

# Combining Ability Studies in Okra (*Abelmoschus esculentus* L.): Understanding Genetic Architecture for Better Breeding

**Kailash Ram**

Assistant Professor, Ag. Botany

Government Degree College, Jakhini, Varanasi, UP, India

**Abstract:** Okra (*Abelmoschus esculentus* L.) stands as one of the most valuable vegetables which people cultivate during warm seasons throughout tropical and subtropical regions. Breeding programs need to establish base genetic knowledge about parental gene interactions to achieve successful results in both yield and quality development. The article analyzes okra research through combining ability study methods which use general combining ability and specific combining ability to identify superior parent plants and hybrid combinations. Researchers discovered through their diallel and line  $\times$  tester crossing systems that both additive and non-additive gene actions control important traits such as fruit yield, days to first flowering, plant height, and fruit length. The relative importance of each gene action varies by trait and environment. Breeders who understand these patterns can make smarter decisions about which parents to cross, which hybrids to develop, and which selection strategies to adopt. The article investigates how combining ability research impacts both hybrid seed programs and population improvement programs which focus on okra development.

**Keywords:** combining ability, specific combining ability, gene action, okra, general combining ability, diallel analysis

## I. INTRODUCTION

Okra appears in kitchen gardens across South Asia and West Africa and the American South because it grows as a tall and resilient plant that produces crops throughout extreme heat. The plant is known by different names depending on the region which include lady's finger and bhindi and gumbo. The crop exists in multiple regions worldwide where it occupies millions of hectares and serves as a vital dietary element for hundreds of millions of people. The pods contain high amounts of fiber and folate and vitamins C and K and different antioxidants. Okra serves an essential function in small-scale agricultural systems because it enables farmers to achieve immediate financial gains with minimal resource requirements.

The developing regions of the world face an ongoing problem because okra production levels remain below their maximum potential despite its critical value. The agricultural system faces multiple problems because farmers cultivate local plant varieties which lack improvement and they experience high levels of disease and they cannot access quality seeds. Plant breeders have been working for decades to develop better varieties but okra breeding presents complex challenges. The species reproduces through cross-pollination which leads to high genetic diversity and breeders cannot achieve better results by choosing the best plants from a population.

The real value of ability studies appears at this point of research. Breeders use systematic parent cross testing to assess hybrid results and develop statistical methods that identify general trait inheritance patterns of parents who pass on beneficial traits. The breeding process receives direct assistance from these insights because they eliminate the need for time-consuming resource-intensive experimental procedures which take several years to complete. The article explains



combining ability analysis and its application in okra breeding research while showing its scientific findings and future benefits for agricultural advancement.

## **II. WHAT IS COMBINING ABILITY? A CONCEPTUAL OVERVIEW**

### **2.1 General vs. Specific Combining Ability**

Sprague and Tatum established their concept of combining ability in 1942, which continues to serve as a vital tool for practical use in plant breeding today. The analysis of combining ability requires researchers to answer a fundamental question about parent combinations which produce successful offspring and which specific combinations show exceptional results. The general combining ability GCA of a parent indicates its typical output across all hybrid combinations which include that parent. A parent with high GCA for fruit yield, for example, tends to produce above-average yields regardless of which other parent it is crossed with.

The typical performance pattern of this type of genetic material occurs through additive gene action because genetic elements produce predictable results which combine their individual impacts. The heritable nature of additive effects makes GCA an essential tool for selecting parents during open pollinated variety development and recurrent selection programs.

SCA, on the other hand, captures something more unpredictable. The system evaluates how two parents work together beyond their regular performance which GCA calculation establishes. The combination of two parents might result in a cross which performs better than both parents because hybrid vigor — also known as heterosis — occurs or it might produce lower results. The SCA connects to non-additive genetic processes which include dominance and epistasis. Breeders focus on high SCA crosses because they serve as the foundation for commercial hybrid development.

### **2.2 The Genetic Basis**

When researchers find that GCA variance is significantly larger than SCA variance for a given trait, it tells them that additive gene action is dominant. This has a direct implication: selection in early generations should work well, and population improvement methods like recurrent selection are appropriate. When SCA variance is larger, non-additive effects matter more, and hybrid breeding becomes the preferred strategy.

In okra, both types of gene action have been reported across different traits and experimental conditions, which is part of what makes this crop so interesting to study genetically. No single breeding approach fits all traits or all environments.

## **III. METHODS USED TO STUDY COMBINING ABILITY IN OKRA**

### **3.1 Diallel Cross Analysis**

Researchers use the diallel cross method as their primary experimental design which they apply to study okra plant breeding. The full diallel method establishes complete hybrid combinations through parent crossbreeding with all other parents. You obtain 15 cross combinations when you have six parents because you must exclude the reciprocal pairs while including the six parents. The researchers conduct replicated field trials to grow all entries and assess their specific traits.

The statistical analysis follows methods developed by Griffing (1956) which enable researchers to divide entry variation into GCA effects which result from individual parents and SCA effects which arise from specific cross combinations. The Griffing method presents four models which determine whether parental and reciprocal data should be included in the analysis. Method 2 (parents and one set of crosses, no reciprocals) and Method 4 (one set of crosses only) are the most commonly used in okra research.

The Hayman (1954) approach is preferred by some researchers because it employs graphical analysis of variance-covariance relationships to determine dominance and additive components from diallel data. This approach adds a visual dimension to the analysis and allows breeders to estimate heritability and the degree of dominance.



### 3.2 Line × Tester Analysis

The line × tester analysis design which Kempthorne introduced in 1957 remains popular among researchers. The researchers cross a group of female lines with a smaller group of male testers. The method provides cost savings because it requires fewer resources than a complete diallel test when multiple parents need to be examined. The researchers conduct field trials to evaluate the crosses while the data analysis process estimates the general combining ability of lines and testers and the specific combining ability of each line and tester pair.

Researchers have used Line × tester analysis in okra studies to evaluate multiple parental lines before conducting more costly complete diallel tests. The method works best during the initial phase of hybrid breeding programs which require selection of several top candidates from a big group of potential parents.

The standard experimental procedure for okra combining ability studies begins with selecting parents and then moves through the stages of crossing and field evaluation and statistical analysis until breeding decisions are made based on the results.

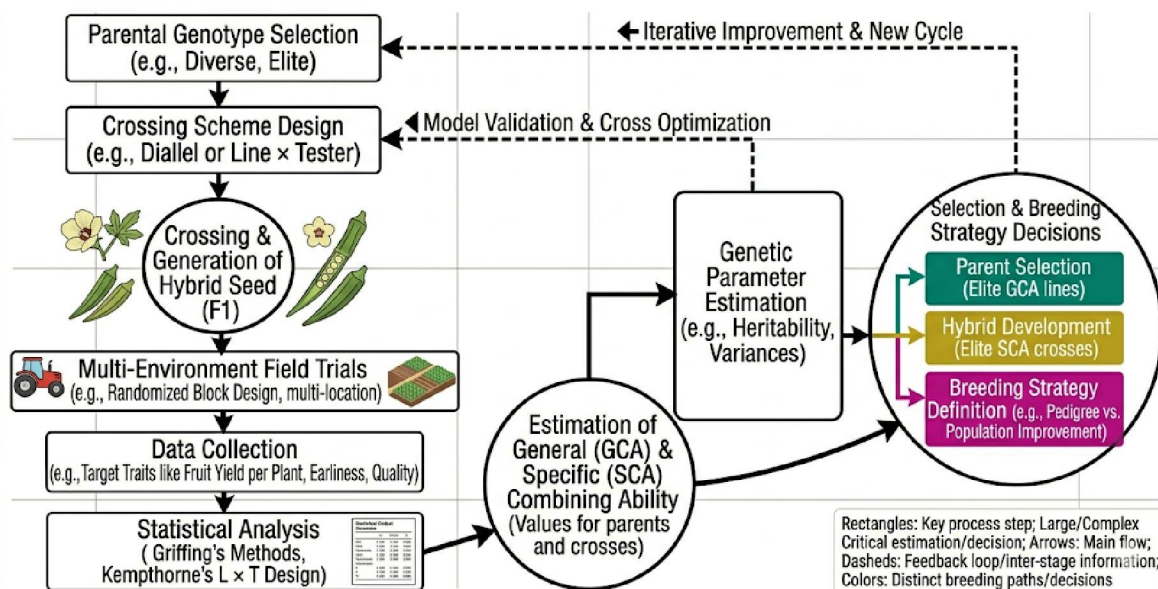


Figure: Experimental Workflow for Combining Ability Studies in Okra

The flowchart shows how researchers conduct a combining ability study in okra which starts with choosing different parental genotypes and continues through the design of crossing schemes which include diallel and line × tester methods and hybrid seed production and multi-environment field testing and target trait data collection and statistical analysis which uses Griffing's or Kempthorne's method. The final stage shows how GCA and SCA estimates feed into parent selection, hybrid development, and breeding strategy decisions. The diagram shows how the process works in a repeated cycle because arrows show how people in the process review their findings to choose their next steps.

## IV. KEY TRAITS STUDIED IN OKRA COMBINING ABILITY RESEARCH

### 4.1 Fruit Yield and Yield Components

The most critical characteristic for commercial okra breeding research is fruit yield per plant which scientists have studied through their work on combining ability research. The research results from different research teams show conflicting results which provide valuable information about the study subject.

Non-additive gene action dominates fruit yield because several studies found that SCA variance exceeds GCA variance for fruit yield. The parent performance does not determine all superior crosses which produce better results than their



parent plants. Reddy *et al.* (2013) found high SCA effects for fruit yield in several specific cross combinations, with the best hybrids showing substantial heterosis over their parents. The researchers discovered similar results when they examined West African okra germplasm according to their study findings.

The studies demonstrate GCA effects which show that certain parents provide better yield results throughout different cross combinations. The study results show that additive gene control operates in this system which enables successful selection methods during segregating generation selection. The apparent contradiction between studies is not really a contradiction — it reflects differences in genetic material used, environments tested, and the specific traits measured.

#### **4.2 Days to First Flowering**

Growers prefer early flowering in okra because it enables them to produce more crops throughout each growing season. Studies on combining ability have determined that first flowering onset occurs due to additive gene action because GCA effects have greater influence on this trait than SCA effects. The selection process allows for reliable early flowering improvements because low GCA parents, who contribute to earliness, serve as essential breeding resources in crossing programs.

The researchers observed that GCA showed greater significance than SCA for flowering time in their diallel study according to their report about GCA which identified multiple parents that produced early-flowering offspring with low values across all cross partners.

#### **4.3 Plant Height and Stem Girth**

The structural characteristics of plant height and stem girth determine both agricultural yield and farming operational efficiency. Plants of greater height develop increased numbers of nodes which results in greater fruit production, yet extreme height in plants increases their risk of falling. Studies on combining ability demonstrate mixed gene action for these traits, while certain crosses exhibit unanticipated heterosis for plant height.

The trait of stem girth demonstrates a strong relationship to plant vigor and drought resistance according to most studies which show that its additive effects create a simple method for conventional selection.

#### **4.4 Fruit Characteristics**

The market acceptability of a product depends on the combination of fruit length, fruit diameter, number of ridges, and pod weight. Consumers in most markets prefer medium-length, straight, tender pods with a deep green color. The research on combining ability has shown that fruit length and pod weight have GCA effects which breeders can use to select their breeding partners. The SCA effects of fruit color and texture show greater strength than parent performance testing thus specific cross combinations need evaluation.

### **V. NOTABLE FINDINGS FROM RESEARCH STUDIES**

#### **5.1 Evidence of Hybrid Vigor in Okra**

The research studies about combining ability have shown that okra exhibits strong hybrid vigor which results in significant heterosis across multiple essential characteristics. The most significant hybrid results occur when genetically distinct parents crossbreed because these parents originate from separate geographical areas and different botanical groups.

The researchers studied eight okra genotypes through a diallel study which revealed that multiple  $F_1$  hybrids showed positive heterosis for fruit yield. The study results confirmed that the SCA effects of high-yielding crosses showed strong positive results because non-additive gene action produced performance enhancements. The findings of this study produce important results for business purposes. The development of  $F_1$  hybrid varieties becomes economically beneficial when hybridization achieves a 30% yield increase which occurs without any costs of seed production exceeding those of open-pollinated varieties.



### 5.2 Identifying Superior Parents

Researchers in combining ability studies aim to identify parental pairs with superior general combining ability through their studies which have discovered reliable genotypes that demonstrate high combining ability. What defines an effective general combiner? A genotype that already shows strong performance for a specific trait becomes a suitable general combiner when it possesses advantageous alleles that exist in a mostly homozygous state which results in their stable inheritance through the next generation.

Research across different okra-growing regions has identified certain varieties — often older, widely adapted cultivars like Pusa Sawani in India or Clemson Spineless in North America — as good general combiners for yield-related traits. These varieties may not always have the highest yield potential, but they consistently improve the performance of their cross partners.

### 5.3 The Role of Environment

The value of combining ability testing shows hidden merit because GCA and SCA results function as variable effects which shift according to different environmental conditions. A parent that is a good general combiner in one location or growing season may not perform as consistently in another. Hybrid development faces challenges because of genotype-by-environment interaction yet this interaction provides research opportunities. Researchers developed a hybrid for late-season production and drought-prone areas which can be improved through location-specific combining ability data.

The researchers Singh and Singh (2006) established that multi-location trials serve as essential methods for okra combining ability analysis in South Asian regions which experience extreme agroclimatic changes across short distances.

## VI. CONCLUSION

The okra breeding process benefits from combining ability analysis which serves as an effective breeding tool that provides essential information to breeders. The method enables accurate prediction of hybrid development results because it identifies which parental lines exhibit preferred genetic traits and which specific cross combinations produce superior hybrid results.

The accumulated evidence from decades of research tells a nuanced story. The genetically driven traits of early flowering and fruit length show traditional selection methods work because they depend on additive gene effects. The genetic makeup of fruit yield includes non-additive genetic components which make hybrid breeding the most effective method to achieve improvements. The choice between breeding methods should depend on the particular trait requirements and environmental conditions and the available germplasm and the real-world needs for producing and sending seed to different locations.

Okra demonstrates actual potential to achieve major yield increases when researchers use combining ability information in their studies. Research programs that screen diverse global germplasm, conduct multi-environment trials, and integrate molecular tools with classical quantitative genetics will be best positioned to develop the next generation of high-performing okra varieties. The investment in research holds complete value because the crop offers essential nutrients while serving as a vital component for food security throughout tropical and subtropical regions.

## REFERENCES

- [1]. Adeniji, O. T. and Kehinde, O. B. (2008). Genetic analysis of fruit yield and yield components in West African okra (*Abelmoschus caillei*). *Journal of Plant Breeding and Crop Science*, 1(1): 14–22.
- [2]. Akotkar, P. K.; De, D. K. and Pal, A. K. (2010). Genetic variability and diversity in okra (*Abelmoschus esculentus* L. Moench). *Electronic Journal of Plant Breeding*, 1(4): 393–398.
- [3]. Amoatey, H. M. and Klu, G. Y. P. (2000). Genetic control of some yield characters in okra (*Abelmoschus esculentus* L. Moench). *Bulletin of Science and Technology*, 16(2): 71–76.



- [4]. Bendale, V. W.; Kadam, S. R.; Bhawe, S. G.; Pethe, U. B. and Mehta, J. L. (2003). Combining ability studies in okra. *Journal of Maharashtra Agricultural Universities*, 28(2): 133–136.
- [5]. Dhankar, S. K. and Dhankar, B. S. (2005). Combining ability analysis in okra (*Abelmoschus esculentus* L. Moench). *Haryana Journal of Horticultural Sciences*, 34(3–4): 235–238.
- [6]. Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences*, 9(4): 463–493. <https://doi.org/10.1071/BI9560463>
- [7]. Hayman, B. I. (1954). The theory and analysis of diallel crosses. *Genetics*, 39(6): 789–809. <https://doi.org/10.1093/genetics/39.6.789>
- [8]. Joshi, A. B. and Hardas, M. W. (2002). Allopolyploid origin of okra, *Abelmoschus esculentus* L. Moench. *Nature*, 198(4880): 601–602.
- [9]. Kempthorne, O. (1957). *An introduction to genetic statistics*. John Wiley & Sons.
- [10]. Kumar, S.; Reddy, M. T.; Reddy, K. R. and Begum, H. (2014). Combining ability analysis for yield and its components in okra (*Abelmoschus esculentus* L. Moench). *SABRAO Journal of Breeding and Genetics*, 46(2): 243–257.
- [11]. Lal, H.; Rai, M. and Kumar, R. (2011). Combining ability and gene action studies for quality and yield traits in okra. *Indian Journal of Horticulture*, 68(3): 374–378.
- [12]. Mishra, R. K. and Mishra, S. P. (2009). Diallel analysis for combining ability in okra under different environments. *Vegetable Science*, 36(1): 83–86.
- [13]. Nwangburuka, C. C.; Kehinde, O. B.; Ojo, D. K.; Denton, O. A. and Popoola, A. R. (2012). Heritability, character association and path coefficient analysis in six agronomic and yield related characters in leaf okra (*Abelmoschus caillei*). *Asian Journal of Agricultural Research*, 6(1): 28–36. <https://doi.org/10.3923/ajar.2012.28.36>
- [14]. Partap, S.; Singh, D. K. and Pal, V. (2016). Genetic analysis of yield and its component traits in okra (*Abelmoschus esculentus* L. Moench). *International Journal of Vegetable Science*, 22(4): 366–372. <https://doi.org/10.1080/19315260.2015.1023253>
- [15]. Reddy, M. T.; Babu, K. H.; Ganesh, M.; Reddy, C. K.; Begum, H.; Reddy, R. S. K. and Babu, J. D. (2013). Exploitation of hybrid vigor for yield and its components in okra (*Abelmoschus esculentus* L. Moench). *SABRAO Journal of Breeding and Genetics*, 45(3): 470–479.
- [16]. Shah, S. M. A.; Rahman, H. and Khalil, I. H. (2010). Combining ability analysis for grain yield and other traits in maize and its implications for okra cross-system adaptation. *Pakistan Journal of Botany*, 42(4): 2527–2534.
- [17]. Singh, B. and Singh, H. N. (2006). Combining ability for yield and component characters in okra. *Vegetable Science*, 33(2): 121–124.
- [18]. Sprague, G. F. and Tatum, L. A. (1942). General vs. specific combining ability in single crosses of corn. *Journal of the American Society of Agronomy*, 34(10): 923–932. <https://doi.org/10.2134/agronj1942.00021962003400100008x>
- [19]. Thirumala Rao, G.; Rao, P. V. and Rao, M. S. (2012). Combining ability studies in okra (*Abelmoschus esculentus* L. Moench) for yield and quality traits. *Asian Journal of Horticulture*, 7(2): 477–481.
- [20]. Yadav, S. K.; Singh, B. K. and Pal, A. K. (2013). Genetic architecture of quantitative traits in okra (*Abelmoschus esculentus* L. Moench). *Electronic Journal of Plant Breeding*, 4(2): 1189–1196.

