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HORTICULTURAL STUDIES

RESEARCH PAPER

Evaluation of the Relations between Yield and Yield Components of Tomato (*Solanum lycopersicum* L.) Hybrids by Correlation and Path Analysis

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Abstract

Tomato is one of the most produced vegetables in the world and there are many plant breeding studies that are carried out on this vegetables species. One of the most important aims of tomato breeding is the improvement of fruit quality and yield in both open-field and greenhouse growing conditions. The knowledge of factors with regard to yield is making plant breeders work easier. In the present study, the correlations of some plant characteristics thought to be related to yield and their direct and indirect effects on yield were analyzed. This study was conducted with 14 genotypes in 2020 and a randomized complete block design was employed as an experimental design. The relationship between 12 traits and yield was determined through path coefficient analysis. It was determined that the number of days from the first fluorescence to the first fruit set time, the length under the first cluster, fruit length, fruit diameter and Brix° value have a directly negative effects on the yield. However, fruit weight, fruit number, leaf diameter, and early yield have a directly positive effect on the yield. However, early yield had a directly positive effect on the yield. According to the result of this study, in the correlation matrix, the number of days from first fruit set time to fruit ripening, internode length, fruit diameter, leaf diameter, leaf length and number of fruit per plant are insignificant. The obtained results a potentially be utilized as selection criteria in the future studies on yield.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a member of the Solanaceae family including the most important crops such as potato, tobacco and pepper in terms of global trade and agricultural production. Moreover, the Solanaceae family includes more than 3000 species that contain both field crops and vegetables. One of the most important members of the Solanaceae family is tomato that is the most produced vegetable in the world. The most important property making tomato the most produced vegetable is its nutritional value that is rich in vitamin A, vitamin C, protein, fat, carbohydrates (Kabelka et al., 2004) and other nutritional elements including phenolic and antioxidants (Seçgin et al., 2018). Tomato also has a wide usage area as the most versatile vegetable.

Even if the origin of the tomato is South America, it is produced in a wide area in the world. Especially, China, India, Türkiye and USA are globally shining out for tomato production (FAO, 2021). Although Türkiye ranks third among tomato producers in the world, the yield value of tomatoes is not at the desired level. This circumstance directly affects profitability of producers and it is specifically becoming a limitation factor for small farmers.

The main objective of tomato breeding studies is to obtain high yielding hybrid tomato varieties in the different greenhouse conditions. In a breeding program for the optimum yield level, plant selection depends on the extent of the effect of factors related to yield and the knowledge of the interaction of these factors with each other. The only consideration of correlation coefficient is not enough for selection in breeding studies. The correlation coefficient between two parameters is not sufficient to identify cause and effect. Sometimes, the relationship between two parameters may depend on another parameter. For this reason, it is necessary to make the relationship between the traits more understandable by separating the correlation coefficient between yield and yield components into direct and indirect effects and by revealing their proportional contribution on yield for an effective selection (Wright, 1934; Gravois and Helms, 1992). The path analysis is based on multiple regression analysis and path coefficients are standardized regression coefficients (Dewey and Lu, 1959; İkiz and Şengonca, 1978).

Alam et al. (2019) employed correlation and path analysis in their study with 23 tomato genotypes to determine 13 traits contributing to yield. In their study, correlation coefficients were determined for relationships among the traits. According to the result of this study, yield per plant (r=0.99), fruit weight (r=0.72), fruit diameter (r=0.67), number of carpel per fruit (r =0.67), and pericarp thickness (0.66) had positive and highly significant correlations with yield. They also studied cause effect relations among yield (t ha^{-1}) and its components through path coefficient analysis. Yield per plant was the most effective factor (1.018), and it was followed by number of flower per plant (0.212) and pericarp thickness (0.155). Fruit diameter (-0.279) had the most negatively direct effect on the yield, but it had positive correlation (r=0.67) with yield. Anuradha et al. (2018) carried out a study to analyze path coefficient and correlation of 13 traits that were related to yield with 40 tomato genotypes in 2017-2018 season. In their study, yield per plant, average fruit weight, yield per hectare, beta carotene and lycopene had highly positive correlations with yield. Moreover, plant height, number of primary branches per plant, number of day from sowing date to fruit set, number of fruit per plant, ascorbic acid and Brix° had significant negative correlation. Path analysis also revealed that some factors such as average fruit weight and number of fruit per plant had directly positive effect and also they had positive correlation with yield.

Kumar et al. (2013) studied on 26 tomato genotypes in India, which the tomato yield is below the world average. In their study, the correlation analysis demonstrated that number of fruit and cluster per plant were significant on yield. Path analysis revealed that fruit weight had the most positive direct effect on yield per plant, followed by number of fruit per plant, fruit diameter and number of fruit per cluster.

Sharma et al. (2019) carried out a study in 2015-2016 spring season with 27 tomato genotypes. Their study revealed that marketable fruit per plant, plant height, internode length and average fruit weight had a positive effect on yield and these criteria could be used as a selection criterion for high yield. According to the result of path coefficient analysis, number of marketable fruit per plant was the most effective parameter on yield and it was followed by average fruit yield and fruit shape index.

According to Tiwari and Apadhyay (2011), fruit weight was significant in terms of both correlation and path analysis on yield, and it can be used as a selection criterion in order to improvement of fruit yield.

Path coefficient analysis is widely used in order to determination of relationship between yield and yield components. Even if many studies have been conducted in another countries, there is no sufficient number of studies in Türkiye. Therefore, the present study on tomato breeding program was carried out to determine factors having significant effects on the yield by using correlation and path coefficient analyses.

2. Material and Methods

The present study was carried out in spring season of 2020 at Batı Akdeniz Agricultural Research Institute (BATEM) in Antalya, Türkiye whose location is at 36°C 928 N latitude and 30°C 982 E longitude and is 18 m above mean sea level. The soil structure is light and loamy.

In the present study, 12 candidate hybrid varieties improved by BATEM and 2 commercial hybrid varieties were used. Randomized complete block design (RCBD) was used as experimental design in 3 replications with 10 tomato plants in each replicate. In planting, inter row spacing (0.80 × 0.50 m) was 0.65 m and intra row was 0.60 m with double row planting. Cultural practices such as irrigation, pruning, weed management, and pesticide applications were carried out regularly.

Hybrid variety candidates and two commercial hybrid varieties used as control group were sown to plastic vials in the autumn period. Three weeks later, when the seedlings had 4-5 true leaves, the seedlings were planted in rows with 10 seedlings in each plot. Irrigation and fertilization were planned as twice a week. Sticky pheromone traps were used against plant disease and insects.

The harvest was started at third month and completed at 4 times. Observations were executed on 10 plants in each plot and consisted of 13 parameters. These parameters were; number of days to 50% flowering (NDFF), number of days from first flowering to first fruit set (NDFR), the length under the first cluster (SLFC), internode length (IL), fruit diameter (FD), fruit length (FL), leaf diameter (LD), leaf length (LL), average fruit weight (FW), average fruit number (NF), total yield of tomato plants (YP) early yield per plant tomato (EYP) and Brix° (According to UPOV criteria) (Table 1). The correlation coefficient was calculated by first

Table 1. The morphological observations methods used in the study.

No	Morphological observations	Explanation
1	Number of days to 50% flowering (NDFF)	Days to 50% flowering were determined by recording the number of days after transplanting (DAT) until 50% of plants in a plot had at least one open flower.
2	Number of days from sowing to first fruit set (NDFR)	The flowers of each plant in the plots were observed and the date of fruit set in half of the plants was recorded.
3	Stem length to first cluster (SLFC)	Flower cluster were observed in each plots and the distance between soil level and flower cluster was measured as cm.
4	First Internode length (IL)	Half of plants were observed in each plots. The internode above the first flower cluster was based on. The data were recorded as cm.
5	Fruit diameter measurement (FD)	Ten fruits were harvested from each genotype and fruit diameters were determined.
6	Fruit length (FL)	Ten fruits were harvested from each genotype and fruit lengths were determined.
7	Leaf diameter (LD)	On the 80th day after sowing, the diameters of the leaves at the 5th node from the top were measured with a ruler. Data were measured in cm.
8	Leaf length (LL)	On the 80th day after sowing, the length of the leaves in the 5th node from the top was measured with a ruler. Data were measured in cm.
9	Early yield per plant (EYP)	The data were obtained by addition of first two harvest values. It was recorded in grams by dividing by the number of plants in the plot.
10	Total yield per plant (YP)	Total weight of harvest was measure in each plot. It was recorded in grams by dividing by the number of plants in the plot.
11	Number of fruit (NF)	Harvested fruits were counted in each plots. These data were divided by number of plants in the plots and average number of fruits were determined.
12	Fruit weight (FW)	The harvested tomatoes were weighed. The average fruit weight was recorded as g by dividing by the number of plants in the plot.
13	Brix°	Digital refractometer was used a with the refractometric method (Gölükcü et al., 2018), (A. Krüss Optronic GmbH, DR6000 series, Germany).

determining the covariance of the variables and then dividing that quantity by the product of those variables' standard deviations. The coefficients were calculated by using a formula for correlation. Path coefficients were estimated according to Dewey and Lu (1959) and Singh and Chaudhary (1985), where yield (kg plot^{-1}) was kept as resultant variable and other contributing characters as causal variables. TARIST (version 5.0) computer software were used for correlation and Path analysis.

3. Results and Discussion

Fruit yield is a polygenic trait. Therefore, interaction among these genes and analyzing of their relationship with fruit yield are very important for selection criteria. For this reason, to find desired traits, plant breeders need to obtain large genetic diversity and variation among their breeding populations (Ritonga et al., 2018). Correlation coefficient among fruit yield per plant and its 12 component traits in all possible combinations are shown in Table 2.

Correlation analysis showed that fruit length (0.610*) and early fruit yield per plant (0.597*) had a positive effect on yield. The increases in these traits lead to significant increases in fruit yield per plant. Moreover, stem length to first cluster (SLFC) and number of days from sowing to first fruit flowering (NDFF) had a positive effect (0.702**) on fruit yield per plant as well. Furthermore, the result of the present study demonstrated that leaf surface (between leaf diameter and leaf length) is significant (0.968**). On the other hand, there were not only some traits that had positive effects on yield, but also some traits with negative effect. Firstly, number of days to 50% flowering (NDFF) had a negative effect (r: -0.576*). In addition, relationship between Brix° value and yield per plant was inversely related (r:-0.569*). Furthermore, there was a negative relationship among fruit diameter and number of days from sowing to first fruit number (-0.664**), and internode length (-0.558*). Moreover, there was a negative correlation between number of fruit and internode length (-0.637*) and also early yield and number of days from sowing to first florescence number had a negative relationship with each other (-0.616*). According to result of the present study observed 12 observed components had positive or negative effects on the yield. While NDFR, IL, FL, FW, NF, FD and EYP have positive effect on the yield, NDFF, SLFC, LL, LD and have positive effect on the yield, NDFF, SLFC, LL, LD and Brix° had a negative effect on the yield. The results of traits effective on yield per plant on other traits are demonstrated in Table 3. Fruit weight (FW) (1.1543), number of fruit (NF) (0.4127), leaf length (LL) (0.1810) and earliness fruit yield (EYP) (0.0492) had a directly and positive effect on the yield. Fruit weight was in the positive correlation with YP, NDFR, IL and FL on fruit yield while it had negative correlation with other parameters. Its path coefficient was 1.154 and its correlation coefficient was 39%. The path coefficient of fruit number was 0.4127 and its correlation was really high with 16% rates. This parameter was in the positive correlation with SLFC (0.1535), NDFF (0.1487), Brix° (0.092) and EYP (0.0167). Leaf length was in the positive correlation with FD and FL while it was negative

Table 2. Correlation coefficient of characters contributing to yield in tomato.

Traits	NDFF	NDFR	SLFC	IL	FD	FL	LD	LL	FW	NF	Brix°	EYP
YP	-0.576*	0.502ns	-0.502ns	0.013ns	0.188ns	0.610*	-0.223ns	-0.283ns	0.187ns	0.485ns	-0.569*	0.597*
NDFF		0.091ns	0.702**	-0.532*	-0.664**	-0.309ns	0.345ns	0.286ns	-0.293ns	-0.025ns	0.429ns	-0.616*
NDFR			-0.202ns	-0.266ns	-0.065ns	0.310ns	0.147ns	0.115ns	0.327ns	0.320ns	-0.076ns	0.187ns
SLFC				-0.195ns	-0.558*	-0.004ns	0.079ns	0.052ns	-0.298ns	-0.152ns	-0.121ns	-0.489ns
IL					0.493ns	0.246ns	0.238ns	0.307ns	0.371ns	-0.637*	-0.165ns	0.156ns
FD						-0.088ns	-0.339ns	-0.270ns	0.673**	-0.444ns	-0.204ns	0.453ns
FL							0.046ns	-0.041ns	0.177ns	0.061ns	-0.519ns	0.175ns
LD								0.968**	-0.254ns	-0.189ns	0.530ns	-0.479ns
LL									-0.250ns	-0.225ns	0.531ns	-0.466ns
FW										-0.548*	-0.082ns	0.339ns
NF											-0.197ns	0.072ns
Brix°												-0.516ns

YP: Yield per plant, NDFF: The number of day from first sowing date to first florescence time, NDFR: The number of day from the first florescence to the first fruit set, SLFC: Stem length to first cluster, IL: Internode length, FD: Fruit diameter, FL: Fruit length, LD: Leaf diameter, LL: Leaf length, FW: Average fruit weight, NF: Number of fruit per plant, EYP: Early yield per plant.
*, **, and ns; significant at the $p < 0.05$, $p < 0.01$ level, and not significant, respectively.

Table 3. Effects of traits effective on yield per plant on other traits (Direct and indirect effects at levels of various component characters on yield of tomato).

No	Traits	Direct effects	Indirect effects											
			1	2	3	4	5	6	7	8	9	10	11	12
1	NDFF	-0.5070	-	-0.0503	-0.3615	0.4490	0.3659	0.0231	0.3130	0.0517	-0.3384	-0.0104	-0.4812	-0.0303
2	NDFR	-0.5511	-0.0463	-	0.1042	0.2247	0.0358	-0.0232	0.1332	0.0208	0.3775	0.1319	0.0852	0.0092
3	SLFC	-0.5147	-0.3560	0.1115	-	0.1641	0.3075	0.0003	0.0712	0.0094	-0.3441	-0.0628	0.1362	-0.0240
4	IL	-0.8434	0.2699	0.1468	0.1001	-	-0.2715	-0.0184	0.2159	0.0555	0.4278	-0.2627	0.1855	0.0077
5	FD	-0.5510	0.3367	0.0358	0.2872	-0.4156	-	0.0065	-0.3067	-0.0489	0.7766	-0.1834	0.2290	0.0223
6	FL	-0.0748	0.1567	-0.1707	0.0021	-0.2073	0.0482	-	0.0417	-0.0074	0.2049	0.0251	0.5824	0.0086
7	LD	0.9060	-0.1751	-0.0810	-0.0405	-0.2010	0.1865	-0.0034	-	0.1751	-0.2926	-0.0782	-0.5953	-0.0235
8	LL	0.1810	-0.1448	-0.0632	-0.0267	-0.2585	0.1490	0.0030	0.8768	-	-0.2885	-0.0928	-0.5957	-0.0229
9	FW	1.1543	0.1487	-0.1803	0.1535	-0.3126	-0.3707	-0.0133	-0.2297	-0.0452	-	-0.2263	0.0920	0.0167
10	NF	0.4127	0.0128	-1.7620	0.0784	0.5369	0.2449	-0.0046	-0.1716	-0.0407	-0.6328	-	0.2212	0.0035
11	Brix°	-1.1223	-0.2174	0.0419	0.0625	0.1394	0.1124	0.0388	0.4806	0.0960	-0.0947	-0.0813	-	-0.0254
12	EYP	0.0492	0.3125	-0.1032	0.2516	-0.1319	-0.2496	-0.0131	-0.4338	-0.0844	0.3912	0.0297	0.5787	-

NDFF: The number of day from first sowing date to first florescence time, NDFR: The number of day from the first florescence to the first fruit set, SLFC: Stem length to first cluster, IL: Internode length, FD: Fruit diameter, FL: Fruit length, LD: Leaf diameter, LL: Leaf length, FW: Average fruit weight, NF: Number of fruit per plant, EYP: Early yield per plant.

correlation with other parameters. Number of days from sowing to first fruit set (NDFR) had a negative effect on the yield. Its path coefficient was -0.507 and its the raito of direct effect to yield was 17%. These results were consistent with the results in the literature (Rasheed et al., 2017; Alam et al., 2019). Moreover, according to Ritonga et al (2018), fruit weight and number of fruit directly effect the yield and the result of the present study correspond to their study.

According to result of the present study, fruit weight (-0.5510, 17%) and fruit length (-0.0748, %4) had a negative path coefficient so it can be said that their effects were negative. On the contrary, fruit weight (1.1543, 39%) and fruit number (0.4127, 16%) were the most positively effective parameters on the yield. Even if fruit diameter had a negative effect on yield, fruit length did not have a similar effect. Fruit number (0.4127, 16%) had a positive effect on the yield. In this context, the result of this study is consistent with the result of Mohanty et al. (2003). On the other hand, some obtained results were not similar with the other studies. According to literature there is an ongoing debate on fruit length and diameter (Ritonga et al., 2018; Alam et al., 2019; Sanchez et al., 2019; Sharma et al., 2019, Singh et al., 2021). These results show that the value of the leaf diameter path coefficient was 0.0960 and its the raito of direct effect to yield was 32.8%. In addition, the path coefficient of the leaf length was found to be 0.1810 and the direct effect ratio was 6.6%. There is no previous study on the effects of leaf length and leaf diameter on yield. The path coefficient showing the direct effect of the average fruit weight on the yield was 1.154 and the ratio in the ratio of direct effect to yield was 39%, the path coefficient for the number of fruit per plant were 0.427 and the ratio was quite high with 16%. Path and correlation coefficients that was used for demonstration of direct and indirect effect on yield show that the number of day from first sowing date to first florescence time had a negative effect on the yield. Its path coefficient was -0.507 and the ratio of direct effect to yield was 17%. These results were similar with the results of Rasheed et al. (2017) and Alam et al. (2019). Moreover, according to Ritonga et al. (2018), fruit weight and number of average fruit number per plant affect the yield directly. The results of the present study were similar with those of Ritonga et al. (2018).

According to result of the present study, fruit diameter (-0.5510, 17%) and fruit length (-0.0748, 4%) had a negative path coefficient so it can be said that they effect yield negatively. However, it is demonstrated that number of fruit (0.4127, %16) and fruit weight (1.1543, %39) were the most effective factors on the yield. Although increasing of fruit diameter has negative effect on the yield, fruit length has no similar effect on the yield. Number of fruit per plant (0.4127, %16) had a positive effect on the yield. In this context, this study has similar results with Mohanty et al. (2003). On the contrary, the results of this study are not similar with those of other studies. The literature on this topic clearly showed that there is an ongoing debate on aspect ratio of fruit, so some researchers say that it has a positive effect on yield, while others say that it has a negative effect on yield (Ritonga et al., 2018; Sharma et al., 2019; Sanchez et al., 2019; Alam et al., 2019; Sing et al., 2021).

According to results, the path coefficient of leaf diameter was 0.9060 and correlation coefficient was 32.8%. Furthermore, the path coefficient of leaf length was 0.1810 and its correlation coefficient rate was 6.6%. No other study was found on leaf diameter and leaf length.

The path coefficient of Brix° was -1.1223 and its the ratio of direct effect to yield was 44%. These results display clearly that Brix° had a negative effect on the yield. There are many studies that have similar results. For example, this value was -0.4098 in Reddy et al. (2013), -0.5027 in Anuradha et al. (2018), -0.26 in Alam et al. (2019), -0.19 in Sing et al. (2021) which were consistent with our results.

4. Conclusion

All observed parameters had a positive or negative effect on tomato yield. Results display that stem length to first cluster had a negative effect on yield. The result of fruit dimension and fruit weight demonstrate that as fruit volume increased, the number of fruit per plant decreased. The cumulative effect of fruit dimensions (fruit diameter and fruit length) and fruit weight can be seen in the fruit weight. Average fruit weight had a positive effect on the yield. In addition to this, when fruit volume increased, Brix° value decreased and this circumstances had a positive effect on the yield.

According to the result of this study, fruit weight and fruit dimension had a direct effect on the yield and other parameters had an indirect effect on the yield. Therefore, it can be said that the used parameters in this study can be used as a selection criterion in breeding program.

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