IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 1, Issue 1, January 2021

Impact Factor: 5.731

Heterosis for Yield and Yield Attributes in Okra (*Abelmoschus esculentus* L.)

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Abstract: *Heterosis the phenomenon by which first-generation hybrid offspring outperform their parents has become one of the most powerful tools in vegetable crop improvement worldwide, and okra (Abelmoschus esculentus L.) is no exception. This article reviews the nature, magnitude, and practical significance of heterosis for yield and yield-contributing traits in okra, drawing on decades of research from South Asia, West Africa, and other major producing regions. Hybrid okra varieties consistently outperform open-pollinated checks for traits including fruit yield per plant, number of fruits per plant, plant height, days to first flowering, and several pod quality characteristics. Heterosis estimates over better parent and standard checks vary considerably across cross combinations, with fruit yield showing the highest and most commercially significant levels of mid-parent and better-parent heterosis. The article examines the genetic basis of heterosis in okra, the methods used to measure it, the role of combining ability in identifying superior hybrid combinations, and the agronomic and commercial dimensions of hybrid okra cultivation. Constraints to hybrid seed production in okra and directions for future research are also discussed.*

Keywords: hybrid vigor, combining ability, hybrid breeding, heterosis, okra, fruit yield**.**

I. INTRODUCTION

There is something almost counterintuitive about heterosis when you first encounter it. Take two plants that perform modestly on their own, cross them, and the offspring outperforms both parents sometimes dramatically. This is not magic, though it can feel that way when you see a hybrid okra plot producing twice the fruit of the open-pollinated variety growing beside it. Heterosis, or hybrid vigor, is a real, reproducible, and biologically grounded phenomenon that plant breeders have been deliberately exploiting since the early twentieth century.

The commercial value of heterosis in okra has increased during the last thirty years. India, which produces more okra than any other country in the world accounting for roughly 70% of global output has seen a significant expansion in hybrid okra cultivation, particularly in states like Maharashtra, Andhra Pradesh, Karnataka, and increasingly the eastern states. Private seed companies have driven much of this shift by introducing F1 hybrid varieties which provide farmers with yield improvements between 30% and 80% when compared to traditional open-pollinated varieties that use standard farming methods (Reddy *et al.,* 2012; Singh and Sharma, 2006). The yield advantage from this method provides a smallholder okra farmer who cultivates half a hectare with a significant benefit because it results in increased household earnings.

Despite this commercial momentum, the scientific literature on heterosis in okra is less consolidated than one might expect. Studies vary widely in their experimental designs, the parental material they use, the environments where they work, and the traits they prioritize. Estimates of heterosis for the same trait can differ enormously from one study to the next, reflecting genuine differences in the genetic divergence between parental lines across experiments rather than inconsistencies in the underlying biology.

Understanding what drives heterosis in okra which crosses show the most vigor, which traits benefit most, and what genetic mechanisms are responsible is not just academically interesting. It is the practical foundation for designing better hybrid breeding programs, selecting superior parent lines, and deciding where hybrid cultivation makes economic sense for farmers.

DOI: 10.48175/IJARSCT-747Q

This article traces the science of heterosis in okra from its biological foundations through to its field-level manifestations, drawing on what decades of research have established and what questions remain genuinely open.

II. UNDERSTANDING HETEROSIS: CONCEPTS AND MEASUREMENT

2.1 Types of Heterosis and What They Mean

Heterosis is measured in relation to a baseline, and the choice of baseline matters a great deal for interpreting results. Three types of heterosis are routinely reported in okra research, each telling a slightly different story.

Mid-parent heterosis (MPH) compares the F_1 hybrid mean to the average performance of its two parents. This is the most sensitive measure because the midparent value is always lower than the better parent, so F_1 superiority over midparent is relatively easy to achieve. A hybrid that exceeds its midparent by 20% for yield is performing well, but that tells you less than you might think about whether it is actually better than what farmers already grow.

Better-parent heterosis (BPH), sometimes called heterobeltiosis, compares the F_1 directly to whichever parent performed better. This is a harder bar to clear and a more meaningful one from a breeding standpoint. If a hybrid cannot exceed its best parent, there is limited justification for the extra cost and complexity of hybrid seed production. BPH values above 15–20% for fruit yield is generally considered commercially meaningful in okra (Aravindakumar *et al.,* 2014; Solanki and Dhaduk, 2009).

Standard heterosis, the comparison of F_1 performance to an established commercial check variety is the most practically relevant measure for variety development decisions. A hybrid that yields 30% more than the best currently available open-pollinated variety under farmer conditions is worth commercializing, even if its BPH is modest, because the comparison to the real-world alternative is what determines farmer benefit.

2.2 Measuring Heterosis in Field Trials

Researchers calculate heterosis estimates by conducting multiple field trials that test parental lines together with their F_1 hybrids and their check varieties under identical management conditions. The experimental design which uses either randomized complete block or alpha lattice design with three to four replications enables researchers to determine genetic differences between generations through their observed results because spatial soil fertility and moisture and environmental gradient differences remain controlled.

Direct evaluation of okra heterosis research faces operational difficulties because the F_1 hybrids and their parental lines exhibit major variations in their growth timing and their physical plant structure. The early-maturing parental lines complete their fruiting cycle before later-maturing F_1 plants reach their maximum production level which creates microenvironmental competition effects that distort estimation results. The evaluation process in well-structured trials requires researchers to assess all fruiting stages while obtaining total harvest results instead of relying on individual harvest data.

III. HETEROSIS FOR FRUIT YIELD AND ITS COMPONENTS

3.1 Magnitude of Heterosis for Fruit Yield Per Plant

Fruit yield per plant consistently shows the largest and most commercially significant heterosis values among all traits studied in okra. Across the published literature, mid-parent heterosis for fruit yield ranges from negligible values in poor cross combinations to values exceeding 100% in the best combinations — meaning the F1 hybrid produces more than twice what its parental average would predict (Dhankar and Dhankar, 2002; Rao *et al*., 2012; Thangamani and Jansirani, 2012). Better-parent heterosis for yield is naturally lower but still commonly reaches 40–80% in superior crosses.

What determines whether a particular cross shows high or low heterosis for yield? The short answer is genetic divergence between parents. When parental lines differ at many loci controlling yield, when they carry different favorable alleles at different places in the genome, their hybrid offspring enjoys complementation at many loci simultaneously. Each locus where the hybrid is heterozygous and where the favorable allele is at least partially dominant contributes positively to hybrid performance. Crosses between genetically distant parents say, one line from

DOI: 10.48175/IJARSCT-747Q

South Indian germplasm and another with West African ancestry often show stronger heterosis than crosses within the same geographic germplasm group (Nwangburuka *et al.,* 2012).

This is not a guarantee, of course. Genetic distance is a necessary but not sufficient condition for high heterosis. The parents must differ specifically at loci that control yield, and the dominance relationships at those loci must be in the favorable direction. Two genetically distant lines that happen to carry similar alleles at yield-relevant loci will produce unimpressive hybrids regardless of their overall molecular divergence.

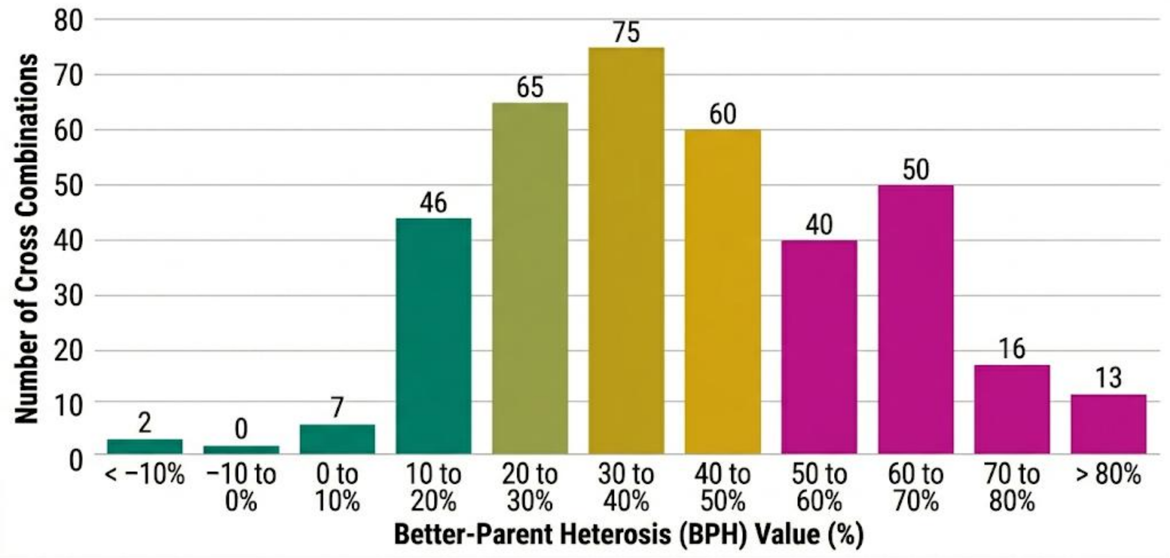

Figure 1: Distribution of Better-Parent Heterosis Values for Fruit Yield Per Plant Across Published Okra Hybrid Studies

As shown in Figure 1, better-parent heterosis for fruit yield per plant varies enormously across cross combinations in published okra studies, ranging from negative values in incompatible crosses to very large positive values in the best combinations, highlighting why screening many crosses is essential before identifying commercially viable hybrids.

The frequency histogram shows how better-parent heterosis (BPH) values for fruit yield per plant distribute among the okra hybridization studies from South Asia and West Africa. The horizontal axis represents BPH percentage in ranges from below −10% to above +80%, and the vertical axis represents the number of cross combinations falling in each range. The distribution shows a right-skewed pattern which contains most crosses with BPH values between 10% and 50% while only a minor number of crosses show negative or negligible heterosis and high-value crosses exceed 60% BPH. The key insight shows that okra displays substantial positive heterosis potential but this breeding method requires specific parent selection and cross testing to produce hybrids which deliver practical yield benefits.

3.2 Number of Fruits Per Plant

The number of fruits produced by each okra plant serves as the primary yield factor that determines total fruit production, which displays positive heterosis to a strong degree in most cross combinations documented in scientific studies. Mid-parent heterosis values for this trait commonly range from 20% to 60%, and better-parent heterosis frequently reaches 25–45% in superior crosses (Aravindakumar *et al.,* 2014 and Reddy *et al*., 2012).

The biological basis for high heterosis in fruit number is relatively intuitive. The cumulative process of okra fruiting allows the plant to establish new pods during an extended period, while its total production depends on its branching pattern and node count and node-to-pod conversion rate and active growth duration. A hybrid that is heterozygous at loci influencing all of these components simultaneously may exhibit complementary advantages in each one, producing a multiplicative effect on total fruit count that exceeds what either parent can achieve alone.

DOI: 10.48175/IJARSCT-747Q

3.3 Average Fruit Weight and Fruit Dimensions

The average fruit weight exhibits greater variability through heterosis measurements which researchers have documented in published studies than the assessment of fruit quantity. Some crosses exhibit significant positive better-parent heterosis for this trait while other crosses demonstrate negative heterosis because F_1 pods weigh less than the better parent while the hybrid produces higher pod quantities (Sharma *et al.,* 2011; Singh and Sharma, 2006). The negative relationship between fruit quantity and single fruit weight represents a typical occurrence in okra which demonstrates an actual biological trade-off because plants need to allocate more resources to their multiple fruits which results in less available resources for each fruit.

The moderate degree of heterosis which fruit length and fruit girth display shows inconsistent results throughout different studies. The studies conducted in India and West Africa show that better cross combinations achieve positive BPH results which produce fruit length improvements between 10 and 30% (Nwangburuka *et al.,* 2012 and Rao *et al*., 2012). The specific length and girth measurements of a product need to meet predetermined limits for each target market which requires South Indian markets to accept shorter thicker pods while East African markets demand longer slender fruits. Hybrid development programs need to choose pod dimension ranges for their target market while applying their selection process because they should not focus only on increasing one specific dimension.

IV. HETEROSIS FOR PLANT CHARACTERS AND EARLINESS

4.1 Plant Height and Branches Per Plant

Plant height shows high heterosis in okra hybrids because their mid-parent and better-parent heterosis values show positive results at moderate and high levels. The F_1 plants show height increases because dominant alleles at height-controlling loci cause greater upward growth. Researchers frequently report better-parent heterosis for plant height which reaches 15 to 35 percent (Dhankar and Dhankar, 2002; Thangamani and Jansirani, 2012).

Positive heterosis for branches per plant occurs because branching creates additional fruiting nodes which the plant can use. Hybrids display more fruiting sites than their parent plants because their advanced branching structure creates an advantage which results in higher fruit number heterosis. Positive BPH for branching in the range of 10–25% is common in the better cross combinations (Sharma *et al*., 2011).

4.2 Days to First Flowering and Maturity

Negative heterosis causes okra plants to show their first flowers after their parent Hybrid plants flower earlier than their parental average and they often flower before their stronger parent. Negative mid-parent heterosis for days to flowering ranging from −5% to −15% is commonly reported, indicating that hybrids tend to reach reproductive maturity faster than expected from parental performance (Aravindakumar *et al.,* 2014; Solanki and Dhaduk, 2009).

The practical value of this earliness heterosis proves to be highly beneficial. Farmers achieve their first harvest earlier because earlier flowering decreases the time between sowing and harvest, which enables them to sell their crops at premium prices before supply reaches its peak during the early season. The practice of planting crops earlier after crops mature creates better land use efficiency throughout the year in intensive cropping systems.

Figure 2 presents a comparative overview of average better-parent heterosis values across the major yield and plant characters in okra, synthesizing estimates from multiple published studies and highlighting which traits show the most consistent and commercially significant hybrid advantage.

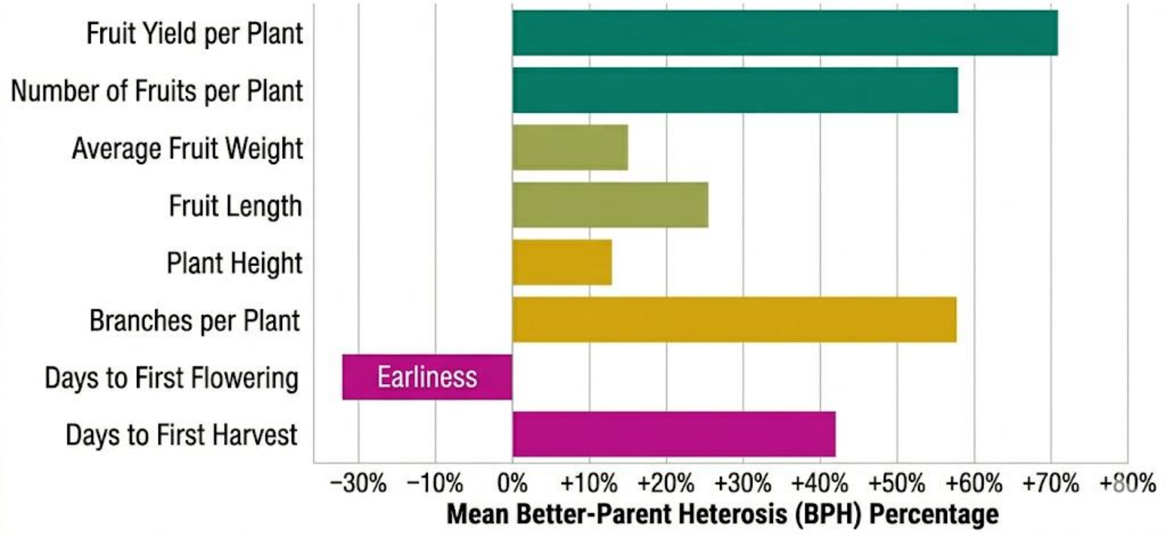

Figure 2: Average Better-Parent Heterosis Values for Key Yield and Plant Traits in Okra — Synthesis Across Published Studies

The horizontal bar chart displays average better-parent heterosis (BPH) percentages for eight essential okra characteristics which include fruit yield per plant and number of fruits per plant and average fruit weight and fruit length and plant height and branches per plant and days to first flowering which shows negative heterosis because of earlier maturity and days to first harvest. The zero line defines BPH which shows positive hybrid results better than the better parent but days to first flowering shows negative BPH because hybrids flower earlier than their parent strains. The longest positive bar shows fruit yield per plant results which get followed by number of fruits per plant and branches per plant. The most significant negative outcome occurs during days to first flowering. The analysis shows that okra hybrids produce better yield results which include yield components than their parent plants because they have one additional benefit which enables them to mature earlier.

V. GENETIC BASIS OF HETEROSIS IN OKRA

5.1 Dominance and Overdominance Hypotheses

The two main genetic theories that scientists created to explain hybrid vigor in agricultural plants show different degrees of effectiveness when applied to okra plants. The dominance hypothesis asserts that heterosis emerges because heterozygous individuals protect their parental lines' hidden harmful recessive genes from detection. Through continuous selfing, pure lines develop genetic defects which cause their performance to decline. When two pure lines are crossed, the resulting F1 plants inherit heterozygous alleles from multiple loci — one parent transmits a dominant functional gene while the other parent transmits a defective recessive gene. The plant outperforms both inbred parents because it contains fewer harmful genes which are actively expressed in its phenotype than its inbred parents.

The overdominance hypothesis establishes a more robust assertion because it states that some loci enable heterozygotes to surpass both homozygotes through their ability to conceal detrimental alleles and their benefit from possessing two different alleles which create diverse protein functions that enable broader metabolic coverage. Establishing overdominance in plants presents more challenges than proving dominance because overdominance which appears at the trait level can emerge from the combined effects of two dominant genes that operate in close proximity (pseudo-overdominance).

In okra, generation mean analysis studies that detect large dominance components and significant dominance × dominance epistasis for yield traits provides indirect support for the dominance hypothesis as a major driver of heterosis (Jinks and Jones, 1958; Kumar *et al.,* 2010). Direct molecular evidence distinguishing true overdominance from pseudo-overdominance in okra remains limited, largely because the QTL mapping infrastructure for this crop is still relatively underdeveloped compared to major cereal and legume species.

5.2 The Role of Epistasis in Hybrid Performance

Advanced interaction between multiple genomic sites determines hybrid vigor measurement, which goes beyond the sum of primary additive effects and primary genomic site effects. When two parental lines carry different alleles at pairs of interacting loci, their hybrid may exhibit complementary interactions that boost performance above what single-locus dominance would predict. The epistatic heritability in heterosis exists mainly within yield traits because those traits show multiple genetic influences and the biological processes that develop them require multiple gene interactions to function. The generation mean analysis of okra yield produces dominant results which demonstrate both dominance x dominance and additive x additive epistatic components thus proving that inter locus interactions exist between different genetic locations to create hybrid performance patterns (Ariyo *et al.*, 2007; Solanki and Dhaduk, 2009). The process of discovering unique epistatic pathways which improve hybrid results represents a major hurdle in okra hybrid breeding because it requires researchers to identify specific parental line pairs whose genetic combinations will positively affect multiple genetic sites at once.

VI. COMBINING ABILITY AND PARENT SELECTION

6.1 General and Specific Combining Ability

The practical tool for identifying which parental lines produce the best hybrids is combining ability analysis, most commonly conducted through diallel crossing designs. General combining ability (GCA) measures how well a particular line performs across all the crosses it is involved in it reflects the average additive genetic value that a line contributes to its hybrids. Specific combining ability (SCA) measures how much a particular cross combination performs above or below what the GCA values of its two parents would predict it reflects non-additive effects specific to that cross.

For traits where GCA effects are large relative to SCA which corresponds to predominantly additive genetic control parent selection based on GCA is highly effective. Lines with high GCA for yield will generally produce good hybrids regardless of which other high-GCA line they are crossed with. For traits where SCA effects dominate reflecting large dominance and epistatic components, parent selection becomes more complex, because the best cross combinations cannot be predicted from the GCA values of either parent alone. They can only be identified by actually making and evaluating the crosses.

In okra, the balance between GCA and SCA effects varies by trait and by germplasm. Studies from India, Nigeria, and Ethiopia generally report that both GCA and SCA effects are significant for fruit yield, with SCA effects often larger in magnitude consistent with the large non-additive genetic control of yield documented through generation mean analysis (Nwangburuka *et al.,* 2012 and Rao et al., 2012). This means that yield heterosis in okra is not fully predictable from parental line performance alone, and that screening of specific cross combinations is a necessary step in hybrid development.

6.2 Identifying Superior Parent Lines

Despite the complexity that large SCA effects introduce, several characteristics of parental lines consistently predict good hybrid performance in okra. Lines with good per se performance — that is, high yield and good agronomic characters in their own right — more often produce strong hybrids than poor per se performers, reflecting the contribution of GCA to hybrid performance even when SCA is also important. Lines from genetically divergent backgrounds, as discussed earlier, tend to produce stronger heterosis when crossed than those from similar origins.

Phenotypic complementarity between parents for yield components is another practical guide. Crosses between one parent with high fruit number but modest individual fruit size and another with lower fruit number but larger, heavier pods sometimes produce balanced F_1 plants that combine high fruit number with acceptable individual weight — capturing the best of both parents and sometimes exceeding both. This complementarity effect operates through dominance at the loci underlying each trait, and experienced okra breeders have learned to look for it deliberately when designing their crossing programs (Singh and Sharma, 2006; Thangamani and Jansirani, 2012).

VII. CONCLUSION

Heterosis in okra is real, substantial, and practically important. The accumulated evidence from decades of hybridization research makes clear that F_1 hybrids can deliver yield advantages that meaningfully improve farm economics — particularly through superior fruit number per plant, earlier maturity, and consistently better overall productivity than open-pollinated alternatives. The genetic basis of this heterosis rests on a combination of dominance and epistatic gene action, consistent with what generation mean analysis studies have independently established about the importance of non-additive variance in okra yield traits.

Translating this biological potential into commercial and farmer-level benefit requires continued investment in three areas: better methods for identifying high-combining parent lines before extensive field evaluation, improved hybrid seed production technologies that reduce the cost of F_1 seed, and multi-environment evaluation programs that ensure hybrids perform reliably under the variable conditions that farmers actually face.

Okra's importance to food security and rural incomes across South Asia and Africa makes that investment worthwhile. The genetic potential for a 40–80% yield step-change through hybridization is genuinely available in this crop. Capturing it consistently and affordably is the challenge that breeders, agronomists, seed companies, and policy makers need to work on together.

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