |                                 |
|----|---|------------------------------------|----|---|-------------------------------|----|---|---------------------------------|
| 1  | = | Nodal position for first flowering | 2  | = | Days to first flowering       | 3  | = | Days first picking              |
| 4  | = | Plant height (cm)                  | 5  | = | No. of primary branches/plant | 6  | = | Number of fruits per plant      |
| 7  | = | Fruit length (cm)                  | 8  | = | Fruit girth (cm)              | 9  | = | Average fruit weight            |
| 10 | = | Days to last picking               | 11 | = | Number of pickings            | 12 | = | Total fruit yield per plant (g) |

## Conclusion

The present study revealed significant line × tester effects for all the traits investigated highlighting the importance of specific parental interactions in influencing hybrid performance. The findings also indicated a considerable contribution of non-additive genetic effects to the inheritance of several traits. The GCA to SCA variance ratio suggested that non-additive gene action was predominant for most characters while additive effects appeared to have greater importance for days to first flowering, days to first picking, days to last picking, number of pickings and total fruit yield per plant (g). Considering the overall performance, five hybrids JOL-22-17 × GJO-3, AOL-22-16 × KS-404, JOL-21-106 × GAO-8, AOL-22-16 × Kashi Lalima, and JOL-24-108 × KS-404 were identified as promising combinations exhibiting significant and favourable sca effects for fruit yield per plant as well as for several yield-associated traits. These hybrids could be evaluated further under diverse environments and over multiple seasons to determine their stability and potential for commercial use through heterosis breeding. In addition, the identified crosses may serve as valuable material in future breeding programmes for obtaining desirable segregants and developing superior, high-yielding inbred lines.

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