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GENOTYPIC AND PHENOTYPIC PATH ANALYSIS STUDIES ON CHILLI PEPPER (*Capiscum annuum* L.)

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ABSTARACT

The present study were conducted at Privet Farm in Al-Rahmania Island, Behaira Governorate, Egypt, during two successive summer seasons of 2016 and 2017, to identify the interrelationships among fruit yield and its related characters using correlation and improved model of path analysis at both genotypic and phenotypic levels on chilli pepper (Capsicum annuum L.*).*

The experimental genotypes were grown in randomized complete blocks design (RCBD), with three replicates on open field. Eight tested genotypes namely, i. e. Shata Balady Hot cv, Shata Balady Hot *line-1, Shata Balady Sweet cv, Serrano cv, Shata Balady Sweet line-3, Shata Balady Sweet line-4, Anheium cv, and Cayenne Large cv were used in this study. The characteristics were studied i.e., plant height (PH); branches number plant^{-1} (BN); fruit length (FL); fruit diameter (FD); locales number fruit^{-1} (LN); average fruit weight fruit^{-1} (AFW); fruits number plant^{-1} (FN) and yield plant^{-1} (Y).*

The results revealed that, there are a significant differences among genotypes for all studied characters. Also, significant and positive correlation coefficients were obtained between fruit yield plant^{-1} and number of fruits plant^{-1}, at the genotypic and phenotypic levels (0.743* and 0.742*), respectively. Moreover, significant and negative correlation coefficients were obtained between yield plant^{-1} and fruit diameter (- 0.889** and - 0.882**) at the genotypic and phenotypic levels, respectively.

Path analysis (genotypic and phenotypic) coefficient showed that the traits, i.e. branches number plant^{-1} and fruits number plant^{-1} and the average of fruit weight gave the maximum influence directly and indirectly upon yield plant^{-1} in chilli pepper indicating their magnitude as selection criteria to obtain a valuable gain of selection for yield in chilli pepper.

Conclusively, *these results may be helpful to plan appropriate selection strategies for improving fruit yield in hot pepper.*
Key words: Chilli pepper, genotypic correlation, phenotypic correlation, phenotypic and genotypic path analysis.

INTRODUCTION

Chilli pepper (*Capsicum annuum* L.) belongs to the genus *Capsicum* and family *Solanaceae* (Rodriguez *et al.*, 2008). The genus consists of approximately 22 wild species and five domesticated species of *C. annuum* L., *C. frutescens* L., *C. chinenses* L., *C. baccatum* L., and *C. pubescens* (Bosland and Votava, 2000 and Patricia *et al.*, 2003). The *capsicum* species can be divided into several groups based on fruit or pod characteristics ranging in pungency, color, shape, intended use, flavor and size. Despite their vast trait differences, most cultivars of peppers commercially cultivated in the world belongs to the species *C. annuum* (Bosland, 1992). However, different uses of pepper resulted in a very strong diversification by the appearance of a large number of cultivars (Bosland, 1996). Chilli pepper fruits are considered to be vegetables, botanically, and they are berries. The fruits are the most widely consumed as a spice, though there are about 25- 30 species of *Capsicum*, where *Capsicum annuum* is the most widely cultivated species (Csillery, 2006 and Ravishankar *et al.,* 2003). Furthermore, pepper is a diploid species, which has 2n = 24 chromosomes (De Candole, 1886) and recent studies (Tong and Bosland, 1997) who indicated that the chromosome number for non-pungent species is n = 13, whereas, it is n = 12 for the pungent species. Pepper is a generally self-pollinated and chasmogamous crop whose flowers open only after pollination take place. However, 11-64% outcrossing was observed under open pollination (Lemma, 1998).

It is the world's most important vegetable after tomato and used as fresh, dried or processed products, as vegetables and spices or condiments (Acquaah, 2004). Its nutritional properties including antioxidants are important for human nutrition (Mateos *et al.,* 2003; Orlinska and Nowaczyk, 2015), phenolics "flavonoids" (Bae *et al.*, 2012), carotenoids (Ha *et al.*, 2007), vitamin C, vitamin E (Garcia- Closas *et al.*, 2004) and alkaloids (Srinivas *et al*., 2009), which play an important roles in human health. Moreover, pepper is also a source for a natural colors and as medicine (Valadez-Bustos *et al.,* 2009 and Zhuang, *et al.*, 2012). Furthermore, hot pepper nutritional constituents, particularly essential amino acids and essential fatty acids, are necessary nutrients for the maintenance of healthy body (Koyuncu *et al.,* 2014). Moreover, to date pepper is used fresh or dried in various foods. In Many poor households, peppers provide spice and color to foods. Peppers likewise are good sources of income to small producers in many developing countries (Green and Kim, 1991).

Yield is a complex character, determined by the interaction of several factors, including genetic, physiological and environmental factors (Zecevic *et al*., 2011). In this concern, the knowledge of the correlations of other agronomic characteristics with yield, or even among them, and the environmental influence in the expression of the studied characteristics are of fundamental importance in choosing the selection strategy (Gomes *et al.,* 2007). Moreover, the Pearson correlation coefficient (r), measures the direction and strength of the linear relationship between two random variables, may be used for studying the linear relationships between traits (Cruz, 2005 and Ferreira, 2009). The use of methods complementary to linear correlations are recommended when the set of variables is studied simultaneously (Cruz and Carneiro, 2006). So, path analysis is recommended for this purpose because it allows partitioning of the correlation coefficient into direct and indirect effects on the main variable (Wright, 1934; Cruz and Regazzi, 1997; Cruz and Carneiro, 2006). Moreover, variables with a strong association measured using the linear correlation coefficient and with direct effects of the same intensity and direction are considered cause and effect variables and are indicated for the indirect selection of plants (Cruz and Regazzi, 1997; Cruz and Carneiro, 2006). Furthermore, the path analysis is successfully employed on plant breeding, being useful for several vegetable crops like tomato (Sobreira *et al.,* 2009 and Rodrigues *et al.,* 2010) and peppers and sweet peppers of *C. annuum* (Luitel *et al.,* 2013; Moreira *et al.,* 2013; Rohini and Lakshmanan, 2015), aiding the indirect selection of promising genotypes (Carvalho *et al.,* 1999; Caierão *et al.,* 2001 and Coimbra *et al.,* 2005).

Breeding decisions based only on correlation coefficients may not always be effective since they provide only one-dimensional information neglecting the complex interrelationships among plant traits (Kang, 1994). Path analysis separates the direct effects from the indirect effects through other traits by partitioning the simple correlation coefficient (Dewey and Lu, 1959). But the results of path analysis may be adversely affected by the multicollinearity problem (strong associations among independent variables, *i.e.* yield components) which leads to unreliable estimates of path coefficients (exceed 1). Therefore, a modified model of path analysis (Carvalho *et al*, 1999) can be used to minimizing the negative effects of the aforementioned problem.

Peppers are grown in most countries of the world and their annual production has increased substantially over the years since the cultivated area in worldwide was 1,938,788 ha with an average of 17.79 ton ha^{-1} (7.475 ton $fed.^{-1}$) with total production 34,497,462 ton in 2016 (Anonymous, 2016). Egypt ranked 8^{th} global among the pepper-producing countries with about 650,554 tons with cultivated area 98,301 fed. with an average of 15.44 ton ha^{-1} (6.488 ton $fed.^{-1}$) with total production 637,760 ton in 2016. While, China ranked the 1^{st} one with total production 17,435,376 with an average 23.220 ton ha^{-1} (9.756 ton $fed.^{-1}$), which coming from 750,893 ha. (**Anonymous, 2016**). Statistical records illustrated that (Egypt) average productivity from cultivated unit (*fed.*) is low, therefore, greatly courtesy must be given to increase the productivity by rising new cultivars or hybrids through breeding programs.

Therefore, the present study was aimed to identify the interrelationships among fruit yield and its related characters using the correlation (at both genotypic and phenotypic levels) and improved model of path analysis at both genotypic and phenotypic levels. The results may be helpful to plan appropriate selection strategies for improving fruit yield in chilli pepper.

MATERIALS AND METHODS

The present investigation was carried out at the Privet Farm at Al-Rahmania Island, Behaira Governorate, Egypt, during two successive summer seasons of 2016 and 2017, to identify the interrelationships among fruit yield and its related characters using correlation and improved model of path analysis at both genotypic and phenotypic levels on chilli pepper (*Capsicum annuum* L.). The tested genotypes consisted of eight genotypes namely, *i.e.* Shata Balady Hot *cv*, Shata Balady Hot line-1 (SBH-L_1), Shata Balady Sweet *cv*, Serrano *cv*, Shata Balady Sweet line-3 (SBS-L_3), Shata Balady Sweet line-4 (SBS-L_4), Anheium *cv* and Cayenne Large *cv* were used in this study. The name, some characteristics and sources of the evaluated genotypes were illustrated in (Table 1).

Table (1): The characteristics of the tested genotypes under the study.

Genotype	PH	BN	FL	FD	LN	Fruit color	Source
Shata Balady Hot	87	8	14	2.5	3.0	Green	Open Market
SBH-L_1	75	8	12	2.8	2.0	Green	Dr. A. S. Gendy
Shata Balady Sweet	70	16	12	1.4	4.0	Green	Open Market
Serrano	70	7	14	2.6	2.0	Green	Dr. A. S. Gendy
SBS-L_3	70	11	11	2.2	3.0	Green	Dr. A. S. Gendy
SBS-L_4	70	11	18	1.7	2.0	Green	Dr. A. S. Gendy
Anheium	60	12	14	2.5	2.0	Green	Dr. A. S. Gendy
Cayenne Large	93	20	17	1.5	2.0	Green	Dr. A. S. Gendy

SBH: Shata Balady Hot and SBS: Shata Balady Sweet

In 2016 and 2017 summer seasons, the 8 genotypes were evaluated. The seeds were sown on nursery in seedling trays at 1^{st} of April and the plants were transplanted in the field on the second week of May. The used design was randomized complete block with three replicates. Each plot consisted of 4 ridges, 5 m long and 0.8 m in width and the space between plants was 0.5 m apart (plot area = 16 m^2) with total 40 individual plant in each plot. Agricultural practices for pepper production were practiced as recommended. Ten plants were randomly chosen to detect the studied characteristics, *i.e.,* plant height, cm (PH); branches number $plant^{-1}$ (BN); fruit length, cm (FL); fruit diameter, cm (FD); locales number $fruit^{-1}$ (LN); average fruit weight $fruit^{-1}$, g (AFW); fruits number $plant^{-1}$ (FN) and yield $plant^{-1}$, g (Y).

Statistical analysis

Analysis of variance of randomized complete block design for the two consecutive seasons was separately performed according to Snedecor and Cochran (1989). Differences among means for all traits were tested for significant, according to the least significance differences (LSD). The interrelationships among yield $plant^{-1}$ and its related traits were studied at the genotypic and phenotypic levels using the following methodologies:

1- Simple correlation coefficients between all pairs of the studied traits were computed as suggested by Snedecor and Cochran (1989) was calculated in both seasons.

2- Path analysis methodology was primarily proposed by Wright (1921 and 1934), that was rediscovered and used by Dewey and Lu (1959) in the agricultural research, and it was calculated as average of two seasons.

The method permits to separate the simple correlation coefficient between the fruit yield plant^{-1} (as a resultant variable) and each of related traits (as explanatory variables) into direct effect (path coefficient) and indirect effects (that exerted through the other variables). On the other hand, the path coefficient is a partial regression coefficient expressed as standardized unit. Accordingly, as the multiple regression model, the orthogonality (no or weak association among the explanatory variables) is a vital assumption to get goodness of fit for the model of path analysis. In agriculture, this assumption is much violated because there are strong associations among some yield components (explanatory variables) for most crops which are called the multicollinearity problem.

In the presence of multicollinearity, the estimates of path coefficients and their corresponding variances, and the coefficient of determination (R^2) may be inflated to record extreme values. Gravois and Helms (1992) mentioned that when some path coefficient values are more than one, as happen much in genotypic path analysis, this case may be returned to the effect of multicollinearity. On the other hand, the wrong sign for some path coefficients (that did not agree with the most previous literature) may be the most serious effect of multicollinearity phenomenon. Williams *et al* (1979) stated that the adverse effects of multicollinearity are enough to make the results ambiguous which lead to reject the model. Therefore, an alternative path analysis model (Carvalho *et al*, 1999) was used to alleviate or correct the undesirable effects of multicollinearity problem. The proposed model (sometimes called a ridge path analysis) is considered as modified form of the normal model of path analysis.

The normal equation to estimate the path coefficients is formulated in matrices as follows:

$$P = (r_{xx})^{-1} * r_{xy} \qquad = (1/r_{xx}) * r_{xy} \qquad = r_{xy}/r_{xx}$$

Where

P : Is the vector of path coefficients (direct effects).

$(r_{xx})^{-1}$: Is the inverse of correlation matrix among the independent variables (yield components).

(r_{xy}) : Is the vector of correlation coefficients between the dependent variable (fruit yield plant^{-1}) and each of independent variable.

Considering the modified path analysis model, the previous equation would also be used but with adding a bias constant (K) usually ranging from 0 to 1, to the diagonal (unity values) of the matrix (r_{xx}). Logically when K=0, the modified model would be identical to the original model and when K > 0, the path coefficients become slightly biased but tend to be more stable and have smaller variance than the ordinary model. The choice of an appropriate value of K is an important challenge faces the researchers. The researcher chooses the smallest value of C where the path coefficients become more stable (less than 1).

A BASIC program (Atia, 2007) was used to automate the computations of genetic parameters, as well as genotypic and phenotypic correlation and path analyses.

RESULTS AND DISCUSSION

Analysis of variance and mean performance

Data in reflected that The analysis of variances due to the traits was highly significant for all studied traits (Table 2). These results indicating the wide variability in this study. It was observed a highly significant difference for all evaluated traits, for all the characteristics indicating the existence of genetic variability among the evaluated genotypes. Expressive variance was also observed for pepper genotypes (*C. frutescens* L.), which was detected for eight characters (Ullah *et al.*, 2011; Soares *et al.*, 2017)

The mean values of yield plant^{-1} and its related characters for the 8 tested genotypes, evaluated in two successive seasons, are given in (Table 3). The results exhibited significantly differences among the tested genotypes, for all studied characters, indicating existence of genetic variation among them.

The results in (Table 3), for vegetative characteristics, revealed that genotype Cayenne Large *cv.* had the tallest plants (94.00 and 92.67 cm) in the two seasons, respectively. While, the shortest genotype was Anheium *cv.* (65.0 and 64.0 cm) in the two seasons, respectively. Regarding the number of branches per plant, the genotype Cayenne Large *cv.* gave the highest number of branches (20.67 and 20.67 branches) in the two seasons, respectively. While, the lowest number of branches was genotype Serrano *cv.* (7.33 branches) in both seasons, respectively.

Regarding the yield characteristics, the results in (Table 3) also showed that the genotype Shata Balady sweet *cv.* produced the maximum number of fruits plant^{-1} (170.41 and 161.56 fruits) in the two seasons, respectively. While, the minimum fruit number plant^{-1} was the genotype was Shata Balady Hot *cv.* (57.54 and 56.35 fruits) in the two seasons, respectively. Regarding to yield plant^{-1}, the genotype SBS-L_3 line produced the highest yield plant^{-1} (2142.00 and 2143.67 g) in the two seasons, respectively. While, the lowest yield plant^{-1} was the genotype was SBH-L_1

line (848.33 and 842.33 g) in the two seasons, respectively. And for the average fruit weight, the results indicated that, the genotype SBS-L_3 line produced the heaviest fruit weight fruit^{-1} (28.33 and 26.33 g) in the two seasons, respectively. While, the lightest weight fruit^{-1} was the genotype of Shata Balady sweet (12.33 and 13.00 g) in the two seasons, respectively.

Regarding to the fruit quality characteristics, Cayenne Large *cv.* had the longest fruit length (16.67 and 16.33 cm) in the two seasons, respectively. While, the SBS-L_3 recorded the shortest fruit length (11.33 and 11.33 cm) in the two seasons, respectively. Moreover, the genotype SBH-L1 line had the widest fruit (2.90 and 2.77 cm) in the two seasons, respectively. While, Shata Balady sweet *cv.* recorded the tinniest fruit (1.30 and 1.40 cm) in the two seasons, respectively. And, for locales number fruit^{-1}, the genotype Shata Balady sweet had the much number of locales fruit^{-1} (4 locales) in both seasons, respectively. While, the fewest number of locales obtained from genotype SBH-L_1 (2 locales) in both seasons, respectively.

These results are in harmony with those reported by Munchi *et al.* (2000) who, conducted that from studying the variability, significantly correlations were found to exist between morphological traits, and between those and the quality ones. Aso, Soares *et al.* (2017) who reported that, there is a genetic variability among the evaluated lines in pepper.

Correlation matrix

The identification of the correlation between easy-to-measure characteristic and productivity-related characteristics is one of the objectives of the breeding programs to facilitate and accelerate the selection of superior plants (Oliveira *et al.*, 2010).

Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among fruit yield plant^{-1} and its related characters are given in Table (4). Generally, there was clear convergence between most genotypic and phenotypic correlation coefficients in sign.

But the correlation coefficients at the genotypic level were higher than their corresponding values at the phenotypic level indicating that the observed associations among most characters may be mostly attributed to genetic effects.

Results showed that the most effective relationships to pepper breeder were those between fruit yield plant^{-1} and number of fruits plant^{-1} since it was significantly and positive correlation (0.743* and 0.742*) at the genotypic and phenotypic levels, respectively. While, it was negative

Table (4): Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among chilli pepper fruit yield plant^{-1} and its related characters in seasons of 2016 and 2017.

Characters	PH	BN	FL	FD	LN	AFW	FN	Y
PH	1.000	0.449	0.302	-0.236	0.030	-0.417	0.055	-0.302
BN	0.447	1.000	0.328	0.868**	0.187	-0.612	-0.820*	0.587
FL	0.281	0.448	1.000	-0.353	-0.599	-0.267	0.125	0.112
FD	-0.234	0.295**	-0.348	1.000	-0.426	0.569**	-0.889**	-0.728*
LN	0.011	-0.236	-0.469	-0.325	1.000	-0.229	0.493**	0.316
AFW	-0.412	0.023	-0.261	0.561**	-0.198	1.000	-0.707*	-0.082
FN	0.055	-0.815*	0.118	-0.882**	0.401**	-0.704*	1.000	0.743*
Y	-0.301	0.584	0.109	-0.723*	0.276	-0.076	0.742*	1.000

* and **: Significant and highly significant at 0.05 and 0.01 probability levels, respectively.
PH: Plant height (cm); BN: Branches number plant^{-1}; FL: Fruit length (cm); FD: Fruit diameter (cm); LN: Locales number fruit^{-1}; AFW: Average fruit weight (g); FN: Fruits number plant^{-1}; Y: Yield plant^{-1} (g).

correlation and significantly between yield plant and fruit diameter (- 0.728* and - 0.723*) at the genotypic and phenotypic levels, respectively.

The correlation between the number of fruits plant^{-1} and yield plant^{-1} reflected the inherent associations; therefore, the breeder can obtain high yielding genotypes through selection program this character, especially if it proved to be more contributor to yield variation.

On the other hand, the yield components exhibited various trends of associations among themselves. There were considerable a positive genotypic and phenotypic associations between fruit number plant^{-1} and locales number (0.493** and 0.401**), fruit diameter and both of branch number plant^{-1} (0.868** and 0.295**) and average fruit weight (0.569** and 0.561**), respectively. However, fruit number plant^{-1} and fruit diameter (- 0.889** and - 0.882**) was negatively correlated and highly significantly at genotypic and phenotypic levels. Moreover, fruit number plant^{-1} and both of branches number plant^{-1} (- 0.820* and - 0.815*) and average fruit weight (- 0.707* and - 0.704*) were negatively too and significantly at genotypic and phenotypic levels, respectively.

The highest positive correlation coefficients were recorded between fruit diameter and average fruit weight (0.569** and 0.561**) at the genotypic and phenotypic levels, respectively. Generally, the highly significant positive genotypic relationship between any pair of characters indicates that the improvement predicted under selection for one of them, would automatically extended to the other.

These findings are in agreement with those obtained by Nogueira *et al.* (2012) who revealed that mean yield trait presented high positive correlation (above 0.7) and Soares *et al.* (2017) reported the genotypic correlations, except between fruit length x fruit diameter, were all higher than the phenotypic correlations, evidencing that the phenotype influenced in greater magnitude by the genetic portion of the trait, which may favor the indirect selection of the traits. However, Yadeta *et al.* (2011), Ullah *et al.* (2011) and Soares *et al.* (2017), they found a positive and significant phenotypic correlation between fruit production (*Capsicum annuum* L.) and fruit length, fruit weight and fruit diameter. Moreover, Lakshmi *et al.* (2017) revealed that in two Tomato F_2 populations, yield per plant had highly significant and positive phenotypic correlation with average fruit weight (0.7732 and 0.8532), number of fruits per plant (0.4378 and 0.2011), respectively. Suggesting the possibility of simultaneous selection to these traits for improving the yield in the respective segregating populations. Also, Singh *et al.* (2018) cited that tomato fruit yield plant^{-1} exhibited a positive correlation with average fruit weight at both genotypic and phenotypic levels.

It is essential to remember that the significance of some small correlation coefficients ($r < 0.5$) may be returned to the large sample size of data (n=48).

In fact, selection decisions based only on correlation coefficients may not always be effective because it measures the mutual association between a pair of traits neglecting the complicated interrelationships among all traits (Kang, 1994). Therefore, the correlation procedure may not provide a deep imagine about the importance of each component in the structure of fruit yield. The path analysis can efficiently play this vital role.

Path analysis

In the current investigation, an alternative model of path analysis (Carvalho *et al*, 1999) called Crest Path Analysis, was used to minimize the adverse effects resulted in the presence of multicollinearity problem (strong associations among yield components), especially at the genotypic level when the path coefficient values exceed one (Gravois and Helms, 1992). The proposed path analysis model is a modified shape of the original model by adding very small constant value (K), ranging from 0 to 1, to the diagonal elements of the correlation X'X matrix. In the present work, the optimum constant value (K) was detected when all path coefficients become stable (less than 1) at the two inherent levels. Statistically, more precise results were obtained using constant values, being 0.03 and 0.05 for genotypic and phenotypic path analyses, respectively.

The matrix of direct and joint effects for the studies traits is shown in Table (5). The value of K = 0.05 was used (Carvalho *et al.*, 1999; Amorim *et al.*, 2008; Moreira *et al.*, 2013) correcting the distortions and all used variables leading to greater reliability in the cause and effect interpretations among the studied characters.

Positive direct effects were recorded for all yield characters considering the genotypic and the phenotypic levels except plant height (PH) and fruit diameter (FD) which had negative in both genotypic and phenotypic (- 0.291 and - 0.218) and (- 0.163 and - 0.103) path coefficients, respectively. The maximum direct effects were observed for fruits number plant^{-1} (0.716 and 0.923) followed by the average of fruit weight (0.593 and 0.694), branches plant^{-1} (0.270 and 0.196), fruit length (0.163 and 0.166) and then locales number fruit^{-1} (0.082 and 0.055) at the genotypic and phenotypic, respectively.

Similar results were reported by Farhad *et al.* (2008) revealed that the number of fruits per plant was the variable with a great direct effect on the *C. annuum* yield, Krishnamurthy *et al.* (2013), Luitel *et al.* (2013) and Maga *et al.* (2013) also verified direct and positive effects of the variable fruits per plant on the yield of green pepper fruits (*C. annuum* L.) and Soares *et al.* (2017) in (*C. chinense* L.) reported that highest direct effects and total correlations, demonstrating a good combination between the path coefficient and/or phenotypic correlation, indicating a large contribution of these characters to increase the yield of peppers.

In fact, the path analysis gave a different picture from what the correlation coefficient did. For example, the simple correlation coefficients (genotypic and phenotypic) between yield plant^{-1} and the average fruit weight (Table 4) were negative and insignificant (-0.082 and -0.076), respectively. When the indirect effects are separated from correlation coefficient, however, the path analysis revealed that the average fruit weight had a great positive effect on yield plant^{-1} (Table 4). The direct effects of seven predictor characters on yield plant^{-1}, at genotypic and phenotypic levels are graphically shown in Figure (1).

Considering the considerable components of the indirect effects, it is noted that branches number plant^{-1} had a positive large indirect effects on yield plant^{-1} through their genotypic and phenotypic associations with fruits number plant^{-1} (0.587 and 0.751), respectively.

Meanwhile, a strong negative influence on yield plant^{-1} was indirectly recorded by fruit diameter *via* the fruits number plant^{-1} whether at the genotypic and phenotypic levels (- 0.636 and - 0.814), respectively. Similar result reported by Luitel *et al.* (2013) who verified by path analysis a negative direct effect of the fruit diameter on production.

The indirect effects (genotypic or phenotypic) of fruit diameter on yield plant^{-1} *via* average fruit weight and locales number fruit^{-1} *via* fruits number plant^{-1} were positive and moderate recording (0.338 and 0.389) and (0.353 and 0.370), respectively. These results confirmed with, Lahbib *et al.* (2012) and Kadwey *et al.* (2015) those reported that fruit weight had an indirect and positive effect on production/plant, through fruit length and diameter in pepper.

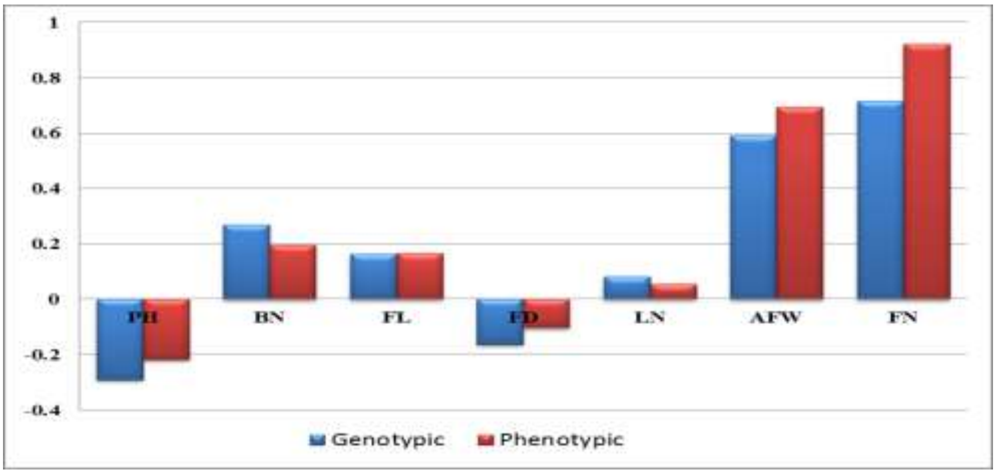
Regarding the fruit number plant^{-1}, it exhibited considerable negative (genotypic and phenotypic) influence on yield plant^{-1} through their associations with average fruit weight (- 0.441 and - 0.503), respectively. Similar results were confirmed the above mentioned conclusion by Luitel *et al.* (2013), when studying a segregate population of *Capsicum annuum* L., observing the correlation and path analysis for yield and fruit quality, verified a positive and significant correlation between the number of fruits per plant and its total production. Also, Shrestha *et al.* (2010) illustrated a positive correlation between the number of fruits, fruit weight and yield of sweet pepper fruits. Moreover, Rohini and Lakshmanan (2015) and Soares *et al.* (2017) using correlation and path analysis for pepper production study, for all evaluated traits, reported that the genotype correlation coefficient was superior than the phenotype.

The remainder indirect effects were very small and low important. An overall view on the results of path analysis, it is revealed that the traits, i.e. branches number plant^{-1} and fruits number plant^{-1} and the average of fruit weight gave the maximum influence directly and indirectly upon yield plant^{-1} in pepper. The current results are in harmony with those obtained by Shrestha *et al.* (2010), Kadwey *et al.* (2015), Rohini and Lakshmanan (2015), and Soares *et al.* (2017), those confirmed that these characters represent the main determinants of fruit yield in chilli prpper. Moreover, Lakshmi *et al.* (2017) revealed that, in two Tomato F_2 populations, path analysis for fruit yield per plant revealed that the average fruit weight (0.8961 and 0.0274), number of fruits per plant (0.6206 and 0.5354) and plant canopy (0.1376) had a direct and positive effects with yield per plant indicating the possibility of increasing fruit yield by selecting these characters in both the segregating populations to have higher potential of

Table (5): The direct and indirect effects of five predictor characters on fruit yield plant^{-1} at genotypic (G) and phenotypic (Ph) levels in chilli pepper.

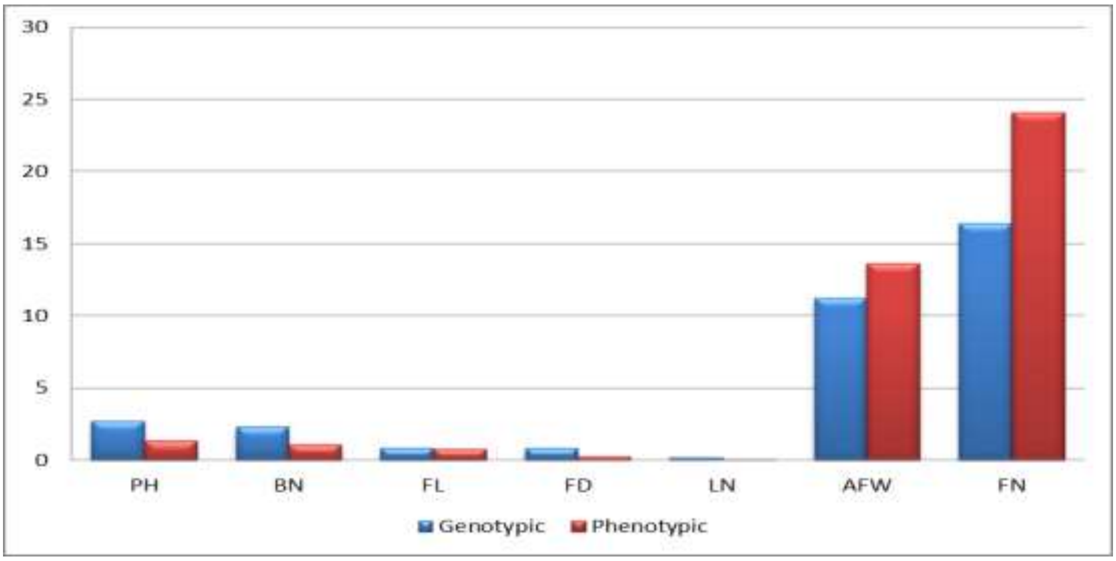
Characters	Level	Pathways							
		Direct effect	Indirect effects						
			PH	BN	FL	FD	LN	AFW	FN
PH	G	**- 0.291**		**0.121**	**0.049**	**0.038**	**0.002**	**- 0.247**	**0.039**
	Ph	**- 0.218**		0.088	0.047	0.024	0.001	- 0.286	0.051
BN	G	**0.270**	- 0.137		**0.054**	**0.142**	**0.015**	**- 0.363**	**0.587**
	Ph	**0.196**	**- 0.101**		0.052	0.088	0.009	- 0.421	**0.751**
FL	G	**0.163**	- 0.092	0.093		**0.058**	**- 0.049**	**- 0.158**	**0.089**
	Ph	**0.166**	**- 0.063**	**0.063**		0.036	- 0.026	- 0.181	0.109
FD	G	**- 0.163**	0.072	- 0.246	- 0.061		**- 0.035**	**0.338**	**- 0.636**
	Ph	**- 0.103**	**0.053**	**- 0.173**	**- 0.060**		**- 0.018**	**0.389**	**- 0.814**
LN	G	**0.082**	- 0.009	0.053	- 0.103	0.073		**- 0.136**	**0.353**
	Ph	**0.055**	**- 0.002**	**0.035**	**- 0.080**	**0.034**		**- 0.137**	**0.370**
AFW	G	**0.593**	0.127	- 0.173	- 0.046	- 0.097	- 0.020		**- 0.506**
	Ph	**0.694**	**0.093**	**- 0.123**	**- 0.045**	**- 0.059**	**- 0.011**		**- 0.650**
FN	G	**0.716**	- 0.017	0.232	0.021	0.152	0.042	- 0.441	
	Ph	**0.923**	**- 0.012**	**0.165**	**0.020**	**0.093**	**0.023**	**- 0.503**	

PH: Plant height (cm); BN: Branches number plant^{-1}; FL: Fruit length (cm); FD: Fruit diameter (cm); LN: Locales number fruit^{-1}; AFW: Average fruit weight (g); FN: Fruits number plant^{-1}; Y: Yield plant^{-1} (g).



PH: Plant height (cm); BN: Branches number plant^{-1}; FL: Fruit length (cm); FD: Fruit diameter (cm); LN: Locales number fruit^{-1}; AFW: Average fruit weight (g); FN: Fruits number plant^{-1}; Y: Yield plant^{-1} (g).

Fig. (1): The direct of 7 predirector characters on pepper fruit yield plant^{-1} at phenotypic and genotypic levels in chilli pepper.



PH: Plant height (cm); BN: Branches number plant^{-1}; FL: Fruit length (cm); FD: Fruit diameter (cm); LN: Locales number fruit^{-1}; AFW: Average fruit weight (g); FN: Fruits number plant^{-1}; Y: Yield plant^{-1} (g).

Fig. (2): The relative importance (RI %) in direct effect for seven predictor characters on fruit yield plant^{-1} at genotypic and phenotypic levels in chilli pepper.

yield. Also, Singh *et al.* (2018) cited that the path coefficient analysis revealed that tomato average fruit weight (1.069) exhibited very high positive direct effect on fruit yield per plant, followed by number of fruits per plant (0.603), and equatorial fruit diameter (0.307). Hence these characters may be simultaneously selected to develop the high yielding with quality rich varieties.

The relative importance (RI %) according to genotypic and phenotypic path analysis are presented in Table (6). It is clearly evident that the most yield plant^{-1} variation (genotypic and phenotypic) was explained by the direct effects for fruits number plant^{-1} (16.404 and 24.081), followed by the average fruit weight (11.272 and 13.614), plant height (2.708 and 1.349) and branches number plant^{-1} (2.331 and 1.090), respectively.

Also, the great genotypic and phenotypic components of joint effects on yield plant^{-1} were expressed by the average fruit weight through fruits number plant^{-1} (18.312 and 24.752), branches number plant^{-1} *via* average

Table (6): The relative importance (RI %) for seven predictor characters on fruit yield plant^{-1} at genotypic and phenotypic levels.

Characters			Genotypic	Phenotypic
Direct effect				
Plant height		**(X_1)**	2.708	1.349
Number of branches plant^{-1}		**(X_2)**	2.331	1.090
Fruit length		**(X_3)**	0.855	0.780
Fruit diameter		**(X_4)**	0.851	0.298
Locales number fruit^{-1}		**(X_5)**	0.213	0.086
Average fruit weight		**(X_6)**	11.272	13.614
Fruits number plant^{-1}		**(X_7)**	16.404	24.081
Total (direct)			34.634	41.298
Indirect effects				
Plant height	**(X_1)** ***via***	**X_2**	**2.149**	**1.052**
		X_3	0.875	0.559
		X_4	0.683	0.288
		X_5	0.043	0.007
		X_6	**4.388**	**3.428**
		X_7	0.698	0.609
Number of branches plant^{-1}	**(X_2)** ***via***	**X_3**	0.882	0.556
		X_4	2.329	0.947
		X_5	0.251	0.101
		X_6	**5.976**	**4.541**
		X_7	**9.659**	**8.098**
Fruit length	**(X_3)** ***via***	**X_4**	0.574	0.326
		X_5	0.487	0.235
		X_6	1.578	1.651
		X_7	0.891	0.993
Fruit diameter	**(X_4)** ***via***	**X_5**	0.346	0.101
		X_6	**3.358**	**2.194**
		X_7	**6.328**	**4.588**
Locales number fruit^{-1}	**(X_5)** ***via***	**X_6**	0.676	0.415
		X_7	1.755	1.118
Average fruit weight	**(X_6)** ***via***	**X_7**	**18.312**	**24.752**
Total (indirect)			62.237	56.566
Total (direct + indirect)			96.871	97.864
Residuals			3.128	2.136
Total			100.00	100.00

fruit weight (5.976 and 4.541) and fruits number plant^{-1} (9.659 and 8.098), fruit diameter *via* each of fruits number plant^{-1} (6.328 and 4.588) and the average fruit weight (3.358 and 2.194), and plant height *via* branches plant^{-1} (2.149 and 1.052) and average fruit weight (4.388 and 3.428), respectively.

Slight values of relative importance were observed for the other direct and indirect effects. Totally, the studied seven characters explained the coefficient of determination of path analysis (R^2) was 0.9687 and 0.9786, characterizing that 96.87 and 97.86% of yield plant^{-1} variation at the genotypic and phenotypic levels, respectively. In accordance, the residual part may be attributed to unknown variation (random error), committing of errors during measuring the studied characters and/or some other traits that were not incorporated in the present investigation. Similar results confirmed by **Soares *et al.* (2017**), who reported that the coefficient of determination of the path analysis (R^2) was 0.9708, characterizing that 97.08% of the variation of the mean yield dependent variable in the model was explained by the effect of the studied variables.

Conclusively, among the studied characters, fruits number plant^{-1} was the most trustworthy yield components as selection criteria in pepper breeding programs. This characters had a considerable value of genotypic coefficient of variation. Furthermore, its significantly reflected and positively correlated with yield plant^{-1} at the genotypic level as well as their influences whether directly or indirectly on yield formation process were positive and the highest over the other yield attributes.

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دراسات تحليل معامل المرور الوراثي والمظهري في الفلفل الحار

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أجريت هذه الدراسة بمزرعة خاصة بجزيرة الرحمانية، محافظة البحيرة- مصر خلال موسمى ٢٠١٦ و٢٠١٧ لدراسة العلاقات المتداخلة بين محصول النبات من الثمار و باقى الصفات المتعلقة به باستخدام معاملي الارتباط وتحليل المرور المعدل علي المستويين الوراثى والمظهرى في الفلفل الحريف. تمت زراعة التراكيب الوراثية المختبرة فى تصميم القطاعات الكاملة العشوائية فى ثلاث مكررات في الحقل المفتوح.

التراكيب الوراثية المختبرة من الفلفل الحار هي: صنف الشطة البلدي الحريف ، سلالة-١ من الشطة البلدي، الشطة البلدي الحلوة، صنف سيرانو، والسلالات ٣ و٤ من الشطة البلدي الحلوة، الصنف أناهيم و الصنف *Cayenne Large*.

تمت دراسة الصفات التالية: إرتفاع النبات، عدد الفروع للنبات، طول الثمرة، قطر الثمرة، عدد الحجرات بالثمرة، متوسط وزن الثمرة، عدد الثمار للنبات و محصول النبات.

وتتلخص أهم النتائج المتحصل عليها فيما يلى:

كانت هناك فروق معنوية بين التراكيب الوراثية لجميع الصفات تحت الدراسة. كما أظهرت وجود علاقة ارتباط موجبة عالية المعنوية بين وزن محصول الثمار للنبات و كل من صفة طول النبات وعدد الثمار للنبات على المستويين الوراثى والمظهرى. أيضاً لوحظ وجود علاقة إرتباط سالبة المعنوية بين محصول النبات وقطر الثمرة.

كما أوضح تحليل معامل المرور (الوراثي والمظهري) أن صفات: عدد الفروع لكل نبات، عدد الثمار للنبات و متوسط وزن الثمرة أعطت الإسهام الاكبر فى محصول النبات من الفلفل الحريف سواء عن طريق التأثير المباشر او غير المباشر (وراثيا و مظهريا) مما يشير إلى أهمية وضع هذه الصفات الثلاث فى الاعتبار من قبل المربى عند وضع برامج التربية لتحسين محصول الفلفل الحار.

التوصية : من هذه النتائج ربما تكون مفيدة عند وضع خطة جيدة لإستراتيجية الإنتخاب لتحسين المحصول من الفلفل الحار.