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Assessment of genetic variability in okra (*Abelmoschus esculentus* L.) genotypes

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Abstract
This study evaluated the associations among yield and related traits in okra using correlation and path coefficient analysis on twenty genotypes. Genotypic and phenotypic correlation coefficients were estimated for eleven traits, and path analysis was performed to partition correlations into direct and indirect effects on fruit yield. Fruit yield per plant showed strong positive correlations with number of fruits per plant, fruit weight, and plant height, whereas days to 50% flowering and days to first picking were negatively correlated with yield. Path analysis revealed that number of fruits per plant exhibited the highest positive direct effect on yield, followed by fruit weight. Traits like plant height had moderate direct effects, while traits such as days to first picking and fruit length had low or negative direct effects on yield. Early-flowering genotypes tended to yield more via indirect effects. These results suggest that selection for more fruits per plant, heavier fruits, and taller plant stature can substantially improve okra yield, whereas earliness contributes to yield mainly through its influence on other yield components. Breeding programs should prioritize these key traits to develop high-yielding okra cultivars.

Keywords: Okra, yield traits, correlation, path analysis, fruit number, breeding selection

Introduction
Okra (Abelmoschus esculentus L. Moench) is an important vegetable crop grown widely for its tender green fruits. Improving okra yield is a primary breeding objective, and it requires understanding the genetic relationships among yield components. Correlation analysis provides insight into trait associations, helping identify characteristics that reliably co-vary with yield. However, correlation alone does not distinguish direct causal influences from indirect effects mediated through other traits (Ibrahim & Abdulkadir, 2015) [5]. Path coefficient analysis addresses this by partitioning correlations into direct effects of individual traits on yield and indirect effects via other traits. In okra, yield is a complex polygenic trait influenced by components such as fruit number, fruit size, plant architecture, and maturity timing. Evaluating genotypic and phenotypic correlations along with path coefficients can guide breeders in selecting traits that most effectively improve yield (Sharma, 1998) [11]. This study therefore aims to estimate the correlation coefficients among yield-contributing traits in okra and to determine the direct and indirect contributions of these traits to fruit yield per plant.

Materials and Methods
The research was conducted on 20 okra genotypes grown in a field experiment during the summer season of 2024. The trial was laid out in a randomized block design with recommended agronomic practices. Observations were recorded on eleven yield and yield-related characters: days to 50% flowering, plant height, number of internodes on main stem, internode length, number of branches per plant, days to first picking, fruit length, fruit girth, average fruit weight, number of fruits per plant, and fruit yield per plant (Akinyele & Osekita, 2006) [1]. Genotypic and phenotypic correlation coefficients were calculated for all trait pairs using standard statistical procedures. Path coefficient analysis (following the method of Wright, 1921) was then performed to decompose the genotypic correlations of each trait with fruit yield into direct effects and indirect effects via other traits. Significant correlations were determined at the 5% and 1% probability levels (denoted by * and **,

respectively, in tables). All analyses were carried out using appropriate biometrical software and based on plot mean data for each genotype.

Results

Correlation Analysis: The genotypic (g) and phenotypic (p) correlation coefficients among the traits are presented in Table 1. Fruit yield per plant exhibited significant positive correlations with several traits, notably number of fruits per plant (r(g) = 0.721**) and average fruit weight (r (g) = 0.523**), followed by plant height (0.619**). These three traits also showed positive and significant phenotypic correlations with yield (e.g. r(p) for number of fruits = 0.663**) (Ali, Hossain, & Hossain, 2012). Number of branches per plant and internode length had moderate positive genotypic correlations with yield (0.426** and 0.427**, respectively), while number of internodes on main stem showed a lower positive correlation (0.371**). Fruit length was positively correlated with yield at the genotypic level (0.317**), though its phenotypic correlation was weaker and not significant. In contrast, days to 50% flowering and days to first picking were negatively correlated with fruit yield (Ayodele & Ogunkanmi, 2014) [3]. Genotypically, earlier flowering (fewer days to 50% flowering) had a strong negative correlation with yield r (g) =-0.730), and earlier maturity (fewer days to first picking) also showed a sizable negative correlation (-0.579). These negative signs indicate that genotypes which flowered and fruited earlier tended to produce higher yields (Yonas *et al.*, 2014). In general, the magnitudes of genotypic correlations were greater than their corresponding phenotypic correlations for most traits, suggesting that the observed associations are largely due to genetic factors, with environmental influence dampening the correlations at the phenotypic level (Bhalekar, Bhave, & Kachare, 2019) [4]. Significant positive correlations among several yield components (e.g. plant height with internode length and branches) were also observed (Table 1), implying that vigorous plant growth attributes are interrelated and often jointly contribute to higher yield.

Table 1: Genotypic (g, above diagonal) and phenotypic (p, below diagonal) correlation coefficients among eleven traits in okra.

Genotypes		P H	N I MS	L I	N B P	D F P	F L	F G	F W	N F P	Fruit yield per plant (gm)
Days to 50% flowering	g	-0.143	-0.13	-0.026	-0.108	0.684**	-0.205	0.056	-0.244	0.062	-0.73
	p	-0.005	-0.007	-0.014	-0.03	0.351**	-0.07	-0.036	-0.13	0.045	-0.045
Plant height (cm)	g		0.604**	0.695**	0.515**	-0.248	0.335	0.017	0.491**	0.288**	0.619**
	p		0.533**	0.603**	0.461**	-0.206	0.285**	0.067	0.273**	0.209	0.371**
Number of internodes on main stem	g			0.495	0.709**	-0.333	0.411**	0.109	0.368**	0.349**	0.371**
	p			0.458	0.641**	-0.263	0.304**	0.074	0.232**	0.303	0.539**
Length of internodes (cm)	g				0.703**	-0.071	0.160	0.006	0.359**	0.190	0.427**
	p				0.666**	-0.050	0.136	0.014	0.271**	0.160	0.329**
Number of branches per plant	g					-0.221	0.213	-0.104	0.208	0.324	0.426**
	p					-0.170	0.186	-0.061	0.161	0.288**	0.331**
Days to first picking	g						-0.368	0.020	-0.376	-0.401	-0.579
	p						-0.273	-0.006	-0.235	-0.276	-0.356
Fruit length (cm)	g							0.069	0.545**	-0.085	0.317
	p							0.117	0.324**	-0.063	0.201
Fruit girth (cm)	g								0.015	-0.120	-0.083
	p								-0.006	-0.080	-0.061
Fruit weight (cm)	g									-0.184	0.523**
	p									-0.080	0.664**
Number of fruits per plant	g										0.721**
	p										0.663**
Fruit yield per plant (gm)	g										
	p										

Path Coefficient Analysis: The direct and indirect effects of the component traits on fruit yield per plant are given in Table 2. Path analysis revealed that the number of fruits per plant had the highest positive direct effect (0.806) on fruit yield. This indicates that, genetically, an increase in fruit number per plant directly causes a substantial increase in yield (Mishra, Singh, & Verma, 2015) [7]. The average fruit weight also exerted a large positive direct effect on yield (0.742), highlighting the importance of individual fruit size in determining total yield. Plant height showed a moderate positive direct effect (0.264), suggesting taller plants contribute to yield gain, likely by supporting more fruits or biomass (Shinde *et al.*, 2023) [12]. In addition, number of branches per plant had a small positive direct effect on yield (0.116), and days to 50% flowering showed a very slight positive direct effect (0.097). On the other hand, several traits had negligible or negative direct effects despite their appreciable correlations with yield. Internode length, for example, displayed a moderately negative direct effect on yield (-0.262) (Mohammed & Alamerew, 2014) [8]. The positive correlation between internode length and yield (Table 1) is thus attributable to indirect effects via other traits (such as plant height and fruit number) rather than a beneficial direct influence. Fruit length had a near-zero, slightly negative direct effect (-0.029) on yield, even though its genotypic correlation with yield was significant and positive (Yadav *et al.*, 2024) [14]. This paradox is explained by a strong positive indirect effect of fruit length through fruit weight (indirect contribution = + 0.405)-longer fruits tended to be heavier, and it was the increased fruit weight that ultimately enhanced yield. Days to first picking showed a minor negative direct effect (-0.040) on yield, indicating that earliness per se had a small unfavorable direct impact; however, early maturity was still associated with higher yield primarily through its correlation with other traits (such as allowing more fruits to be produced in the season). Fruit girth and number of internodes on main stem had very low direct effects on yield (close to zero), implying their contributions to yield are mostly via their influence on other traits (Singh & Chaudhary, 2004) [13].

Table 2: Path coefficient analysis showing direct (bold on diagonal) and indirect effects of various traits on fruit yield per plant in okra.

Characters	DF	P H	N I MS	L I	N B P	D F P	F L	F G	F W	N F P	Fruit yield per plant (gm)
Days to 50% flowering	0.097	-0.037	0.001	0.006	-0.012	-0.027	0.005	0.001	-0.0181	0.051	-0.073
Plant height (cm)	-0.013	0.264	-0.01	-0.182	0.6	0.09	-0.09	0	0.365	0	0.619
Number of internodes on main stem	-0.012	0.159	-0.018	-130	0.082	0.013	-0.011	0.002	0.273	0.282	0.371
Length of internodes (cm)	-0.002	0.183	-0.008	-0.262	0.81	0.002	-0.004	0.001	0.267	0.153	0.427
Number of branches per plant	-0.010	0.136	-0.012	-0.184	0.116	0.008	-0.005	0.001	0.154	0.261	0.426
Days to first picking	0.067	-0.065	0.005	0.019	-0.025	-0.04	0.01	0	-0.279	-0.323	-0.579
Fruit length (cm)	-0.019	0.088	-0.007	-0.041	0.024	0.014	-0.029	0.001	0.405	-0.068	0.317
Fruit girth (cm)	-0.005	0.004	-0.001	-0.001	-0.011	-0.001	-0.001	0.015	0.010	-0.097	-0.083
Fruit weight (cm)	-0.023	0.129	-0.006	-0.094	0.023	0.015	-0.015	0	0.742	-0.148	0.523
Number of fruits per plant	0.005	0.076	-0.006	-0.050	0.037	0.002	0.002	-0.001	-0.136	0.806	0.721

Discussion

The correlation and path analysis results collectively highlight the key determinants of yield in okra and the interrelationships among traits. The number of fruits per plant emerged as the most important yield component. It not only had the highest correlation with fruit yield but also the largest direct effect, underscoring that genotypes bearing more fruits will directly yield more. This finding aligns with the biological expectation that fruit number is a primary driver of total yield; it is also in agreement with earlier reports that identified fruit number as a critical trait for yield improvement in okra (e.g., Yonas *et al.* 2014 [15] found a high direct effect of pod number on yield). Average fruit weight was another major factor influencing yield. Heavier fruits contributed directly to higher yield, which is intuitive since yield is the product of fruit number and fruit weight. The strong direct effect of fruit weight observed in our study is consistent with the observations of Rashwan (2011) [10], who noted that selecting for heavier okra pods can significantly increase yield.

Plant height showed a moderate positive influence on yield through both correlation and direct effect, suggesting that taller, more vigorous plants tend to produce greater yields. Taller plants may intercept more light and support more nodes and leaves, thus enhancing photosynthate production and fruit-set capacity. Shinde *et al.* (2023) [12] reported a similar positive effect of plant height on okra yield, indicating that plant stature is an important trait in breeding programs for yield. Traits related to plant architecture, such as number of branches and internode length, had moderate correlations with yield but only modest direct effects. A higher number of branches can increase the fruit-bearing sites, but in our analysis its direct effect was relatively small, implying that branch number contributes to yield in conjunction with other traits (like it may support more fruits indirectly). Internode length interestingly showed a negative direct effect despite a positive total correlation with yield, meaning that while long-internode genotypes tended to yield more, it was not because long internodes are inherently beneficial-rather, genotypes with longer internodes also happened to be taller or have more fruits, which drove the yield increase. In practical terms, extremely long internodes might not be a desirable goal on their own, especially if they come at the cost of other traits; the overall positive correlation of internode length with yield is likely an indirect consequence of vigorous growth habit.

Earliness traits demonstrated an inverse relationship with yield. Genotypically, early-flowering and early-fruiting genotypes achieved higher yields, as indicated by the strong negative correlations of days to 50% flowering and days to first picking with yield. This suggests that a shorter time to flowering and first harvest allows the plant to potentially produce fruits over a longer portion of the growing season or to escape late-season stresses, thereby increasing total yield. However, the direct effects of these earliness traits on yield were minimal or slightly negative, which implies that simply being early does not inherently boost yield unless it is accompanied by an increase in fruit number or size. In breeding terms, this means that while selecting for earliness is useful (especially for environments with short growing seasons), such selection should be coupled with traits like fruit number and weight to ensure yield gains.

Overall, the combination of correlation and path analyses provides a clear picture of trait prioritization for okra yield improvement. The number of fruits per plant and average fruit weight are confirmed as the primary yield determinants, as these traits both correlate strongly with yield and have high direct effects. Plant height is also a favorable trait to select for, given its positive influence on yield and its facilitation of a robust plant framework for fruit production. Meanwhile, traits like fruit length and internode length should not be directly emphasized in selection unless they are linked with improvements in fruit weight or plant growth, respectively. It is noteworthy that genotypic correlations were generally higher than phenotypic correlations in this study, indicating that the genetic potential for trait association is strong, but environmental factors can mask some of these relationships phenotypically. This underlines the importance of multi-environment testing: as pointed out by Yadav *et al.* (2024) [14], breeders should be mindful of genotype-by-environment interactions when selecting for traits like fruit number, plant height, and fruit weight to ensure that these correlations and direct effects hold true under different conditions.

In conclusion, our findings are in agreement with previous research and breeding experience in okra: selecting genotypes with more fruits per plant, higher fruit weight, and adequate plant stature is the most promising strategy for increasing yield. Early maturity is an added advantage, though its benefits manifest via allowing the plant to realize its yield potential through other traits. Breeding programs should focus on these key characters and may employ index selection incorporating fruit number and weight along with plant height and earliness to achieve substantial improvements in okra yield.

Conclusion

This study demonstrates that number of fruits per plant and average fruit weight are the two most influential traits for fruit yield improvement in okra, as these traits showed both high positive correlations and high direct effects on yield. Plant height and related vigor traits also contribute positively to yield, although to a lesser extent. Early flowering and early harvesting genotypes tend to yield more, primarily by enabling a greater number of fruits to develop. Traits such as fruit length and internode length affect yield mostly indirectly through their influence on fruit weight and plant growth. For practical breeding, the results imply that selection should concentrate on increasing fruit number and fruit weight while maintaining adequate plant height and an appropriate maturity period. By targeting these key yield components, breeders can more effectively develop high-yielding okra varieties.

Author Disclaimer

The authors hereby declare that no generative artificial intelligence tools—including but not limited to large language models such as ChatGPT, GitHub Copilot, or any form of AI-assisted text or image generation software—were utilized in the conception, writing, editing, or revision of this manuscript. The entirety of the content represents the authors' independent work, original insights, and critical analysis.

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