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Correlation and path analysis in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
Okra [*Abelmoschus esculentus* (L.) Moench] is an economically and nutritionally important vegetable crop; however, improvement in fruit yield is constrained by its complex genetic architecture. The present investigation was undertaken to study character associations and to assess the direct and indirect effects of yield-contributing traits on fruit yield per plant in okra. Genotypic correlation analysis revealed that fruit yield per plant had significant positive associations with number of fruits per plant, average fruit weight, fruit diameter, number of nodes, number of branches, plant height, and fruit length. In contrast, significant negative correlations were observed with node at first flowering, days to first flowering, days to 50% flowering, and days to first harvest, indicating the importance of earliness in yield improvement. Path coefficient analysis identified average fruit weight as the trait exerting the highest positive direct effect on fruit yield per plant, followed by number of fruits per plant. Number of branches, number of nodes, and fruit diameter also contributed positively through direct and indirect effects, particularly via number of fruits per plant. Overall, the study demonstrated that average fruit weight, number of fruits per plant, number of branches, and number of nodes are key yield-determining traits and may serve as reliable selection criteria for improving fruit yield in okra breeding programmes.

Keywords: Okra, genotypic correlation, path coefficient analysis, fruit yield, yield components

Introduction
Okra (*Abelmoschus esculentus* (L.) Moench) is an important vegetable crop cultivated extensively across tropical, subtropical, and warm temperate regions of the world. It belongs to the family *Malvaceae* and is valued not only for its culinary uses but also for its nutritional and functional properties. Okra pods are rich in dietary fibre, particularly viscous fibre, minerals such as sodium, calcium, potassium, zinc, and iron, and vitamins including A, B, and C, along with antioxidants and folate (Gopalan *et al.*, 2007; Kumar *et al.*, 2016; Sami *et al.*, 2019) [8, 13, 17]. Owing to these attributes, okra has gained prominence as a potential nutraceutical crop (Elkhalifa *et al.*, 2021) [7].

India is the world's leading producer of okra, contributing approximately 7.30 million metric tonnes from an area of about 557 thousand hectares, with an average productivity of 13.12 t ha^{-1}. Major okra-producing states include Gujarat, Madhya Pradesh, and West Bengal, underscoring the crop's economic significance in the country. Despite its importance, productivity levels remain variable, largely due to the complex genetic control of yield and its strong interaction with environmental factors (DAFW, 2024) [4].

Fruit yield in okra is a complex quantitative trait governed by the combined action of several component characters rather than a single gene. Although variability studies provide information on the magnitude of genetic variation available for different traits, they do not explain the nature and extent of interrelationships among these characters. Direct selection for yield alone is often ineffective, as yield is a dependent trait influenced by multiple yield-attributing characters and their interaction with the environment (Ryniah *et al.*, 2020) [16]. Moreover, phenotypic expression of a trait is the result of both genetic and environmental effects, complicating the identification of reliable selection criteria (Vinod and Gaibrival, 2023) [22].

Correlation analysis serves as a valuable statistical tool to quantify the degree and direction of association between yield and its component traits and aids in identifying traits that can be exploited for indirect selection. Genetic correlations arise due to linkage or developmental relationships between traits (Harland, 1939) [9] and play a crucial role in determining the effectiveness of selection strategies. However, correlation alone does not reveal whether the association between traits is due to a direct influence or mediated indirectly through other characters.

Path coefficient analysis overcomes this limitation by partitioning correlation coefficients into direct and indirect effects, thereby providing a clearer understanding of the cause-effect relationships among yield and its contributing traits. This approach enables breeders to identify characters exerting a true direct influence on yield and to formulate more efficient selection strategies. Therefore, a combined application of correlation and path coefficient analysis is essential for identifying key yield-determining traits and improving fruit yield in okra.

In this context, the present investigation was undertaken to study character associations and to assess the direct and indirect effects of yield-contributing traits on fruit yield per plant in okra, with the objective of identifying reliable selection criteria for yield improvement.

Materials and Methods

Experimental Material and Design

The experiment was conducted at the experimental block of the Department of Vegetable Science, College of Horticulture, Bagalkot, Karnataka, India. The study comprised twenty-seven okra (*Abelmoschus esculentus* (L.) Moench) genotypes collected from different regions of India. Details of the experimental material are provided in Supplementary Table 1. The field experiment was laid out during the *Rabi* season (February 2024) under open field conditions at the Vegetable Science experimental block, College of Horticulture, Bagalkot.

A total of eighteen quantitative traits were recorded, namely: plant height (PH), internodal length (IL), number of branches per plant (NB), stem diameter (SD), number of nodes per plant (NN), days to first flowering (DFF), days to fifty percent flowering (FPF), node at first flowering (NFF), days to first harvest (DFH), fruit length (FL), fruit diameter (FD), average fruit weight (FW), number of fruits per plant (NFP) and fruit yield per plant (FY).

Statistical Analysis

Genotypic correlation coefficients among all possible pairs of traits were estimated following the method described by Al-Jibouri *et al.* (1958) [2]. Path coefficient analysis was carried out according to the procedure outlined by Dewey and Lu (1959) [6] to partition correlation coefficients into direct and indirect effects of component traits on fruit yield per plant. All statistical analyses were performed using R software (version 4.2.2) employing the *corr* and *corrplot* packages.

Table 1: Estimates of the genotypic correlation coefficient between 14 different traits in okra genotypes

	PH	IL	NB	SD	NN	DFF	FPF	NFF	DFH	FL	FD	FW	NFP	FY
PH	1 **	0.6605 **	0.3359 ^{NS}	0.029 ^{NS}	0.5181 **	-0.2927 ^{NS}	-0.3014 ^{NS}	-0.1403 ^{NS}	-0.2841 ^{NS}	0.0458 ^{NS}	0.041 ^{NS}	-0.0456 ^{NS}	0.634 **	0.4778 *
IL	0.6605 **	1 **	0.2862 ^{NS}	0.0272 ^{NS}	0.2178 ^{NS}	-0.0946 ^{NS}	-0.0812 ^{NS}	-0.215 ^{NS}	-0.1409 ^{NS}	0.1997 ^{NS}	0.0929 ^{NS}	-0.1437 ^{NS}	0.4844 *	0.3011 ^{NS}
NB	0.3359 ^{NS}	0.2862 ^{NS}	1 **	0.3268 ^{NS}	0.5561 **	-0.2947 ^{NS}	-0.2378 ^{NS}	-0.4838 *	-0.3255 ^{NS}	0.1346 ^{NS}	0.0316 ^{NS}	-0.0597 ^{NS}	0.5907 **	0.4864 *
SD	0.029 ^{NS}	0.0272 ^{NS}	0.3268 ^{NS}	1 **	0.261 ^{NS}	-0.1365 ^{NS}	-0.034 ^{NS}	-0.0415 ^{NS}	-0.1363 ^{NS}	0.2784 ^{NS}	-0.3055 ^{NS}	-0.3844 *	0.2119 ^{NS}	-0.0896 ^{NS}
NN	0.5181 **	0.2178 ^{NS}	0.5561 **	0.261 ^{NS}	1 **	-0.3158 ^{NS}	-0.3467 ^{NS}	-0.3049 ^{NS}	-0.3215 ^{NS}	0.089 ^{NS}	-0.063 ^{NS}	-0.0796 ^{NS}	0.7437 **	0.5465 **
DFF	-0.2927 ^{NS}	-0.0946 ^{NS}	-0.2947 ^{NS}	-0.1365 ^{NS}	-0.3158 ^{NS}	1 **	0.9393 **	0.209 ^{NS}	1.081 **	-0.1244 ^{NS}	-0.139 ^{NS}	0.001 ^{NS}	-0.2982 *	-0.3136 *
FPF	-0.3014 ^{NS}	-0.0812 ^{NS}	-0.2378 ^{NS}	-0.034 ^{NS}	-0.3467 ^{NS}	0.9393 **	1 **	0.0516 ^{NS}	0.9362 **	-0.0882 ^{NS}	-0.1763 ^{NS}	-0.0715 ^{NS}	-0.3562 *	-0.3756 *
NFF	-0.1403 ^{NS}	-0.215 ^{NS}	-0.4838 *	-0.0415 ^{NS}	-0.3049 ^{NS}	0.209 ^{NS}	0.0516 ^{NS}	1 **	0.3591 ^{NS}	-0.3813 *	-0.271 ^{NS}	-0.2293 ^{NS}	-0.2396 *	-0.3793 *
DFH	-0.2841 ^{NS}	-0.1409 ^{NS}	-0.3255 ^{NS}	-0.1363 ^{NS}	-0.3215 ^{NS}	1.081 **	0.9362 **	0.3591 ^{NS}	1 **	-0.203 ^{NS}	-0.1263 ^{NS}	-0.0239 ^{NS}	-0.2655 *	-0.3089 *
FL	0.0458 ^{NS}	0.1997 ^{NS}	0.1346 ^{NS}	0.2784 ^{NS}	0.089 ^{NS}	-0.1244 ^{NS}	-0.0882 ^{NS}	-0.3813 *	-0.203 ^{NS}	1 **	0.559 **	0.2837 ^{NS}	0.242 ^{NS}	0.4369 *
FD	0.041 ^{NS}	0.0929 ^{NS}	0.0316 ^{NS}	-0.3055 ^{NS}	-0.063 ^{NS}	-0.139 ^{NS}	-0.1763 ^{NS}	-0.271 ^{NS}	-0.1263 ^{NS}	0.559 **	1 **	0.5638 **	0.1692 ^{NS}	0.5811 **
FW	-0.0456 ^{NS}	-0.1437 ^{NS}	-0.0597 ^{NS}	-0.3844 *	-0.0796 ^{NS}	0.001 ^{NS}	-0.0715 ^{NS}	-0.2293 ^{NS}	-0.0239 ^{NS}	0.2837 ^{NS}	0.5638 **	1 **	-0.1007 ^{NS}	0.6071 **
NFP	0.634 **	0.4844 *	0.5907 **	0.2119 ^{NS}	0.7437 **	-0.2982 ^{NS}	-0.3562 *	-0.2396 *	-0.2655 *	0.242 ^{NS}	0.1692 ^{NS}	-0.1007 ^{NS}	1 **	0.6947 **
FY	0.4778 *	0.3011 ^{NS}	0.4864 *	-0.0896 ^{NS}	0.5465 **	-0.3136 *	-0.3756 *	-0.3793 *	-0.3089 *	0.4369 *	0.5811 **	0.6071 **	0.6947 **	1 **

PH-Plant height, IL-Internodal length, NB-Number of Braches, SD-Stem Diameter, NN-Number of nodes per plat,
DFF-Days to first flowering, FPF-Days to 50% flowering, NFF-Node at first flowering, DFH-Days to first harvest, FL-Fruit length,
FD-Fruit Diameter, FW-Fruit weight, NFP-Number of fruits per plant FY-Fruit yield per plant

Table 2: Path coefficient analysis depicting the direct (bold) and indirect effects of various morphological characters on fruit yield per plant in okra

	PH	IL	NB	SD	NN	DFF	FPF	NFF	DFH	FL	FD	FW	NFP
PH	0.010	0.025	0.049	-0.002	0.073	0.058	-0.076	-0.020	0.028	0.003	0.005	-0.029	0.353
IL	0.006	0.039	0.042	-0.002	0.031	0.019	-0.021	-0.030	0.014	0.012	0.012	-0.090	0.269
NB	0.003	0.011	0.147	-0.019	0.079	0.058	-0.060	-0.068	0.032	0.008	0.004	-0.037	0.328
SD	0.000	0.001	0.048	-0.058	0.037	0.027	-0.009	-0.006	0.014	0.017	-0.038	-0.241	0.118
NN	0.005	0.008	0.082	-0.015	0.142	0.062	-0.088	-0.043	0.032	0.005	-0.008	-0.050	0.414
DFF	-0.003	-0.004	-0.043	0.008	-0.045	-0.196	0.238	0.029	-0.108	-0.008	-0.017	0.001	-0.166
FPF	-0.003	-0.003	-0.035	0.002	-0.049	0.253	-0.185	0.007	-0.093	-0.005	-0.022	-0.045	-0.198
NFF	-0.001	-0.008	-0.071	0.092	-0.043	-0.041	0.201	-0.100	-0.050	-0.048	-0.034	-0.144	-0.133
DFH	-0.003	-0.005	-0.048	0.008	-0.046	-0.212	0.237	0.050	-0.100	-0.012	-0.016	-0.015	-0.148
FL	0.000	0.008	0.020	-0.016	0.013	0.024	-0.022	-0.053	0.020	0.062	0.070	0.178	0.135
FD	0.000	0.004	0.005	0.018	-0.009	0.027	-0.045	-0.038	0.013	0.034	0.124	0.354	0.094
FW	0.000	-0.006	-0.009	0.022	-0.011	0.000	-0.018	-0.032	0.002	0.017	0.070	0.627	-0.056
NFP	0.006	0.019	0.087	-0.012	0.105	0.059	-0.090	-0.034	0.026	0.015	0.021	-0.063	0.556

Residual effect = 0.0194

PH-Plant height, IL-Internodal length, NB-Number of Braches, SD-Stem Diameter, NN-Number of nodes per plat,
DFF-Days to first flowering, FPF-Days to 50% flowering, NFF-Node at first flowering, DFH-Days to first harvest, FL-Fruit length,
FD-Fruit Diameter, FW-Fruit weight, NFP-Number of fruits per plant FY-Fruit yield per plant (Dependent Variable)

Results and Discussion

Yield is a quantitative character, hence, its association with other traits is important. Correlation analysis is extensively used in plant breeding to quantify the associations between yield and its component traits, thereby enabling the identification of characters contributing to productivity enhancement.

In the present study, yield per plant exhibited significant and positive correlations with number of fruits per plant (r_g = 0.695), average fruit weight (r_g = 0.607), fruit diameter (r_g = 0.581), number of nodes (r_g = 0.546), number of branches (r_g = 0.486), plant height (r_g = 0.478) and fruit length (r_g = 0.437) (Table 1). Furthermore, fruit yield per plant was found to have negative and significant association with node at first flowering (r_g = -0.379), days to fifty per cent flowering (r_g = -0.376), days to first flowering (r_g = -0.314) and days to first harvest (r_g = -0.309).

Positive correlations among desirable traits are advantageous in plant breeding, as they enable simultaneous improvement of multiple characters through selection. The strong association between yield and number of fruits per plant suggests that improvement in okra yield can be effectively achieved through selection for increased fruit bearing capacity (Shuirkar *et al.*, 2018) [18]. Similarly, Vennila *et al.* (2024) [21] reported a positive correlation of fruit yield per plant with average fruit weight, Kumari *et al.* (2019) [19] for fruit diameter, Jadhav *et al.* (2022) [10] with number of nodes, Singla *et al.* (2018) with number of branches, Alam *et al.* (2020) [1] with plant height and Das *et al.* (2012) [5] with fruit length.

Correlation matrix analysis showed presence of significant negative association between node at first flowering (r_g = -0.379) and earliness parameters like days to fifty per cent flowering (r_g = -0.376), days to first flowering (r_g = -0.314) and days to first harvest (r_g = -0.309). Similar trend of negative significant correlation of fruit yield per plant with earliness parameters was concluded by Jadhav *et al.* (2022) [10] and Karadi *et al.* (2018) [11]. This observation indicates that an increase in fruit yield per plant was closely associated with favourable expression of yield determining traits in conjunction with earliness parameters.

Although correlation analysis provides an estimate of the degree and direction of association between traits, it does not elucidate the underlying cause-effect relationships. A trait may exhibit a strong correlation with yield despite contributing indirectly through other interrelated characters. Path coefficient analysis overcomes this limitation by partitioning the correlation coefficients into direct and indirect effects of component traits on yield. This approach enables precise identification of characters exerting a true direct influence on yield and clarifies the relative importance of indirect contributions mediated through other traits. Consequently, path analysis offers a more reliable and biologically meaningful framework for selecting key yield determining traits in plant breeding programmes.

The results of path coefficient analysis (Table 2) indicated that average fruit weight exerted the highest positive direct effects on fruit yield per plant, followed by number of fruits per plant. Traits such as number of branches (0.147), number of nodes (0.142), and fruit diameter (0.124) also exhibited positive, though comparatively lower, direct effects on fruit yield per plant. Similar findings have been reported by Thulasiram *et al.* (2017) [20] for average fruit weight, Balai *et al.* (2014) [3] for number of fruits per plant, Kumar *et al.* (2019) [12] for number of branches, Rathava *et al.* (2019) [15] for number of nodes, and Kumari *et al.* (2019) [19] for fruit diameter. Further, Thulasiram *et al.* (2017) [20] and Alam *et al.* (2020) [1] emphasized that average fruit weight and number of fruits per plant are major contributors to fruit yield in okra.

Maximum positive indirect effects on yield per plant were seen in number of nodes by number of fruits per plant followed by fruit diameter by fruit weight, plant height and number of branches through number of fruits per plant at genotypic level which indicated the parameter consideration of these parameters during selection. The indirect effects of remaining traits were too low to be considered important. The residual effect is 0.0194 which denoted a reasonable fit explain the cause and relationship between the yield and yield attributing traits.

Conclusion

Fruit yield per plant in okra was governed by multiple interrelated yield components. Genotypic correlation analysis revealed significant positive associations of fruit yield with number of fruits per plant, average fruit weight, fruit diameter, number of nodes and number of branches, while earliness-related traits showed significant negative associations. Path coefficient analysis identified average fruit weight and number of fruits per plant as the major traits exerting the highest positive direct effects on fruit yield, with number of branches and number of nodes contributing through favourable direct and indirect effects. Overall, the combined interpretation of correlation and path coefficient analyses revealed that average fruit weight, followed by number of fruits per plant, number of branches and number of nodes were important yield components in okra as all these traits exhibited significantly positive association with fruit yield per plant at genotypic level and direct effect of these traits on fruit yield per plant was highly positive.

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