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Genetic Variability and Character Associations for Quantitative Traits of Squash (*Cucurbita pepo*) Genotypes

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ABSTRACT

For the majority of characteristics, there were only minor variations between GCV% and PCV%, suggesting that genetic influences play a significant role in regulating how these traits are inherited. The majority of the traits under study exhibited high GCV/PCV %, according to the results. In terms of yield, the genotypes showed significant and nearly equal genetic advancement. For practically every trait under study, the range of variability between several genotypes was very significant. The potential utility of these traits and genotypes to create breeding programs to increase fruit output and quality was demonstrated by strong estimates of heritability and a high predicted genetic progress. Analysis of correlations showed that variables related to yield had a high genetic connection. Path coefficient analysis identified the number of fruits per plant (direct effect: 1.3786) and average fruit weight (direct effect: 0.7794) as having the strongest positive direct effects on yield. The results suggest that selection based on the number of fruits per plant and average fruit weight would be most effective for improving squash yield. Regarding the relative importance of joint effects, it is obvious that their effective parts were obtained by number of fruits/plant on yield through its associations with each of average of fruit weight (25.5 & 24.2%) and 100-seed weight (3.8 & 9.03%).

Keywords: Correlation, Genetic variability, Path analysis, Squash breeding, Yield components.

INTRODUCTION

In Egypt, squash (*Cucurbita pepo*) is referred to locally as "Kousa." Its chromosome number is 2n = 40 and it is a member of the *Cucurbitaceae* family. Both Northern and Southern America are the native home of this crop. The genus *Cucurbita* contains 27 species, five of which are cultivated. It is cross-compatible with *C. maxima, C. moschata, and C. mixta* and is commonly referred to as *C. pepo*. It is likely the most commonly grown species of *Cucurbita* in Egypt (Tindall, 1983 & Galala, 2016). According to Bose & Som (1998) and Abdein *et al.* (2023) squash is a strong source of vitamins, particularly high carotenoid pigments and minerals, and is quite high in energy and carbs. In order to properly characterize populations and enable the efficient development of breeding populations that are intended to accomplish certain goals, a thorough understanding of the genetic diversity of economically significant traits is necessary for the effective management and use of the germplasm. In addition to yield, a crop breeding program that aims to increase plant productivity must take into account its constituents that either directly or indirectly affect yield. Important biometric technologies that successfully show the relationship and association between various crop yields and quality components and aid in the selection of superior genotypes are correlation and path coefficient analysis. Correlation is a measure of the degree of association between two or more features (Gomez and Gomez, 1984). It can be genetic or environmental (non-genetic) in origin (Hallauer and Miranda, 1988) and is expressed as a correlation coefficient. Selection for complex features is more successful because complex traits are associated with simple ones (Falconer, 1981). In addition to allowing for a critical review of the supplied correlation and determining the relative relevance of each factor, the route coefficient analysis developed by Dewey and Lu (1959) offers an efficient way to determine the direct and indirect reasons for relationship. Character selection may be employed to improve the dependent variable if the independent character directly affects it, indicating an actual association between the two traits. Such data makes it possible to enhance various attributes at the same time and aids in choosing complex inherited traits more effectively. Breeders spend less time on the selection process when they use path coefficient analysis, which offers a selection criterion (Qaizar *et al.*, 1991). The relationship between yield and quality features, as well as both the direct and indirect impacts of these interactions on fruit production in various squash genotypes under Upper Egypt circumstances, have not yet been the subject of any noteworthy research in Egypt. In light of these facts, the current study was conducted to determine the correlation and path coefficient among features in squash F1 breeding hybrids as well as assess variability in various squash genotypes under Upper Egypt conditions.

MATERIALS AND METHODS

The present investigation was carried out at a private farm, Sohag Governorate, Egypt, (latitude 26° 33' N, longitude 31° 41' E) during both summer seasons of 2023 and 2024. The experimental material for the present study consisted of fifteen F1 hybrids of squash obtained from a 6x6 half diallel cross during 2023 summer season. The seeds of fifteen F1 hybrids were sown in the field during summer 2024 season for comparative evaluation on various quantitative traits. The experiment was laid out in a Randomized

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Complete Block Design with three replications of each hybrid. The soil texture of the experimental site was a sandy loam soil with a pH of 7.5, an organic matter content was 0.96%, electrical conductivity (EC) of 1.23 dS m^{-1}. The healthy crop stand was raised by adhering to the traditional cultural practices for squash. When the peduncle dried and reached maturity, the fruits were picked. The quantitative traits, *i.e.,* Sex ratio (SR), fruit length (FL, cm), Fruit diameter (FD, cm), 100-seed weight (100-SW, g), number of fruits per plant (NF/P), and average fruit weight (AFW, g) as well as total yield per plant (TYP, kg) were recorded from ten randomly selected competitive plants in each plot.

Statistical Analysis:

Analysis of variance was applied to the mean values of the data collected for various attributes (Gomez and Gomez, 1984). Allard (1960) and Falconer (1989) were used to assess broad sense heritability (h^2). Stanfield (1983) defined heritability as follows: $0 \le x < 0.2$ = low, $0.2 \le x \le 0.5$ = medium, and $x > 0.50$ = high. In accordance with Singh and Chaudhury (1985), the phenotypic (PCV%) and genotypic (GCV%) coefficients of variability were computed. Using the formula proposed by Johnson *et al.* (1955), genetic advance (GA) was computed as follows: $GA = K \times \delta^2 g / \sqrt{\delta^2 p}$, where K = 1.76, constant (based on selection intensity 10%). According to Hadiati *et al.* (2003), genetic advance as a percentage of mean (GAM%) = $(GA/\bar{X}) \times 100$. GAM% ranges from 0 to 7% for low, 7 to 14% for medium, and >14,1 for high. Phenotypic and genotypic correlation coefficients among all pairs of traits were estimated using the OPSTAT statistical software. Subsequently, path coefficient analysis was performed to partition the correlation coefficients into direct and indirect effects, following the methodology of Dewey and Lu (1959). This analysis treated fruit yield as the effect variable and the other six traits (SR, FL, FD, 100-SW, NF/P, AFW) as causal factors.

RESULTS AND DISCUSSION

Genetic variability

The phenotypic (PCV) and genotypic (GCV) coefficient of variations differed in magnitude across all traits, according to the data in Table 1. The PCV and GCV levels of the characters examined in this study were low, moderate, and high. The yield characters 100-SW, NF/P, and AFW had the highest PCV and GCV values (Mahmoud and El-Mansy, 2018). For the majority of traits, there were only minor variations between GCV% and PCV%, suggesting that genetic effects play a significant role in regulating how these traits are inherited. According to our findings, the majority of the qualities under study had high GCV/PCV percentages. The presence of high genetic variability for various traits and less environmental influence was shown by the fact that high phenotypic variations were made up of high genotypic variations and fewer environmental variations. As a result, phenotypic selection alone may be useful for enhancing these characteristics. We can infer from the explanation above that the best qualities for selection are 100-SW, NF/P, and AFW. As a result, these characteristics may be more genotypically prevalent, and they could potentially be further improved.

Table 1. Different genetic parameters for quantitative traits of squash

	SR	FL	FD	100-SW	NF/P	AFW	TYP
Mean±SE	1.36±0.21	14.73±1.01	3.85±0.29	12.76±0.70	25.84±1.18	60.48±6.46	2.33±0.23
PCV	2.84	7.14	1.50	23.16	16.21	47.37	2.05
GCV	1.26	3.71	0.41	21.24	13.54	12.89	0.91
GCV/PCV	44.37%	51.96%	27.33%	91.71%	83.53%	27.21%	44.39%
h^2b	0.71	0.76	0.53	0.97	0.94	0.53	0.70
GA% of means	12.41	33.76	4.92	139.15	94.15	154.98	8.93

SE: standard error, SR: Sex ratio%, FL: Fruit length (cm), FD: Fruit diameter, 100-SW: 100 Seed weight (g), NF/P: number of fruit per plant, AFW: average fruit weight, and TYP: total yield/plant (kg)

Plant breeders use the heritable fraction of the variation as a basis for selection based on phenotypic performances. The findings showed that, of all the variables examined, wide sense heritability (based on Stanfield, 1983) had the highest proportion (Table 1). Rapid advancement through selection for these qualities was suggested by high heritability. These findings suggested that environmental influences had little effect on the inheritance of these qualities and that mean-based selection would be effective in enhancing them. According to Hadiati *et al*. (2003), genetic advance was low for FD (4.92%), moderate for both sex ratio (12.41%) and yield (9.5%), and high for all other traits examined. These parameters' high heritability suggested that selecting them would be more effective than selecting the other parameters. The genotypes showed significant and nearly comparable genetic advance in FL, NF/P, 100-SW, and AFW, respectively (33.76, 94.15, 139.15, and 154.98). According to Johnson *et al.* (1955), estimations of genetic advancement combined with heritability values were more effective than heritability alone at forecasting the impact of selection. In general, all characteristics had strong heritability, while FD, 100-SW, NF/P, and AFW all had high genetic advance as a percentage of the mean (GAM%). Selection for these traits would thus be more successful due to their high genetic advance percentage and heritability. Based on the current study's findings, it can be said that nearly all of the features under investigation showed a significant range of variability among various genotypes. These results are in agreement partially with those obtained by Deshmukh *et al.*, (1986), Abdein, (2016), Samlindsujin *et al.* (2017), Pujer *et al.* (2017), Mahmoud and El-Mansy (2018), Tirkey *et al.* (2018) and Hassan *et al.* (2021).

Correlation:

The correlation coefficients between characteristics, both genotypic and phenotypic, were calculated (Tables 2). The findings showed that the signals and values' magnitudes were either equal or quite near to one another for every pair of traits. For nearly all of the traits under study, the genotypic coefficient values were greater than the phenotypic ones, indicating that the environment has little effect on how genes are expressed. This suggests that there is a strong intrinsic relationship between the traits under study, which is consistent with the findings of Tiwari & Upadhyay (2011), and Abdelkader and Abdein (2023). Total yield per plant with SR, FL, FD, 100-SW, and NF/P was found to have a positive and highly significant genotypic correlation. This suggests that these traits have stable relationships and are indicators of yield, so they could be chosen simultaneously for breeding program improvement (Tasisa *et al.*, 2012), which is supported by findings from Ghosh *et al.* (2010). Thus, either 100-SW or NF/P selection, either separately or in combination, should improve the genotypes' potential for yielding (Mpayo, 2010). These findings were consistent with those of Jeberson *et al.* (2016), Tadesse *et al.* (2014), and Yadav *et al.* (2010). Conversely, the yield had a weak or ignored connection with AFW (-0.003) and a desired negative correlation with the sex ratio (-0.553*).

Table 2. Phenotypic (above diagonal) and genotypic (below diagonal) correlations among yield and its attributes of squash

	SR	FL	FD	100-SW	NF/P	AFW	TYP
SR	1	-0.145	-0.087	-0.187	-0.333	0.079	-0.209
FL	-0.501	1	0.786**	0.16	-0.071	0.334	0.245
FD	-0.554*	0.938**	1	0.402	0.091	0.377	0.424
100-SW	-0.383	0.177	0.744**	1	0.592*	0.047	0.523*
NF/P	-0.492	-0.097	0.17	0.703**	1	-0.378	0.544*
AFW	0.068	1.000**	1.080**	0.223	-0.502	1	0.562*
TYP	-0.553*	0.573*	0.897**	0.965**	0.872**	-0.003	1

**** Significant at 1 % level of significance; * Significant at 5% level of significance; SR: Sex ratio%, FL: Fruit length (cm), FD: Fruit diameter, 100-SW: 100 Seed weight (g), NF/P: number of fruit per plant, AFW: average fruit weight and TYP: total yield/plant (kg)**

There was a highly substantial positive genotypic relationship between the fruit diameter, fruit length, average fruit weight, and total yield/plant (Table 2). Fruit diameter and length were positively correlated with average fruit weight, either significantly or extremely significantly. Danquah and Ofori (2012) and Muniappan *et al.* (2010) both supported these findings for fruit diameter. Plant height, fruit production per plant, and fruit yield per feddan significantly correlated with the average fruit weight. At the genotypic and phenotypic levels, there was a positive and substantial association between the 100-seed weight and the number of fruits and yield. A very strong and substantial association between yield and fruit weight was discovered by Islam *et al.* (2010). Additionally, fruit diameter and fruit production were found to be positively connected by Akpan *et al.* (2016), suggesting that selecting for these traits may indirectly increase fruit output per plant. This outcome supports the findings of Danquah and Ofori (2012), who found a positive correlation between fruit weight and fruit diameter. While Parihar *et al.* (2014) found that yield had a positive and significant correlation with the majority of the qualities, these results are consistent with those of Prabhu and Nataranjan (2007) and Manna and Paul (2012).

Path coefficient analysis:

To identify the specific factor causing that correlation, the phenotypic and genotypic correlation between yield and yield components was divided into direct and indirect effects (Tables 3&4 and Fig. 1).

Table 3. Path coefficient analysis of fruit yield *vs* sex ratio (SR), fruit length (FL), fruit diameter (FD), 100-seed weight, fruits number/plant (NF/P) and average fruit weight (AFW)

Trait	Pathway			phenotypic	genotypic
SR	Direct effect		P17	0.0209	-0.0271
	Indirect effect via	FL	P27*r12	-0.0001	0.0469
	Indirect effect via	FD	p37*r13	-0.0028	-0.0264
	Indirect effect via	100-SW	p47*r14	0.0163	0.0797
	Indirect effect via	NF/P	p57*r15	-0.3143	-0.6784
	Indirect effect via	AFW	p67*r16	0.0714	0.0527
	Total		r	-0.2086	-0.5526
FL	Direct effect		P27	0.0006	-0.0935
	Indirect effect via	SR	p17*r12	-0.0030	0.0136
	Indirect effect via	FD	p37*r23	0.0255	0.0446
	Indirect effect via	100-SW	p47*r24	-0.0139	-0.0367
	Indirect effect via	NF/P	p57*r25	-0.0672	-0.1344
	Indirect effect via	AFW	p67*r26	0.3034	0.7794
	Total		r	0.2454	0.5730
FD	Direct effect		P37	0.0324	0.0476
	Indirect effect via	SR	P17*r13	-0.0018	0.0150
	Indirect effect via	FL	p27*r23	0.0005	-0.0877
	Indirect effect via	100-SW	p47*r34	-0.0349	-0.1546
	Indirect effect via	NF/P	p57*r35	0.0854	0.2345
	Indirect effect via	AFW	p67*r36	0.3424	0.8418
	Total		r	0.4240	0.8966
100-SW	Direct effect		p47	-0.0869	-0.2079
	Indirect effect via	SR	p17*r14	-0.0039	0.0104
	Indirect effect via	FL	p27*r24	0.0001	-0.0165
	Indirect effect via	FD	p37*r34	0.0131	0.0354
	Indirect effect via	NF/P	p57*r45	0.5584	0.9696
	Indirect effect via	AFW	p67*r46	0.0425	0.1739
	Total		r	0.5233	0.9649
NF/P	Direct effect		p57	0.9429	1.3786
	Indirect effect via	SR	p17*r15	-0.0070	0.0133
	Indirect effect via	FL	p27*r25	0.0000	0.0091
	Indirect effect via	FD	p37*r35	0.0029	0.0081
	Indirect effect via	100-SW	p47*r45	-0.0514	-0.1462
	Indirect effect via	AFW	p67*r56	-0.3434	-0.3911
	Total		r	0.5440	0.8718
AFW	Direct effect		P67	0.9083	0.7794
	Indirect effect via	SR	p17*r16	0.0016	-0.0018
	Indirect effect via	FL	p27*r26	0.0002	-0.0935
	Indirect effect via	FD	p37*r36	0.0122	0.0514
	Indirect effect via	100-SW	p47*r46	-0.0041	-0.0464
	Indirect effect via	NF/P	p57*r56	-0.3565	-0.6918
	Total		r	0.5617	-0.0027

P: path way, r: correlation coefficient of the trait with yield, ** Significant at 1 % level of significance; * Significant at 5% level of significance; SR: Sex ratio%, FL: Fruit length (cm), FD: Fruit diameter, 100-SW: 100 Seed weight (g), NF/P: number of fruit per plant, AFW: average fruit weight, and TYP: total yield/plant (kg)

Table 4. Partitioning of the phenotypic (P) and genotypic (G) correlation coefficients into direct effects (main diagonal, bold) and indirect effects (above and below the main diagonal) in fifteen F1 squash hybrids

Item		SR	FL	FD	100-SW	NF/P	AFW	correlation
SR	P	0.0209	-0.0001	-0.0028	0.0163	-0.3143	0.0714	-0.2087
	G	-0.0271	0.0469	-0.0264	0.0797	-0.6784	0.0527	-0.5525
FL	P	-0.003	0.0006	0.0255	-0.0139	-0.0672	0.3034	0.2454
	G	0.0136	-0.0935	0.0446	-0.0367	-0.1344	0.7794	0.573
FD	P	-0.0018	0.0005	0.0324	-0.0349	0.0854	0.3424	0.424
	G	0.015	-0.0877	0.0476	-0.1546	0.2345	0.8418	0.8966
100-SW	P	-0.0039	0.0001	0.0131	-0.0869	0.5584	0.0425	0.5232
	G	0.0104	-0.0165	0.0354	-0.2079	0.9696	0.1739	0.9648
NF/P	P	-0.007	0	0.0029	-0.0514	0.9429	-0.3434	0.5439
	G	0.0133	0.0091	0.0081	-0.1462	1.3786	-0.3911	0.8719
AFW	P	0.0016	0.0002	0.0122	-0.0041	-0.3565	0.9083	0.5618
	G	-0.0018	-0.0935	0.0514	-0.0464	-0.6918	0.7794	-0.0027

SR: Sex ratio%, FL: Fruit length (cm), FD: Fruit diameter, 100-SW: 100 Seed weight (g), NF/P: number of fruit per plant, AFW: average fruit weight, and TYP: total yield/plant (kg)

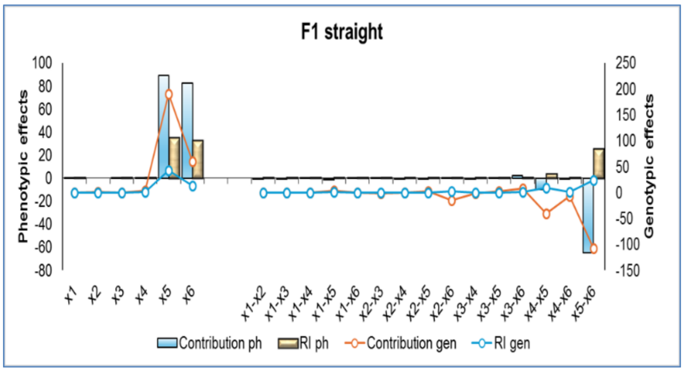

Fig. 1. Relative importance (R %) and percentage contribution of yield-attributing traits to total fruit yield in squash (Cucurbita pepo L.), based on genotypic and phenotypic path coefficient analysis.

In addition to the indirect negative effects through fruit diameter and number, the sex ratio had a direct negative (desirable) effect on yield (-0.027). Fruit length also had a negative direct impact on yield (-0.0935). Additionally, it demonstrated both favorable indirect effects through AFW and FD and negative indirect effects through 100-SW and NF/P. Fruit diameter had a favorable direct impact on yield (0.0476) and a positive indirect impact through average fruit weight and fruit count. 100-SW had a negative direct influence on yield (-0.2079) and shown good indirect effects through average fruit weight and fruit number (Table 3). However, the greatest genotypic positive direct influence on yield (1.579) was found for fruit number. Additionally, it demonstrated detrimental indirect impacts through 100-seed weight and AFW. Fruit number (-0.6918), fruit length, and 100-seed weight all shown negative indirect impacts on yield, whereas average fruit weight demonstrated the second-highest positive direct effect (0.7794) and indirect effect via fruit diameter. There had previously been reports of supporting evidence of a direct beneficial relationship of fruit number per plant on yield per plant (Ezzo *et al.*, 2012; Galala *et al.,* 2012 Islam *et al.,* 2010). The outcome supported the conclusions of Saleem *et al.* (2013) and Abdein *et al.,* (2021). To increase yield, these qualities could be directly selected.

Different breeding material and ambient circumstances may have contributed to some of the parallels and differences between the results of previous researchers and ours. It was proposed that a constrained simultaneous selection model might be utilized to remove the undesired indirect effects so as to appropriately employ the direct influence. Given the strong correlation and desired direct effect of sex ratio, fruit number, and average fruit weight on yield, these parameters could be taken into account for the development of elite hybrids through heterosis breeding or for the development of inbred lines after pure line selection in subsequent generations. Consequently, these traits may be taken into account while choosing genotypes to increase fruit production. Conversely, yield (phenotypic and/or genotypic level) was directly impacted negatively by fruit length and 100-SW. However, each character's indirect influence through other characters offset its negative direct effect, leading to a highly substantial positive association with yield in the end.

The direct effect points out that, with other variables held constant, increasing any of these traits will decrease yield. However, the more suitable indirect effects play a more important part and mask the direct influence (Dewey and Lu, 1959). A desirable negative genotypic effects (Table 3) was recorded indirectly by sex ratio on yield through number of fruits (-0.6784) and fruit diameter (-0.0264) due to fact the number of fruits and diameter were negatively correlated (r = -0.492 and +0.554*), respectively with sex ratio (Table 1) which in turn had a large genotypic direct effects (1.3786) and (0.0476) upon yield, respectively as well as 0.9429 and 0.0324 in phenotypic level.

Fig. 1 displays the relative importance (R%) based on the path analysis of squash crop yield and its related features. The findings showed that the direct effects of fruit number per plant (35.1 & 42.6%), average fruit weight (32.5 & 13.6%), and 100-seed weight (0.298 & 0.968%) accounted for the largest portions of the yield variation. These features' significant yield contributions demonstrate how important they are as selection criteria in squash breeding programs. The direct effects on fruit yield, however, were minimal or insignificant for the other characters. In terms of the relative significance of joint effects, it is clear that the number of fruits per plant had an impact on production, as evidenced by its correlations with the average fruit weight (25.5 & 24.2%) and the weight of 100 seeds (3.8 & 9.03%) as shown in Fig.1.

The study demonstrated that there is genetic variation among the genotypes, which the breeding program may take use of. The nation's squash breeding program should be planned using the genetic parameter estimated in this study. More testing in various settings is necessary to determine which genotypes perform the best, as the findings were only collected from a single location. Additionally, selecting the best characteristics for next squash breeding efforts may be made easier by revealing the genotypes' genetic potential through the use of several squash genotypes in various conditions.

The current study makes it evident that the correlation analysis provided an alternate picture of the relationship between fruit production and the number of fruits per plant, average fruit weight, sex ratio, and fruit diameter than did the path coefficient analysis. In order to increase yield, indirect selection using additional component properties that have these traits and have shown desired positive or negative indirect impacts might be suggested.

At the phenotypic level, it was evident that the majority of the direct impacts were smaller than one, suggesting that multicollinearity-induced inflation was negligible. In all, the features under study explained between 99.5% and 100.1% of the variation in fruit output. Random error and/or other characteristics not covered in the current study could be the cause of the residual content (0.5 and 0.1%).

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التباين الوراثي والعلاقات الارتباطية للصفات الكمية في بعض هجن الكوسة

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الملخص

أجريت الدراسة الحالية لتحديد الارتباط ومعامل المرور بين الصفات في هجن الجيل الأول للكوسة وكذلك تقييم التباين في مختلف الأنماط الجينية في ظل ظروف صعيد مصر. بالنسبة لمعظم الصفات، لم تكن هناك سوى اختلافات طفيفة بين GCV% وPCV%، مما يشير إلى أن التأثيرات الوراثية تلعب دورًا مهمًا في تنظيم كيفية وراثة هذه الصفات. أظهرت غالبية الصفات قيد الدراسة نسبة عالية من GCV/PCV%.من حيث المحصول، أظهرت الهجن تقدمًا وراثيًا كبيرًا ومتساويًا تقريبًا بالنسبة لكل صفات الدراسة تقريبًا، كان نطاق التباين بين العديد من الهجن مهمًا للغاية. وقد تم إثبات الفائدة المحتملة لهذه الصفات والهجن لإنشاء برامج تربية لزيادة إنتاج الثمار وجودتها من خلال التقديرات القوية للتوريث والتقدم الوراثي المرتفع المتوقع. أظهر تحليل الارتباط أن المتغيرات المتعلقة بالمحصول لها علاقة وراثية عالية. حدد تحليل معامل المرور عدد الثمار/ نبات (التأثير المباشر: ١,٣٧٨٦) ومتوسط وزن الثمرة (التأثير المباشر: ٠,٧٧٩٤) باعتبارهما الأكثر تأثيرًا إيجابيًا ومباشرًا على المحصول. تشير النتائج إلى أن الانتخاب بناءً على عدد الثمار/ نبات ومتوسط وزن الثمرة سيكون الأكثر فعالية في تحسين محصول الكوسة. وفيما يتعلق بالأهمية النسبية للتأثيرات المشتركة ، من الواضح أن الأجزاء الفعالة منها تم الحصول عليها من خلال عدد الثمار/ النبات على المحصول من خلال ارتباطه بكل من متوسط وزن الثمرة (٢٥,٥ و٢٤,٢٪) ووزن ١٠٠ بذرة (٣,٨ و٩,٠٣٪).