Linear relationships between cherry tomato traits

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ABSTRACT: *The objective of this study was to identify the linear relationship between cherry tomato yield components. Two uniformity trials, without treatments, were conducted on Lilli cherry tomato plants in a plastic greenhouse during the 2014 spring/summer season, with the plants in two stems. Variables observed for each plant were mean fruit length, mean fruit width, mean fruit weight, number of bunches, number of fruits per bunch, total number of fruits, and total fruit weight; a Pearson's correlation matrix was used to estimate the relationship between the variables. Path analysis was then performed considering total fruit weight as the main variable and the remaining variables as explanatory. Due to the severe multicollinearity, the variable 'number of fruits per bunch' was eliminated. Pearson's correlation coefficients were significant between explanatory and main variables. Mean fruit weight has a low cause-and-effect relationship with the total weight of fruits produced. A low cause-and-effect relationship was also observed between number of fruits and number of bunches. Cherry tomato productivity is directly related to the number of fruits per plant.*
Key words: **Solanum lycopersicum** *var.* **cerasiforme***, path analysis, correlation.*

Relações lineares entre caracteres de tomate do tipo cereja

RESUMO: *O objetivo deste artigo foi identificar a relação linear entre os componentes da produtividade do tomate cereja. Dois ensaios de uniformidade, sem tratamentos, foram instalados em estufas plásticas nas estações primavera/verão de 2014 com tomate cereja Lilli, com as plantas conduzidas em duas hastes. As variáveis observadas em cada planta foram o comprimento médio de fruto, a sua largura média, o peso médio seu, o número de cachos, o número de frutos por cacho, o número total de frutos e o peso total de frutos, sendo estimada a matriz de correlação de Pearson entre elas. Posteriormente, foi realizada a análise de trilha considerando-se o peso total de frutos como variável principal e as demais como variáveis explicativas. Devido à multicolinearidade severa, optou-se pela eliminação da variável número de frutos por cacho. Os coeficientes de correlação de Pearson, entre as variáveis explicativas e a variável principal, foram significativos. O peso médio de frutos tem baixa relação de causa e efeito com o peso total de frutos produzidos. Também, o número de frutos e o número de cachos apresentaram baixa relação de causa e efeito entre si. A produtividade do tomate cereja está diretamente relacionada com o número de frutos por planta.*
Palavras-chave: **Solanum lycopersicum** *var.* **cerasiforme***, análise de trilha, correlação.*

INTRODUCTION

Tomato is an important edible plant cultivated in Brazil. In 2015, 56,880 hectares of tomato plants were cultivated in Brazil resulting in a production of 3,686,816 tons of fruit (IBGE, 2014). Among the various types of tomato, cherry tomato is highlighted in this study due to its use in plate decoration and its use as a starter (GUSMÃO et al., 2006), and also for its higher economic value in the market, as compared to other tomato varieties. The importance of cherry tomato justifies the development of experiments on this plant, and the greater the amount of data collected, the better the chances of researchers to help farmers in an effective way.

When a large number of variables are measured, it is desirable to understand how they are related. The linear relationship between traits is very important in agricultural sciences, mainly for improvement programs, in the indirect selection of genotypes (CRUZ et al., 2006). It can also be an auxiliary tool, demonstrating the level of relationship

between traits and statistics during planning and experimental conditions, as verified by LÚCIO et al. (2006) on bell peppers and by CARGNELUTTI FILHO et al. (2011) on beans. In addition, knowing the relationship between the production components and productivity may help to decide on the type of handling that should be used.

Pearson's linear correlation is one way to determine the degree of relationship between two variables. However, a simple correlation does not detect the influence of a third variable or group of variables on this relationship, which may lead to incorrect conclusions (CRUZ et al., 2006). Path analysis, proposed by WRIGHT (1921) and WRIGHT (1923), is a technique of multivariate analysis that specifically studies the existing relationship between a set of explanatory variables and a main dependent variable. In this analysis, Pearson's linear correlation is decomposed into direct and indirect effects, allowing the determination of a cause and effect relationship between an explanatory variable and a main variable, independently of the remaining variables (CRUZ et al., 2006).

Linear relationships between production components and productivity are important in improvement programs, as they indicate which trait must be improved or selected in order to obtain the most productive tomato genotypes. Furthermore, comprehending this relationship may help decide which handling approach to adopt. The linear relationship between production components and productivity has been studied in various cultures, such as wet rice (MARCHEZAN et al., 2005), maize (ENTRINGER et al., 2014), salad tomato (RODRIGUES et al., 2010), and wheat (SILVA et al., 2005; GONDIM et al., 2008). However, no studies were found that evaluated the degree of relationship between cherry tomato production components. As such, the aim of this study is to evaluate the linear relationship between productivity components in cherry tomato plants.

MATERIALS AND METHODS

Two uniformity trials (without treatments) were performed in plastic greenhouses Pampeano type, placed in a north-south orientation, with different dimensions: a 20m long and 10m wide (200m²) greenhouse with a height of 3mon the sides and 4m in the central area; and a 25m long and 10m wide (250m²) greenhouse with a height of 4m on the sides and 5m in the central area. Both greenhouses were covered with a low-density polyethylene film with a thickness of 150 micron and anti-UV additive.

In the month before the start of the experiment, the soil pH was set to 6.5 and the levels of phosphorus to 300mg dm^{-3} in both greenhouses. Limestone and phosphorus used to correct the soil were incorporated using a rotary tiller, and ridges measuring approximately 0.20m in height and 0.30m in width were then created and covered with black opaque film "mulching" strips. Eight ridges were erected in each greenhouse, with a 1m distance between each one; drip irrigation was used.

Trails were performed using the Lilli cherry tomato hybrid during the spring/summer season of 2014. Seedling transplant was performed on the October 26, 2014 when the first sprouting occurred. Seedlings were planted at 0.5m distances, in a total of 34 plants per row in the 200m² greenhouse and 44 plants in the 250m² greenhouse. Fertilization was performed using 150kg ha^{-1} of N, 250kg ha^{-1} of P, and 125kg ha^{-1} of K, in both greenhouses. Two topdressing fertilizations were performed with 30kg ha^{-1} of N, 15kg ha^{-1} of P, and 30kg ha^{-1} of K with a 23day interval between them. Base and top dressing fertilizations were performed based on chemical analysis of the soil and according to the recommendations of the Network of Soil and Plant Tissue Analysis Laboratories of the states of Rio Grande do Sul and Santa Catarina (ROLAS, 2004).

Tomato plants were grown using two stems in both greenhouses, and all lateral growths were eliminated. Every 14 days were applied calcium and boron in order to avoid flower abortion and "black bottom" tomatoes. Fungicides and insecticides were also applied every 14 days to control plagues and diseases.

Each fruit bunch, and each fruit, from all the plants were collected and from them the following variables were measured: a) mean fruit length per plant (MFL, in cm), corresponding to the transverse fruit measure; b) mean fruit width per plant (MFWd, in cm), corresponding to the longitudinal fruit measure; c) mean fruit weight per plant (MFW, in g); d) number of bunches per plant (NBP); e) number of fruits per bunch (NFB), obtained by dividing the total number of fruits by the total number of bunches; f) number of fruits per plant (NFP); and g) total fruit weight per plant (TFW, in g). Measurements were performed with the help of caliper rulers and precision scales (0.01g).

Existence of outliers was determined using dispersion graphs and, when they were identified, the outliers were eliminated. From the variables measured in 247 plants from the 200m² greenhouse and 347

plants from the 250m² greenhouse, the minimum and maximum values, mean, variance, standard deviation, coefficient of variation, and standard error were estimated. A Pearson's correlation matrix was then constructed and the significance of the correlation coefficients obtained was verified using a t-test (P-value<0.05). The means obtained in each plastic greenhouse were compared for each variable using a paired t-test with independent samples (P-value<0.05).

A multicollinearity diagnosis was performed from the Pearson's correlation matrix of the variables observed for each trail, and the results were interpreted according to the condition number (CN), as proposed by MONTGOMERY & PECK (1982). Following that, path analysis was performed considering TFW as the main variable and the remaining variables as explanatory. Genes software was used to perform the analyses (CRUZ, 2006).

RESULTS AND DISCUSSION

TFW did not differ statistically between the two experiments. The 250m² greenhouse produced larger and heavier fruits, but in a lower amount compared to the 200m² greenhouse. The NBP in the 250m² greenhouse was lower than it was in the 200m² greenhouse; however, the NFB did not differ. There was increased variability between the plants (CV>20%) regarding the variables TFW, NBP, NFP, and NFB, and decreased variability regarding the remaining variables (Table 1). Characteristics observed in Lilli hybrids in this experiment are in accordance with the results obtained by AGUIRRE & CABRERA (2012).

A weak (r values close to zero) or inexistent (non-significant r values) linear relationship was observed between the MFL, MFWd, and MFW, with theNBP, NFP, and NFB. Conversely, the variables NBP, NFP, and NFB showed a strong and positive linear relationship to the TFW (r values closer to 1), whereas the variables MFL, MFWd, and MFW; although significant, show low r values, indicating a weak relationship with the TFW (Table 2).

As fruits are metabolic drains, it was expected that in plants with a lower number of fruits, the fruit size would increase, due to a higher amount of photoassimilates being available for the development of each individual fruit. As such, a negative linear relationship was expected between the MFW and the NFP, which was not observed. This result can be explained by the fact that the source-drain relationship was not significantly affected due to the elevated number of tomatoes per plant.

Table 1 - Number of observations (n), minimum, maximum, mean, variance, standard deviation (SD), and coefficient of variation (CV%) of the variables mean fruit length per plant (MFL, in cm), mean fruit width per plant (MFWd, in cm), mean fruit weight per plant (MFW, in g), number of bunches per plant (NBP), number of fruits per bunch (NFB), number of fruits per plant (NFP), and total fruit weight per plant (TFW, in g) observed in two uniformity trails with cherry tomato.

	TFW	MFL	MFWd	MFW	NBP	NFP	NFB
--------250m² greenhouse--------							
n	347	347	347	347	347	347	347
Minimum	100.00	2.24	2.28	9.09	2.00	11.00	5.50
Maximum	3542.00	2.99	3.31	19.18	23.00	270.00	19.50
Mean	1592.14 a[1]	2.61 a	2.75 a	13.60 a	10.46 a	117.82 a	11.27 a
Variance	325416.41	0.2	0.02	3.05	10.90	1788.66	5.92
SD	570.45	0.12	0.14	1.75	3.30	42.29	2.43
CV%	35.83	4.66	5.23	12.84	31.56	35.90	21.58
--------200m² greenhouse--------							
n	247	247	247	247	247	247	247
Minimum	173.00	2.20	2.27	7.23	3.00	23.00	4.60
Maximum	3016.00	2.88	3.11	16.21	22.00	225.00	20.00
Mean	1583.52 a	2.53 b	2.70 b	12.50 b	11.49 b	125.36 b	10.98 a
Variance	313394.01	0.01	0.02	2.13	10.60	1701.41	6.57
SD	559.81	0.12	0.14	1.46	3.26	41.25	2.56
CV%	35.35	4.69	5.12	11.67	28.34	32.91	23.34

[1]Mean values followed by the same letter, within each variable and between the two greenhouses, did not differ according to the t-test (P-value<0.05).

Table 2 - Pearson's correlation matrix between the variables mean fruit length per plant (MFL, in cm), mean fruit width per plant (MFWd, in cm), mean fruit weight per plant (MFW, in g), number of bunches per plant (NBP), number of fruits per bunch (NFB), number of fruits per plant (NFP), and total fruit weight per plant (TFW, in g) observed in two uniformity trails with cherry tomato.

	TFW	MFL	MFWd	MFW	NBP	NFP	NFB
--250m² greenhouse--							
TFW	1	0.205[*]	0.287[*]	0.239[*]	0.830[*]	0.964[*]	0.565[*]
MFL		1	0.912[*]	0.874[*]	-0.083	-0.028	0.086
MFWd			1	0.888[*]	-0.032	0.052	0.163[*]
MFW				1	-0.080	-0.027	0.081
NBP					1	0.877[*]	0.092
NFP						1	0.560[*]
NFB							1
--200m² greenhouse--							
	TFW	MFL	MFWd	MFW	NBP	NFP	NFB
TFW	1	0.421[*]	0.479[*]	0.599[*]	0.773[*]	0.970[*]	0.572[*]
MFL		1	0.916[*]	0.768[*]	0.133[*]	0.253[*]	0.242[*]
MFWd			1	0.796[*]	0.172[*]	0.313[*]	0.290[*]
MFW				1	0.282[*]	0.391[*]	0.271[*]
NBP					1	0.803[*]	-0.019
NFP						1	0.581[*]
NFB							1

[*]Significant according to the t-test (P-value<0.05), with 345 degrees of freedom in the 250m² greenhouse and 245 degrees of freedom in the 200m² greenhouse.

Thus, individually, cherry tomato fruits are weak drains (HEUVELINK, 1997; PEIL et al., 2014). The low magnitude linear relationship between the variable TFW and the variables MFL, MFWd, and MFW, and the high magnitude relationship between the variables NBP, NFP, and NFB indicated that, individually, the fruits have little influence on the plant's total production.

It is therefore understood that plants with a higher number of fruits are the most productive. However, this cause-and-effect relationship cannot be truly proved using the Pearson's correlation coefficient, as it does not quantify the influence of other variables on this relationship. Therefore, path analysis was performed in order to determine the cause-and-effect relationship between the production components (explanatory variables) and the production of fruits per plant (dependent variable).

Condition numbers, obtained through the multicollinearity diagnosis from the correlation matrix of the explanatory variables, were higher than 100 in both plastic greenhouses, indicating severe multicollinearity (MONTGOMERY & PECK, 1982). Among the problems caused by multicollinearity is the variance inflation of the path coefficient estimates, obtaining values that are too

high, without biological interpretation. Elimination of explanatory variables is one of the most efficient ways of reducing or eliminating the problem of multicollinearity. As such, the variable NFB was removed from the statistical analyses, which lowered the CN to 35.80 and 37.02 in the 250m² and the 200m² greenhouses, respectively (Table 3). In this way, the multicollinearity problem was overcome, and path analysis was then performed with the remaining explanatory variables.

The direct, low magnitude, effects of the MFWd, MFL, and MFW on the TFW, in both experiments, confirms that the size of the cherry tomato fruit has little influence on total production. The elevated same directional magnitude values indicated that the productivity of cherry tomato is highly related to the NFP. The NBP has a low direct effect on the TFW, even though it showed a high r-value (Table 3). The indirect effect of the NBP through a positive, high magnitude NFP indicates that the number of bunches is closely related to the number of fruits. This is expected since for the plant to produce more fruit, more floral bunches need to be fertilized.

Therefore, results showed that cherry tomato production is directly related to the number

Table 3 - Estimates of Pearson's correlation coefficients and the direct and indirect effects of the variables mean fruit length per plant (MFL, in cm), mean fruit width per plant (MFWd, in cm), mean fruit weight per plant (MFW, in g), number of bunches per plant (NBP), number of fruits per bunch (NFB), number of fruits per plant (NFP), and total fruit weight per plant (TFW, in g) observed in two uniformity trails with cherry tomato.

Effect	250m² greenhouse	200m² greenhouse
Direct effect of MFLonTFW	-0.004	0.011
Indirect effect of MFLthroughMFWd	0.005	-0.004
Indirect effect of MFLthrough MFW	0.232	0.195
Indirect effect of MFLthroughNBP	0.000	0.001
Indirect effect of MFLthrough NFP	-0.027	0.219
Pearson's correlation	0.205[*]	0.421[*]
Direct effect of MFWd onTFW	0.005	-0.005
Indirect effect of MFWd through MFL	-0.004	0.010
Indirect effect of MFWd through MFW	0.235	0.203
Indirect effect of MFWd through NBP	0.001	0.001
Indirect effect of MFWd through NFP	0.051	0.271
Pearson's correlation	0.287[*]	0.479[*]
Direct effect of MFW on TFW	0.265	0.254
Indirect effect of MFW through MFL	-0.004	0.008
Indirect effect of MFW through MFWd	0.005	-0.004
Indirect effect of MFW through a NBP	0.001	0.001
Indirect effect of MFW through NFP	-0.027	0.339
Pearson's correlation	0.239[*]	0.599[*]
Direct effect of NBP on TFW	0.002	0.005
Indirect effect of NBP through MFL	0.001	0.001
Indirect effect of NBP through MFWd	0.001	-0.001
Indirect effect of NBP through MFW	-0.021	0.072
Indirect effect of NBP through NFP	0.849	0.695
Pearson's correlation	0.830[*]	0.773[*]
Direct effect of NFP on TFW	0.969	0.866
Indirect effect of NFP through MFL	0.000	0.003
Indirect effect of NFP through MFWd	0.000	-0.002
Indirect effect of NFP through MFW	-0.007	0.100
Indirect effect of NFP through NBP	0.001	0.004
Pearson's correlation	0.964[*]	0.970[*]
Determination coefficient	0.999	0.998
Residual variable	0.028	0.041
Condition number	35.805	37.023

[*]Significant according to the t-test (P-value<0.05), with 345 degrees of freedom in the 250m² greenhouse and 245 degrees of freedom in the 200m² greenhouse.

of fruits produced, and that the individual weight of each fruit has little influence on total production. This result clashes with what is observed regarding salad-type tomato, in which the weight and number of fruits have equal importance in determining the final fruit weight per plant (RODRIGUES et al., 2010). As such, handling actions that aim to increase mean fruit size, or reduce the harvest period, such as apical pruning and fruit thinning, must be performed with caution on cherry tomato plants, as the loss in production caused by the reduction of the number of fruits will not be

compensated by an increase in MFW as that which occurs in salad-type tomato.

Due to the importance of NFP on cherry tomato production, plant or stem thickening appears to be a promising handling technique in the search for increased productivity. AZEVEDO et al. (2010) and PEIL et al. (2014) verified an increased cherry tomato production in dense cultures, which corroborated the results found in this study. High density planting leads to a reduction in the number of tomatoes per plant due to increased competition between plants. However, this reduction is compensated for by the higher number of plants (and consequently, of fruits) per area, increasing the overall productivity. Therefore, the highest cherry tomato productivity will be reached at the density in which the reduction in number of fruits per plant is no longer compensated by the increase in number of plants per area (PEIL et al., 2014).

Regarding cherry tomato plants, the relationship between number of fruits and total production is extremely important, since the results from this research demonstrated that the reduction in fruit number is not compensated by an increase in fruit size. Consequently, a reduction in the number of cherry tomato fruits leads to a reduction in fruit weight per plant. This is distinct from what occurs with salad-type tomato. Correspondingly, handling practices used to maximize the production of salad-type tomatoes may not be equally effective for cherry tomatoes.

Based on the linear relationships between the variables obtained in this study, it can be verified that tomato productivity is related to the number of fruits a plant produces. As such, the search for an ideal plant density, varying not only the spacing between the plants on each row but also the spacing between rows, can lead to considerable gains in cherry tomato productivity.

CONCLUSION

Fruit size, mean fruit weight, and the number of bunches per plant showed weak linear relationships with the total fruit weight produced by cherry tomato plants. Number of fruits per plant showed a positive linear relationship with the total fruit weight produced by cherry tomato plants.

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