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PHENOTYPIC CORRELATIONS AMONG GROWTH, FLORAL, AND YIELD TRAITS IN OKRA (*ABELMOSCHUS ESCULENTUS*) UNDER *ASPERGILLUS NIGER* INFECTION

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ABSTRACT

Effective breeding for stress resilience and high yield in okra (*Abelmoschus esculentus*) requires a clear understanding of the phenotypic correlations among key agronomic traits under *Aspergillus niger* (*Asp*) infection. This study investigates the interrelationships among growth, floral, and yield traits under *Asp* stress, with the aim of identifying morphological indicators that can support indirect selection for improved performance. Twenty okra germplasm lines of diverse genetic backgrounds were obtained from the National Centre for Genetic Resources and Biotechnology and evaluated in a screen house experiment using a completely randomized design with three replicates. *Asp* inoculation was conducted at sunset to ensure effective infection, while a common regional landrace of okra was maintained as the uninfected control. Morphological data on growth, flowering, and yield traits were collected using standard descriptors, and phenotypic correlations among traits were analyzed using SPSS. Strong positive correlations among growth (leaf length-width r=0.98, stem diameter-leaf length r=0.91), flowering (number of petals-sepals r=1.00, flower count-petal length r=0.80), and yield traits (fruit length-weight r=0.91, peduncle length-fruit length r=0.87) were identified in okra under *Asp* infection. These key morphological indicators can guide effective selection for disease resistance and improved yield. These relationships provide a basis for efficient indirect selection and marker-assisted breeding to develop high yielding, disease resilient okra varieties adaptable to diverse environments.

Keywords: Okra, *Aspergillus*, Phenotypic correlations, Yield traits, Disease resistance

INTRODUCTION

Okra (*Abelmoschus esculentus*) is a widely cultivated vegetable crop, highly valued for its rich nutritional profile, including vitamins, minerals, and dietary fiber, making it an important food source in tropical and subtropical regions (Romdhane *et al*., 2020; Gemede *et al*., 2015). Beyond its dietary benefits, okra contributes significantly to the livelihoods of smallholder farmers and local economies, serving both as a cash crop and a staple vegetable. Despite its importance, okra production is frequently challenged by a range of biotic stresses, particularly pests and pathogens, which severely reduce plant health and crop yield. These biotic factors compromise key physiological processes such as vegetative growth, flowering, and fruit development, thereby limiting overall productivity. A recent comprehensive review by Ounis *et al*. (2024) extensively documents the diversity of arthropod pests, nematodes, and microbial pathogens that afflict okra, highlighting their widespread distribution and detrimental impact on yield stability. These biotic stresses not only reduce the quantity of fruit produced but also affect fruit quality, further complicating breeding and management efforts. Therefore, addressing these constraints remains a critical priority for enhancing okra production and ensuring food security in vulnerable regions.

Morphological traits associated with growth, flowering, and yield are crucial determinants of plant performance and adaptability under varying environmental conditions. These traits often display complex interactions, shaped by underlying genetic factors and environmental influences such as soil fertility, climate, and pathogen presence. Understanding the nature and extent of these trait relationships is essential for developing effective selection criteria in breeding programs. Farooqkhan *et al*. (2024) demonstrated significant positive correlations between fruit yield and various fruit traits in okra, including fruit girth, fruit weight, number of fruits per plant, and harvest period. Such correlations suggest that selecting for these morphological attributes could indirectly improve overall yield potential. Additionally, growth and reproductive traits influence resource allocation within the plant, affecting both the quantity and quality of harvestable produce. By elucidating the associations among these traits, breeders can identify reliable phenotypic markers that facilitate rapid and cost-effective screening of genotypes, especially when combined with molecular tools.

Despite progress in okra breeding, there remains a notable gap in comprehensive analyses that simultaneously consider vegetative growth, reproductive development, and yield traits, particularly under biotic stress conditions. Integrating these trait categories is crucial to fully understand how okra plants respond to disease pressure and to identify traits that contribute most significantly to resilience and productivity. Investigating the genetic variability and phenotypic associations among these traits under stress conditions enables breeders to develop robust selection strategies that enhance both yield and resistance. Yadav *et al*. (2024) emphasized the importance of such integrated character association studies in okra, demonstrating that a better understanding of genetic variability and trait interrelationships is fundamental for effective selection and genetic improvement. By pinpointing key morphological and yield-related markers, breeding programs can be streamlined to develop cultivars that perform well under diverse environmental and pathological challenges, thus contributing to sustainable okra production and food security.

Okra (*Abelmoschus esculentus*) is a vital crop whose yield is often compromised by biotic stresses like *Asp* infection, which impacts vegetative growth, flowering, and fruit development. Effective breeding requires identifying easily measurable traits that correlate strongly with yield and stress tolerance. This study aimed to investigate the phenotypic correlations among key growth, floral, and yield traits in okra to support efficient selection strategies. Specifically, the objectives were to assess the interrelationships among vegetative, reproductive, and yield traits under *Asp* stress and identify morphological indicators useful in selecting high performing genotypes. It was hypothesized that strong and significant correlations exist among these traits, and that selecting for one could enhance others due to genetic linkage or pleiotropy. The findings are expected to guide indirect selection in okra breeding programs, contributing to the development of resilient and high yielding cultivars suited to diverse growing environments.

MATERIALS AND METHODS

Germplasm Collection, Site Conditions, and Study Design

Twenty okra accessions (NGB02411, NGB00371, NGB00342, NGB00397, NGB02431, NGB00340, NGB00350, NBG00400, NGB02432, NGB02423, NGB00356, NGB00373, NGB00346, NGB02437, NGB02212, NGB00378, NGB00297, NGB02405, NGB00466, and NGB00338) were obtained from the National Centre for Genetic Resources and Biotechnology. Seed and soil sterilization were carried out following the methods of Anakaa *et al*. (2025). The study was conducted from January to April 2025 under meteorological conditions typical for the region, including temperatures ranging between 24.1°C and 28.7°C, relative humidity averaging 71.7%, and prevailing northeast winds. Soil characteristics observed during the study matched those reported by Anakaa *et al*. (2025), providing a consistent environmental baseline. The experiment was conducted in the screenhouse of the Biological garden at the Federal University Dutsin-Ma (12˚28'25"N, 7˚29'5"E) using a completely randomized design with three replicates. Plants were spaced 60 cm apart both between and within rows to ensure optimal growth, which helped minimize environmental variability and facilitated reliable morphological and genetic analyses.

Fungal Inoculation and Morphological Trait Evaluation

Aspergillus niger was isolated from infected okra plants in farmers' fields and cultured aseptically on Potato Dextrose Agar (PDA). For inoculation, fungal spores were suspended in sterile water to an optical density (OD_{600}) of 0.5 (Anakaa *et al*., 2025). At the fourth week of growth, 40 mL of the spore suspension was applied to scarified crown regions of the plants during the evening to ensure effective infection. A non-inoculated control, consisting of commonly cultivated landraces in the region, was maintained as a baseline for comparison. Brown lesions observed on the lower leaves of treated plants confirmed *Asp* infection, which was further validated by isolating and identifying the pathogen from infected leaf tissues cultured on PDA medium. Morphological traits assessed included various growth, floral, and yield related parameters such as stem length, number of leaves, leaf dimensions, floral structures, and fruit characteristics. Trait measurements followed the guidelines of the IPGRI okra descriptor. Growth traits were recorded weekly over a four-week period in the morning, whereas flowering and yield traits were measured once 50% of the plants had reached flowering and fruiting stages.

Statistical Analysis

Morphological data collected from the evaluated growth, floral, and yield traits were subjected to statistical analysis using IBM SPSS Statistics version 26. Pearson's correlation coefficients were computed to assess the strength and direction of phenotypic relationships among traits. The significance of the correlations was tested at 1% and 5% probability levels to identify key traits with potential for indirect selection in breeding programs.

RESULTS AND DISCUSSION

Correlation of Growth Traits in Okra Under *Asp* Infection

The strong positive correlations among key growth traits in okra have important implications in the context of *Asp* infection. Since the pathogen primarily affects overall plant vigor and can lead to stunted growth, the observed associations such as leaf length and leaf width (r = 0.98), and stem diameter with both leaf length (r = 0.91) and leaf width (r = 0.93) suggest that reductions in one trait due to infection are likely to reflect broader declines in plant health. The significant correlation between number of leaves and stem diameter (r = 0.83), as well as stem length (r = 0.73), indicates that infection induced stress could disrupt coordinated vegetative development. These findings underline the potential of using easily measurable traits like leaf width or stem diameter as indicators of infection severity or resistance. Therefore, selecting for robust expression of these traits may enhance early detection and improve resistance breeding strategies against *Asp* in okra.

Correlation of Flowering Traits in Okra Under *Asp* Stress

Strong and highly significant ($P \leq 0.01$) correlations were observed among key flowering traits in okra, indicating tight developmental coordination. Days to first flower showed strong positive associations with number of flowers (r = 0.93), petal length (r = 0.80), sepal length (r = 0.73), petal width (r = 0.97), number of petals (r = 1.00), and number of sepals (r = 0.90), suggesting synchronized floral development. Petal and sepal lengths were also positively correlated (r = 0.61), as were stamen length with both petal length (r = 0.90) and flower count (r = 0.85). A perfect correlation between number of petals and sepals (r = 1.00) further highlights morphological consistency in floral architecture. These findings imply that floral trait expression in okra is tightly regulated and highly interdependent, offering reliable phenotypic markers for selecting early and prolific flowering genotypes, which is particularly valuable for improving resilience under stress conditions, such as *Asp* infection.

Correlation of Yield Traits in Okra Under *Asp* Stress

Significant and strong positive correlations ($P \leq 0.01$) were observed among key yield related traits in okra, highlighting the interconnectedness of fruit size, shape, and productivity. Fruit length was strongly correlated with cumulative fruit weight (r = 0.91), fruit width (r = 0.94), and fruit diameter at the base (r = 0.89), indicating that larger fruits contribute directly to higher yield. Fruit width also showed strong associations with cumulative fruit weight (r = 0.89) and other fruit dimensions (r = 0.83–0.94). The number of ribs was positively linked to fruit size traits and yield, including fruit width (r = 0.83) and cumulative fruit weight (r = 0.63), suggesting its utility as a morphological indicator of yield potential.

Peduncle traits were highly correlated with yield components peduncle length with fruit length (r = 0.87) and cumulative weight (r = 0.80), and peduncle width with seed number (r = 0.80) and fruit length (r = 0.88) emphasizing the peduncle's role in fruit development. Number of locules correlated strongly with seed number (r = 0.89) and fruit weight (r = 0.65), while seed thickness was associated with fruit width (r = 0.94), peduncle length (r = 0.90), and locule number (r = 0.78). Negative correlations were relatively weak but notable, such as between fruit rib spacing and cumulative fruit weight (r = -0.30), suggesting that tighter rib spacing may be linked to heavier fruits. Generally, the results reveal that selecting for fruit and peduncle dimensions can serve as effective proxies for improving yield and seed productivity, critical for breeding high performing okra varieties under both optimal and stress conditions.

Table 1: Correlation of Growth Traits in Okra under *Asp* Stress

Traits	Stem length	Number of leaves	Leaf length	Leaf width
Number of leaves	0.73			
Leaf length	0.79	0.83		
Leaf width	0.78	0.81	0.98	
Stem diameter	0.71	0.83	0.91	0.93

P≤ 0.001, **P≤ 0.01, *P≤ 0.05

Table 2: Correlation of Flowering Traits in Okra under *Asp* Stress

Traits	Days of first flower	Sepal length	Petal length	Number of flowers	Number of petals	Number of sepal	Stamen length	Width of flower from base	Width of from top
Sepal length	0.73								
Petal length	0.80	0.61							
Number of flowers	0.93	0.67	0.80						
Number of petals	1.00	0.73	0.81	0.93					
Number of sepa	0.90	0.74	0.82	0.92	1.00				
Stamen length	0.84	0.75	0.90	0.85	0.85	0.86			
Width of flower from base	0.75	0.71	0.88	0.70	0.76	0.77	0.84		
Width of flower from top	0.53	0.45	0.70	0.47	0.54	0.57	0.63	0.78	
Petal width	0.97	0.70	0.79	0.90	0.97	0.97	0.83	0.78	0.63

***P≤ 0.001, **P≤ 0.01, *P≤ 0.05

Table 3: Correlation of Yield Traits in Okra under *Asp* Stress

Traits	CFW	NF	FL	FW	FDMM	NR	FDMT	FDMB	TFW	TP	PL	NL	NS	LT	WT	FRS	SC	PW	DP	TP	TT
NF	0.04																				
FL	0.91	0.12																			
FW	0.89	0.13	0.94																		
FDMM	0.72	0.17	0.81	0.81																	
NR	0.63	0.39	0.79	0.83	0.73																
FDMT	0.67	0.37	0.78	0.82	0.70	0.80															
FDMB	0.82	0.18	0.89	0.92	0.76	0.82	0.79														
TFW	0.45	0.37	0.55	0.61	0.53	0.73	0.68	0.63													
TP	0.09	0.44	0.29	0.36	0.27	0.47	0.35	0.38	0.430.												
PL	0.80	0.11	0.87	0.89	0.75	0.84	0.77	0.84	0.66	0.31											
NL	0.65	0.24	0.78	0.83	0.70	0.94	0.81	0.80	0.73	0.37	0.85										
NS	0.63	0.22	0.74	0.74	0.64	0.88	0.66	0.73	0.71	0.37	0.75	0.89									
LT	0.86	0.16	0.92	0.87	0.73	0.73	0.70	0.82	0.50	0.20	0.81	0.71	0.67								
WT	0.41	0.41	0.43	0.53	0.45	0.47	0.48	0.51	0.36	0.16	0.53	0.46	0.31	0.39							
FRS	-0.30	0.96	0.11	0.65	0.08	0.15	0.11	0.06	0.30	0.61	-0.10	-0.07	-0.10	-0.03	-0.05						
SC	0.87	0.09	0.94	0.97	0.80	0.84	0.79	0.90	0.62	0.31	0.94	0.84	0.74	0.87	0.56	-0.13					
PW	0.78	0.30	0.88	0.91	0.76	0.87	0.76	0.86	0.68	0.41	0.78	0.83	0.80	0.85	0.38	0.17	0.88				
PD	0.38	0.06	0.41	0.49	0.43	0.45	0.48	0.47	0.36	0.13	0.56	0.47	0.31	0.34	0.95	-0.11	0.54	0.33			
TP	0.86	0.20	0.95	0.94	0.78	0.88	0.83	0.90	0.69	0.39	0.89	0.86	0.79	0.89	0.44	-0.01	0.95	0.93	0.42		
TT	0.82	0.26	0.91	0.93	0.78	0.88	0.86	0.88	0.71	0.38	0.90	0.87	0.78	0.83	0.46	0.04	0.93	0.90	0.44	0.97	
ST	0.85	-0.05	0.89	0.94	0.75	0.76	0.72	0.84	0.49	0.31	0.90	0.78	0.69	0.79	0.49	-0.32	0.95	0.80	0.46	0.87	0.87

P≤ 0.001, **P≤ 0.01, *P≤ 0.05, CF=Cumulative fruit weight, NF=number of fruit, FL= Fruit length, FW =Fuit width, FDMM=Fruit diameter at maturity middle, NR= Number of ribs, FDMT=Fruit diameter of maturity tip, FDMB=Fruit diameter of maturity base, TFW=Thickness of fruit wall, TP=Thickness of pericarp, PL=Peduncle length, NL=Number of locus, NS=Number of seeds, LT=Length of tip, WT=Width of tip, FRS=Fruit rib spacing, SC=Size of core, PW=Peduncle width, DP= Diameter of peduncle, TP= thickness of peduncle, TT=thickness of fruit tip, ST= Seed thickness

Discussion

Genetic Correlation of Growth Traits and Breeding Implications under Asp Stress

Genetic correlations among vegetative traits in okra particularly between leaf length and width, as well as between stem diameter and leaf dimensions are exceptionally high, hinting at strong pleiotropy or tightly linked loci. This is consistent with the observed high broad-sense heritability for these traits in Ethiopian okra germplasm, where traits like leaf width and stem diameter exhibited notably high heritability and genetic advance (Melaku *et al*., 2020). Furthermore, multivariate analyses in Ethiopian and Dire Dawa (Ethiopia) okra populations highlight leaf width, leaf length, and stem diameter as primary contributors to genetic diversity and phenotypic differentiation (Mohammed *et al*., 2022).

In the context of *Asp* infection, which compromises plant vigor, these strong genetic correlations imply that a decline in one trait (leaf width) would likely signal simultaneous reduction across other growth dimensions. From a plant breeding perspective, targeting such traits particularly those with both high genetic control and ease of measurement can streamline selection. Specifically, breeders can employ indirect selection using leaf width or stem diameter as early phenotypic markers for resistance or resilience. Given the high heritability and genetic gain potential of these traits, selection is likely to be both efficient and durable (Melaku *et al*., 2020). Generally, integrating these traits within genetic improvement programs enhances early detection of disease impact and facilitates the development of okra varieties that combine vigor with resistance ultimately reinforcing yield stability under pathogen pressure.

Genetic Correlations and Breeding Implications of Flowering Traits in Okra

Research has reinforced the genetic interdependence among key flowering traits in okra (*Abelmoschus esculentus*), such as days to first flower, petal and sepal length, and flower number. These traits exhibit strong positive correlations, suggesting tight genetic integration likely due to pleiotropic effects or closely linked genes controlling floral development. Priyanka *et al*. (2018) reported high heritability and significant genetic advance for flowering-related traits in okra, indicating the predominance of additive genetic variance that facilitates effective selection. Similarly, Agbowuro *et al*. (2019) observed genetic variability, heritability, and genetic advance in okra, further supporting the potential for selection based on these traits.

From a breeding perspective, these findings emphasize the utility of easily measurable flowering traits as reliable indirect selection markers. Traits like petal number and flowering time can serve as proxies for complex floral architecture, streamlining the breeding process by reducing phenotyping effort. Importantly, in the context of biotic stress such as *Asp* infection, selecting for early and synchronized flowering could confer adaptive advantages by enabling escape or tolerance mechanisms. Integrating these genetically correlated traits into breeding programs is therefore a promising strategy to enhance stress resilience and improve yield stability in okra. The strong genetic correlations among key flowering traits underscore the potential for efficient selection in breeding programs aimed at improving yield and stress resilience. The high heritability and genetic advance observed for these traits further support their use as reliable selection criteria.

Correlation of Yield Traits and Selection Strategies for Okra Improvement

Significant interrelationships among key morphological traits in okra (*Abelmoschus esculentus*) highlight their potential as reliable indicators of yield and productivity. Strong positive correlations between fruit length, width, diameter, and cumulative fruit weight suggest a coordinated development pattern that enhances general yield potential. Patel *et al*. (2019) identified substantial associations among these traits, emphasizing their relevance in breeding programs aimed at improving okra performance. The dimensions of the peduncle have also been shown to influence nutrient transport and fruit set. Akinwale *et al*. (2011) demonstrated that variations in peduncle traits are closely linked to seed yield components, indicating their role in determining reproductive success.

The association between seed traits and fruit morphology supports the concept of integrated development, as seed size and quality often reflect patterns of fruit growth. Although negative correlations such as those between rib spacing and fruit weight are relatively weak, they may point to subtle trade-offs that deserve further investigation. Understanding these relationships is essential for the development of high yielding okra varieties adaptable to a range of growing environments. Generally, the selection of easily measurable fruit and peduncle traits offers a practical strategy for enhancing both yield and seed productivity in breeding programs.

CONCLUSION

The strong and consistent correlations among growth, flowering, and yield related traits in okra indicate a high degree of morphological and physiological integration, with key traits such as stem diameter, leaf width, fruit dimensions, and peduncle size serving as reliable indicators of overall plant performance. These relationships suggest that improvements in one trait are likely to enhance others, offering opportunities for efficient indirect selection in breeding programs. The genetic basis of these correlations may involve pleiotropy or linkage among genes controlling vegetative vigor, reproductive development, and fruit productivity. Notably, traits like peduncle width and seed thickness are valuable proxies for yield, especially under stress conditions like *Asp* infection. The findings support the use of easily measurable morphological traits in early selection and provide a foundation for marker-assisted breeding strategies aimed at developing high yielding, disease-resilient okra varieties adaptable to diverse environments.

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