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GENETIC VARIABILITY AND GENOTYPIC AND PHENOTYPIC CORRELATION COEFFICIENTS FOR YIELD-RELATED TRAITS IN CUCUMBER (*CUCUMIS SATIVUS* L.)

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SUMMARY

This study aimed to determine the genetic behavior of three parental cultivars and their six F1 hybrids obtained through full-diallel crosses in cucumber. Variance components, broad-sense heritability, and genotypic, phenotypic, and environmental correlation coefficients underwent estimations for yield-related traits. The results revealed genotypic and phenotypic variances exceeded environmental variance for the studied traits. Broad-sense heritability estimates were high for most traits, indicating a significant genetic influence in trait expression. In the correlation analysis, total yield revealed significant positive genotypic association with early yield per plant (r = 0.642) and branches per plant (r = 0.432). In contrast, the total yield enunciated a notable negative correlation with fruit diameter (r = −0.393) and crust thickness (r = −0.404). Phenotypic correlation mirrored genotypic trends, especially between the total yield and early yield per plant (r = 0.642). In environmental correlation, the number of branches displayed a remarkable positive relationship with dry weight (r = 0.459) and harvest date (r = 0.422). Dry weight also showed a considerable positive correlation with crust thickness (r = 0.575). Additionally, the fruit diameter expressed a positive correlation with total yield (r = 0.551), and peel thickness had a highly significant positive correlation with early yield (r = 0.795).

Keywords: Cucumber (*C. sativus* L.), cultivars, diallel crosses, variance components, heritability, genotypic and phenotypic correlations, yield-related traits

Key findings: The study showed genotypic and phenotypic variances exceeded environmental variance for the yield-related traits in cucumber cultivars and their diallel F1 hybrids. According to the correlation analysis, a significant positive genotypic association appeared between total yield and early yield per plant.

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INTRODUCTION

Cucumber (*Cucumis sativus* L.) is one of the most economically important vegetable crops, belonging to the Cucurbitaceae family. It is a belief that it originated in Northern India, where the wild species *C. hardwickii* could be the ancestral form of the cultivated cucumber (Hassan, 1993). Cucumber is a diploid crop (2n = 14), and the majority of its genotypes are monoecious, producing unisexual flowers. However, perfect (bisexual) flowers occasionally appear, and typically, one reproductive organ develops, resulting in either a male or a female flower (Muhammad, 1983). The said species is partially cross-pollinated and has crucial implications for hybrid breeding programs.

The hybrid vigor (heterosis) discovery has stimulated considerable interest among plant breeders to develop cucumber hybrids with improved yield and quality. Yield is a complex quantitative trait controlled by multiple genes and substantially influenced by environmental factors. Therefore, direct selection for the yield is often unproductive. Instead, indirect selection based on yield-related traits having genetic association with yield and exhibiting high heritability has proven to be a more effective strategy in such types of breeding in crop plants (Ramadan*,* 2024).

Genetic correlation provides insight into trait expression stability across the different environments and helps identify the beneficial traits that can serve as reliable selection indicators. Phenotypic variability depends upon the combination of genetic differences, environmental variations within treatments, and external environmental influences. These factors may weaken the correlation between genotypic and phenotypic values, thereby reducing the efficiency of the selection made for yield-related traits in crop plants (Ali *et al.,* 2021).

The correlation coefficient is an important tool for identifying traits that positively contribute to yield while avoiding those variables associated with undesirable outcomes in different crops (Ahmed *et al.,* 2020). Understanding the interrelationship among the multiple traits also provides a sound basis to plant breeders, particularly when making simultaneous selection for multiple characteristics (Aruna *et al.,* 2019).

Accordingly, the presented study sought to evaluate the variance components, broad-sense heritability, genetic, and phenotypic correlations among the key agronomic traits in cucumber. Its goal was identifying reliable selection criteria for yield in three parental cultivars and their six F1 hybrids obtained through full-diallel crosses in cucumber under the agro-climatic conditions of Central Iraq.

MATERIALS AND METHODS

Breeding materials and procedure

The following experiment on cucumber (*C. sativus* L.) transpired for two successful seasons at the farm located in District Abu-Ghraib, Baghdad, Iraq. In the autumn crop season of 2022, a complete diallel-crossing program (including reciprocal crosses) proceeded among three cucumber parental cultivars, viz., Marketmore 76, Ocucmmol (st), and Lahoba 361034, following Griffing's method (1956), to produce the six F1 hybrids. During the next crop season of spring 2023, the parental cultivars and their F1 hybrids entailed growing in a randomized complete block design with three replications. Experimental units comprising parental cultivars and their hybrids received random assignment within each block to ensure unbiased evaluation of the genotypes for various genetic parameters. All the standard agronomic practices, including fertilization, irrigation, weed control, and pest management, were successful in their application in accordance with the recommendations for the said crop (Matloob *et al.,* 1989).

Traits measurement and analysis

The evaluated traits included percentage of nodes bearing fruit (knot percentage), branches per plant, dry weight, harvest date, the number of fruits, fruit diameter, peel thickness, early plant yield, and total yield.

The genetic (σ^2g), phenotypic (σ^2p), and environmental (σ^2e) variances' estimation engaged the analysis of variance (ANOVA). Broad-sense heritability (h^2b.s.) calculation for all traits helped assess the proportion of total variation attributable to genetic factors. Additionally, genotypic (rg) and phenotypic (rp) correlation coefficients among the various traits of cucumber underwent calculations with the following equations (Das, 1972; Singh and Chaudhary, 1985).

$$\delta^2 G = \frac{msv - mse}{r},$$

$$\delta^2 E = mse,$$

$$\delta^2 p = \delta^2 G + \delta^2 E$$

$$h^2{}_{b.s} = \frac{\delta^2 G}{\delta^2 p} \times 100$$

For the estimation of the genetic and phenotypic correlation coefficients, the study used the following equations:

$$rgij = \frac{\delta gigj}{\sqrt{{}^2\delta gi \delta^2 gj}}$$

$$\text{rpij} = \frac{\delta pipj}{\sqrt{\delta^2 pi \delta^2 pj}}$$

Where $\delta\ gigj$ = the genetic variance between the two traits,

$\delta^2\ gi$ ***=the*** genetic variation for the first trait,

$\delta^2\ gj$ **=** the genetic variation for the second trait,

$\delta\ pipj$ = the phenotypic variance between the two traits,

$\delta^2\ pi$ **=** the phenotypic variation for the first trait,

$\delta^2\ pj$ = the phenotypic variation for the second trait, and

$h^2{}_{b.s}$ = heritability in the broad sense.

RESULTS AND DISCUSSION

Variance components and heritability

The expression of each trait is the result of the combined influence of genetic makeup, environmental factors, and their interaction, collectively referred to as the phenotypic form. The variations in these phenotypic forms among the genotypes are usually the phenotypic variation. Genetic variation arises from the differences in the genetic composition of genotypes grown under the same environmental conditions, whereas environmental variation refers to differences in traits of genetically identical genotypes grown under different environments (Abudlgaffor *et al.,* 2011).

Among the parental cultivars and F1 hybrids of the cucumber, the studied traits showed varied values for the variance components (Table 1). The genetic variance of the trait peel thickness was low (0.002), while other traits exhibited higher genetic variance values, excelling in their corresponding environmental variance values. The results revealed traits with increased genetic variance tend to have a reduced environmental variance. Phenotypic variance also displayed diverse patterns among the studied traits. Notably, most traits demonstrated high genetic and phenotypic variations relative to the environmental variation, aligning with past findings on the genetic variability studies in cucumber genotypes (Arunkumar *et al.,* 2011a, 2011b; Phani *et al.,* 2018; Al-Jaf *et al.,* 2024).

Heritability, defined as the proportion of phenotypic variance attributable to genetic variance, reflects the degree to which a quantitative trait becomes inherited from parental genotypes to their offspring (Al-Sahuki, 1990). Broad-sense heritability estimates varied across traits; however, they were generally higher for most traits in cucumber genotypes, owing to substantial genetic variation coupled with low environmental influence (Table 1). High heritability values suggested these traits were reliable targets for selection and improvement in the cucumber breeding program. These results were also consistent with prior studies

Table 1. The estimates of genetic, environmental, and phenotypic variances and the broad-sense heritability for various traits in cucumber.

Attributes	δ^2G	δ^2E	δ^2P	h^2(b.s.)
Knot percentage	15.123	3.593	18.716	80.80
Branch number	1.741	0.776	2.517	69.16
Harvest date	3.130	0.371	4.241	73.80
Dry weight	138.413	3.065	196.478	70.44
Fruit number	20.861	0.907	21.768	95.83
Fruit diameter	4.730	0.880	5.609	84.32
Crust thickness	0.002	0.0004	0/003	66.66
Early plant yield	2.432	0.001	2.433	99.95
Total yield	54.641	0.029	54.670	99.94

Table 2. The genetic correlation above the diagonal and phenotypic correlations below the diagonal among the various traits of cucumber.

Attributes	Knot percentage	Branch number	Harvest date	Dry weight	Fruit number	Fruit diameter	Crust thickness	Early plant yield	Plant yield
Knot percentage	1.00	*-0.480**	*0.397**	*-0.343*	*0.971***	*-0.621***	-0.203	*0.137*	-0.040
Branch number	*-0.325*	*1.00*	*0.452**	*-0.703***	-0.326	*0.652***	-0.752**	*0.466**	*0.432**
Harvest date	*0.293*	*0.443**	*1.00*	*-0.656***	*0.374*	*0.182*	-0.894**	-0.023	-0.013
Dry weight	-0.253	*-0.372*	*-0.578***	*1.00*	-0.360	*-0.213*	0.794**	-0.256	-0.140
Fruit number	0.843**	-0.203	0.252	*-0.248*	*1.00*	*-0.736***	-0.259	0.234	0.251
Fruit diameter	*-0.559***	*0.361*	*0.018*	*-0.166*	*-0.676***	*1.00*	-0.083	-0.186	*-0.393**
Crust thickness	*-0.157*	*-0.632***	*-0.592***	*0.496***	-0.239	-0.128	1.00	*-0.437**	-0.404*
Early plant yield	*0.127*	*0.376*	*-0.017*	*-0.229*	0.212	-0.172	-0.401*	*1.00*	*0.642***
Total yield	*-0.038*	*0.355*	-0.013	-0.124	0.228	-0.356	-0.380	*0.642***	*1.00*

*Significance at the probability level, r 0.05 = 0.381, **Significance at the probability level, r 0.01 = 0.487.

based on the genetic parameters in cucumber (Al-Bahrani, 2002; Al-Qarghouli, 2010; Ndukauba *et al.,* 2015; Chikezie *et al.,* 2016; Al-Jaf, 2017).

Genotypic correlation

The genetic correlation coefficient measures the degree of relationship between the genetic variances of two quantitative traits in a population and has had wide uses in the inheritance of quantitative traits in crop breeding (Reeve, 1955). Among the cucumber parental cultivars and their F1 hybrids, the studied traits showed varied values of the genetic correlation (Table 2). Total yield exhibited a highly significant positive correlation with early plant yield and the number of branches, with correlation coefficient values of 0.642 and 0.432, respectively. This indicates that earlier-maturing cultivars with more branches tend to have a higher total yield in cucumbers. Conversely, the total yield indicated a nonsignificant positive correlation with fruit number and a nonsignificant negative correlation with fruit diameter (-0.393) and crust thickness (-0.404). Additionally, total yield had a nonsignificant negative correlation with fruit set percentage, dry weight, and harvest date in cucumbers.

Regarding crust thickness, a highly significant positive genetic correlation appeared with dry weight (0.794), while it revealed a significant negative correlation with the number of branches and dry weight in cucumber genotypes. Fruit diameter emerged to be positively correlated with branch number (0.652); however, it had a negative correlation with knot percentage (-0.621) and fruit number (-0.736). A significant positive genetic correlation (0.971) existed between the traits of fruit number and knot percentage. Reports of similar findings have also occurred in the correlation studies of cucumber genotypes (Chandan and Singh, 2018; Murtadha and Sanni, 2018).

Harvest date showed a highly significant negative genetic correlation with branch number (-0.703) and dry weight (-0.656). Dry weight exhibited a notable positive correlation with both fruit set percentage (-0.343) and branch number (-0.703). The number of branches had a substantial negative genetic correlation with fruit set percentage (-0.480). Overall, these genetic correlation values highlighted the complex relationship among the yield-related traits. These results were greatly analogous to past findings on correlation studies in cucumber parental cultivars and their hybrids (Shah *et al.,* 2018; Al-Jaf *et al.,* 2024).

Phenotypic correlation

According to phenotypic correlation coefficients, the studied traits revealed varied values of significance for trait association among the cucumber parental cultivars and F1 hybrids (Table 2). The trait total plant yield exhibited a highly significant positive correlation with early plant yield (*r* = 0.642). However, the total plant yield correlation was nonsignificant and positive with branch number and fruit number. A nonsignificant negative correlation of total yield was evident with the traits of knot percentage, dry weight, harvest date, fruit diameter, and crust thickness in the cucumber genotypes. The positive correlation observed between total plant yield and early yield indicates that earliness is a key determinant of productivity in cucumber and can be effective as a reliable indirect selection criterion in breeding programs (Sharma *et al.,* 2018). In contrast, the nonsignificant association of total yield with branch number and fruit number suggests these traits may not consistently contribute to yield improvement, likely due to variation in fruit retention efficiency. The weak negative correlations between total yield and traits, such as knot percentage, dry weight, harvest date, fruit diameter, and crust thickness, further imply that excessive vegetative growth or delayed maturity could be detrimental to yield stability (Pal *et al.,* 2017; Kumar *et al.,* 2024).

The trait early plant yield showed a nonsignificant positive phenotypic correlation with the knot percentage, branch number, and fruit number. Conversely, the early plant yield had a highly significant negative correlation with crust thickness (*r* = -0.401). The trait of crust thickness emerged to be significantly positively correlated with dry weight (*r* = 0.496), while the said trait had a significant negative correlation with branch number and harvest date (*r* = -0.632 and -0.592, respectively).

Fruit diameter provided a nonsignificantly positive correlation with branch number and dry weight yet exhibited a highly significant negative correlation with fruit set percentage and fruit number (*r* = -0.559 and -0.676, respectively). Fruit number showed a highly remarkable positive correlation with fruit set percentage (*r* = 0.862) and a nonsignificant positive correlation with dry weight in cucumber genotypes. Early plant yield in cucumbers showed a minimal influence from knot percentage, branch number, and fruit number but decreased significantly with increasing crust thickness, indicating that thinner fruits favor early productivity (Mehta and Sharma, 2020). Crust thickness signified a positive association with later harvest but a negative association with branch number and dry weight, reflecting a trade-off between fruit protection and vegetative growth (Rathod *et al.,* 2021). A larger fruit diameter reduced fruit set and number, while fruit number strongly depended on fruit set efficiency (Serhiienko *et al.,* 2024). These patterns suggest that breeding for high early yield should focus on optimal crust thickness, efficient fruit set, and balanced vegetative growth rather than increasing branch number or fruit size alone.

Harvest date had a highly significant negative phenotypic correlation with dry weight (*r* = -0.578). Additionally, dry weight demonstrated a significantly positive correlation with branch number (*r* = 0.443), while the said trait had a non-significant positive correlation with knot percentage. These results align with past findings based on correlation analysis among the yield-related traits of cucumber genotypes (Afangideh *et al*., 2005).

Environmental correlation

It is a given that plant genes are responsible for the inheritance and transmission of traits; however, their expression mostly acquires influences from the different environmental factors. These environmental factors considerably affect all genetic traits, whether qualitative or quantitative, although their impact is generally greater on quantitative traits. Environmental variation estimation for a given trait can be successful by assessing the variation within a population of individuals sharing the same genetic makeup while also considering changes in genetic variance associated with the genetic backgrounds of the different genotypes (Al-Jaf *et al.,* 2024).

Based on the environmental correlation analysis, the number of branches revealed a significant positive correlation coefficient with the traits, dry weight and harvest date, among the cucumber parental cultivars and F1 hybrids (0.459 and 0.422, respectively) (Table 3). It indicates that more vegetative growth may extend the crop cycle and increase biomass. Likewise, it negatively impacted key yield components, such as fruit number, fruit diameter, and early plant yield. Conversely, branch number exhibited a significant negative correlation with three other yield-related traits, viz., fruit number, fruit diameter, and early plant yield in cucumber genotypes, with the values of -0.534, -0.623, and -0.508, respectively. This suggests a trade-off between vegetative vigor and reproductive efficiency. These patterns are consistent with previous studies, which reported that excessive branching can divert assimilates from fruit development, reducing early and total yield (Onyia et al., 2012; Chinatu et al., 2017). Therefore, selection for an optimal branch number is critical to balance vegetative growth with fruit production and improve overall yield performance in cucumber breeding programs.

Furthermore, the trait, dry weight, demonstrated a highly significant negative environmental correlation with crust thickness (-0.790). However, the said trait showed a significant negative correlation with harvest day (-0.568). The environmental correlation of the harvest date was highly significant negatively with the traits of crust thickness and early plant yield, with coefficients of -0.790 and -0.656, respectively. Fruit diameter displayed a highly substantial positive environmental correlation with the total yield (0.551), yet a noteworthy negative correlation with peel thickness (-0.408). The trait of crust thickness was evident with a highly significant positive correlation environmentally with early plant yield (0.795) (Table 3). These results showed a greater similarity with past findings observed in the correlation analysis in cucumber genotypes (Singh *et al.,* 2022; Al-Jaf *et al.,* 2024).

Table 3. The environmental correlation among the various traits of cucumber.

Attributes	Knot percentage	Branch number	Harvest date	Dry weight	Fruit number	Fruit diameter	Crust thickness	Early plant yield	Plant yield
Knot percentage	1.00	0.141	-0.024	0.055	0.025	-0.265	0.087	0.341	-0.220
Branch number		1.00	0.422*	0.459*	-0.534**	-0.623**	-0.238	-0.508**	-0.331
Harvest date			1.00	-0.376	-0.069	-0.568**	0.575**	0.139	-0.210
Dry weight				1.00	-0.258	0.007	-0.790**	-0.656**	-0.353
Fruit number					1.00	0.084	0.158	0.098	0.018
Fruit diameter						1.00	-0.408*	-0.157	0.551**
Crust thickness							1.00	0.795**	-0.229
Early plant yield								1.00	-0.147
Total yield									1.00

*Significance at the probability level $r_{0.05}$ = 0.381, **Significance at the probability level $r_{0.01}$ = 0.487.

CONCLUSIONS

The results revealed genotypic and phenotypic variances exceeded environmental variance for the studied traits among the cucumber (*C. sativus* L.) parental cultivars and F1 hybrids. Broad-sense heritability estimates were high for the majority of the traits, indicating a significant genetic influence in the traits' expression. The environmental factors remarkably influence the correlation among the various growth and yield-related traits of cucumbers.

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