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Agronomic performance of mini-tomato hybrids from dwarf lines

Desempenho agronômico de híbridos de minitomate provenientes de linhagens anãs

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ABSTRACT

Little is known about the commercial potential of mini-tomato hybrids obtained from one dwarf parent. Thus, our objective was to evaluate the agronomic performance of mini-tomato hybrids obtained by crossing a dwarf line (A) with normal lines with indeterminate (I), determinate (D) and semi-determinate (SD) growth habits. The experiment was conducted in a greenhouse at the Estação Experimental de Hortaliças at the Universidade Federal de Uberlândia-UFU in Monte Carmelo, Brazil. The experiment was completely randomized with 17 treatments and four repetitions. The genetic material consisted of 16 experimental mini-tomato hybrids from the tomato germplasm bank at UFU, and a commercial hybrid (Mascot) as a control. The following variables were used to evaluate agronomic performance: fruit weight (g); number of fruits plant^{-1}; productivity (kg plant^{-1}); number of bunches plant^{-1}; number of fruits bunch^{-1}; stem diameter (mm); distance between first bunch and soil (cm); internode length (cm) and total soluble solids (°Brix). The growth habit of the parents influenced the performance of the hybrids. In general, the mini-tomato hybrids from dwarf lines differed from the control with respect to all variables except number of fruits plant^{-1}, number of fruits bunch^{-1} and stem diameter. On average, hybrids from dwarf lines showed higher productivity (20%), shorter internodes (11%) and a shorter distance between the first bunch and the ground (30%), relative to the control. Using dwarf lines to obtain mini-tomato hybrids was shown to be viable since the hybrids demonstrated better agronomic performance.

Index terms: Brix; dwarfism; growth habit; *Solanum lycopersicum*.

RESUMO

Pouco se sabe a respeito do potencial comercial de híbridos de minitomate obtidos a partir de um genitor anão. Assim, o objetivo deste trabalho foi avaliar o desempenho agronômico de híbridos de minitomate obtidos pelo cruzamento entre linhagens anãs (A) versus linhagens normais de crescimento indeterminado (I), determinado (D) e semideterminado (SD). O experimento foi conduzido em casa de vegetação, na Estação Experimental de Hortaliças da Universidade Federal de Uberlândia (UFU), Monte Carmelo. Utilizou-se o delineamento inteiramente casualizado com 17 tratamentos e quatro repetições. O material genético consistiu de 16 híbridos experimentais de minitomate pertencentes ao Banco de germoplasma de tomateiro da UFU, e um híbrido comercial Mascot (testemunha). As variáveis utilizadas para analisar o desempenho agronômico foram: peso do fruto (g); número de frutos planta^{-1}; produtividade (kg planta^{-1}); número de pencas planta^{-1}; número de frutos penca^{-1}; diâmetro do caule (mm); distância do primeiro cacho ao solo (cm); comprimento de internódios (cm) e sólidos solúveis totais (ºBrix). O hábito de crescimento dos genitores influenciou o desempenho dos híbridos provenientes de linhagens anãs. De maneira geral, os híbridos de minitomate provenientes de linhagens anãs e a testemunha se diferenciaram em todas as variáveis, exceto no número de frutos planta^{-1}, número de frutos penca^{-1} e no diâmetro do caule. Em média, os híbridos provenientes de linhagens anãs apresentaram maior produtividade (20%), internódios mais curtos (11%) e menor distância da primeira penca ao solo (30%) em relação à testemunha. A exploração de linhagens anãs demonstra ser viável na obtenção de híbridos de minitomate, uma vez que estes apresentam potencial comercial.

Termos para indexação: Brix; nanismo; hábito de crescimento; *Solanum lycopersicum*.

INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is one of the vegetables most economically important in the world. Among the types of tomatoes, mini-tomatoes stand out from the rest because of their smaller fruit and sweeter taste. Their appealing taste has led to greater demand in grocery stores (Maciel et al., 2016). Moreover, this type of tomato is distinguished by the higher margins it commands in the market (Abraham; Boas; Bull, 2014; Maciel et al., 2016). Thus, increasing investment in mini-tomatoes has led to greater demand for new hybrids with improved agronomic performance.

Heterosis is mainly manifested in tomatoes by an increased number of fruits per plant, resulting in greater productivity (Borém; Miranda, 2009; Graça et al., 2015). Higher fruit quantity is closely related to the genes that control the growth habit of tomato plants belonging to the self-pruning family (SP) (Piotto; Peres, 2012). Some studies have shown that the hybrid vigor of tomatoes may stem from a single growth habit gene in heterozygous genotypes [flowering gene - single flower truss (SFT)], representing increases in tomato yield of up to 60% (Krieger; Lippman; Zamir, 2010).

Plant breeders have explored the heterotic potential of contrasting parents on tomato growth habit. Nevertheless, there is currently no information on crossing dwarf homozygote lines with normal lines (determinate, semi-determinate and indeterminate), especially due to the divergence between these parents (dwarf versus normal) (Maciel; Silva; Fernandes, 2015). Moreover, assuming that a single allele can change the hybrid vigor of a tomato (Krieger; Lippman; Zamir, 2010), the study of other genes in heterozygosity (e.g. dwarfism genes) gains relevance. However, there are few studies on the agronomic performance of mini-tomato hybrids from a dwarf parent (Gardner; Panthee, 2012; Panthee; Gardner, 2013a, 2013b).

In Brazil, there are no reports of mini-tomato hybrids with commercial potential that come from one dwarf parent. Few dwarf lines of mini-tomatoes with high Brix values are available for direct use in breeding (Maciel; Silva; Fernandes, 2015). Therefore, the objective of this study was to evaluate the agronomic performance of mini-tomato hybrids obtained by crossing dwarf lines with normal lines of indeterminate, determinate and semi-determinate growth.

MATERIAL AND METHODS

The experiment were conducted from November, 2014 to May, 2016 at the Estação Experimental de Hortaliças at the Federal University of Uberlandia – Monte Carmelo Campus, MG, Brazil (18º42'43.19"S, 47º29'55.8" and 873 m above sea level). The plants were grown in a hoop-style greenhouse (7 x 21 m, 4 m ceiling height), with a roof of 150-micron polyethylene that had been treated against ultraviolet raysand lateral curtain walls made from white anti-aphid screens.

The genetic material that was evaluated consisted of 16 experimental mini-tomato hybrids (UFU-1502, UFU-1503, UFU-1504, UFU-1505, UFU-1506, UFU-1507, UFU-1509, UFU-1510, UFU-1511, UFU-1512, UFU-1513, UFU-1514, UFU-1516, UFU-1518, UFU-1519, UFU-1520) and a commercial hybrid (Mascot). The hybrid Mascot (Topseed®) has fruit of intense red color, small (18g), and indeterminate growth habit. All 16 experimental hybrids were obtained by crossing different normal lines [determinate (D), semi-determinate (SD) and indeterminate (I) growth habit] with dwarf lines (A) from the tomato germplasm bank at the Federal University of Uberlandia. The dwarf lines has fruit of intense red color, small (10g), and indeterminate growth habit (Maciel; Silva; Fernandes, 2015). The UFU-1502, UFU-1503, UFU-1504, UFU-1505, UFU-1506, UFU-1507 and UFU-1513 hybrids came from an SDxA cross; UFU-1509, UFU-1510, UFU-1511, UFU-1512 and UFU-1514 from IxA; and UFU-1516, UFU-1518, UFU-1519, UFU-1520 from DxA.

Hybrids of the dwarf lines were sown in 200-cell polystyrene trays on May 27th, 2015. The resulting seedlings were transplanted into five liter containers 31 days after sowing. A commercial substrate based on coconut fiber was used in both the trays and the containers. Cultivation of these plants throughout the experiment followed recommendations for tomato crops grown in protected environments (Alvarenga, 2013). In addition, the plants were supported by two stakes and polythene strips using a string weave system.

A drip fertigation system (SPAGHETTI PEBD micro-tube) was used for irrigation with one arrow drip unit per plant and a flow rate of 4.0 l h-1. Irrigation was carried out three or four times per day depending on the stage of plant development and environmental conditions. Macronutrients (commercial formulation of 1.0:1.2:1.0 NPK) were applied between the first and eighth week after transplant during the plant development stage. Starting at the ninth week, a production nutrient solution was used with an NPK ratio of 1.0:0.7:2.0 (Maciel et al., 2016).

The experiment was completely randomized with 17 treatments (hybrids) and four replications. The experimental plots consisted of six plants distributed in double rows and spaced at 0.4 x 0.4 m. Each double row (carrier) was spaced 0.8 m from the next for a total of 408 plants covering 147 m² of greenhouse space.

The tomatoes were collected twice per week from August 29th to November 14th, 2015 (18 harvests). The fruit from each plot was harvested when it had reached full maturity (fully ripe fruit). The following agronomic characteristics were evaluated:

Average fruit weight (g): determined as the ratio between the weight and the number of all the tomatoes harvested from a plot.

Average productivity (kg plant^{-1}): determined as the ratio between the weight of the harvested tomatoes and the number of plants in the plot.

Average number of fruits plant^{-1}: determined as the ratio between the total number of tomatoes and the number of plants in a plot.

Number of bunches plant^{-1}: obtained by counting the total number of bunches on the two centermost plants from each plot.

Average number of fruits bunch^{-1}: determined as the ratio of the number of fruits plant^{-1} to the number of bunches plant^{-1}.

Stem diameter (mm): measurement of stem diameter between the third and fourth fluorescence of the two centermost plants from each plot. Diameter was measured with a digital caliper.

Distance between the first bunch and the soil (cm): determined as the distance between the first bunch and the soil and measured with a ruler (cm) from the two centermost plants from each plot.

Internode length (cm): determined by measuring the length between every node between the beginning of the first fork in the stem until the first leaf below the last inflorescence. Internode lengths were measured with a ruler (cm) on the two centermost plants from each plot.

Total soluble solids (ºBrix): determined as the mean of 15 tomatoes harvested from each bunch on the two centermost plants from each plot. After harvesting, the tomatoes were crushed in a blender and analyzed for total soluble solids using a Portable Digital Refractometer (Atago PAL^{-1} 3810).

After checking assumptions using the analyses of homogeneity of variance ("Levene's test") and normality ("Kolmogorov-Smirnov's test"), data transformation was used ($\sqrt{x}$) on only the number of fruits bunch^{-1} variable, for which real values were tabulated. The data were analyzed using two independent statistical models. The first examined the effect of the parent growth habit on hybrid performance and the second compared performance among hybrids.

In the first model, an unconventional analysis using a hierarchical model (also called a nested model) was used, which allowed the study of a single isolated factor (parent growth habit). For both models, the data were submitted to analysis of variance (F= 0.05) and the means were compared by the Scott-Knott test (p= 0.05), using the Sisvar statistical program (Ferreira, 2011). Simple correlation measurements were also performed (Pearson's test) between variables.

RESULTS AND DISCUSSION

Regardless of the parent growth habit, 100% of the hybrids showed indeterminate growth. This occurred, as expected, because the dwarf lines have indeterminate growth (Maciel; Silva; Fernandes, 2015). According to the review done by Piotto and Peres (2012), the indeterminate growth habit is controlled by the dominant allele Self Pruning (SP), which has dominance among the others growth habits. Despite all the hybrids had indeterminate growth, the growth habit of the parents had influenced the performance of the hybrids.

In general, hybrids from dwarf lines differed from the commercial hybrid (Mascot) regarding all agronomic variables except for number of fruits plant^{-1}, number of fruits bunch^{-1} and stem diameter. Parent growth habit only influenced internode length, number of bunches plant^{-1}, fruit weight and total soluble solids (Figure 1).

The hybrids produced an average of 446 fruits plant^{-1} and 33 fruits bunch^{-1}. Although the number of fruits did not differ, the productivity of the hybrids from dwarf lines was 20% greater than that of the commercial hybrid (Mascot) (Figure 1.c). This increase in productivity is explained by differences in fruit weight. Specifically, the hybrids from dwarf lines produced fruits that were 17% heavier than those of the commercial hybrid (Mascot) (Figure 1.a).

Presumably, increases in fruit weight were influenced by the shortening of the internodes in the hybrids from dwarf lines (Figure 1.f). The internodes of these hybrids were, on average, 11% shorter than those of the commercial hybrid (Mascot). Furthermore, shorter internodes did not change the stem diameter of the hybrids, which averaged 10.1 mm. Shorter internodes change the capacity of the tomato plant to absorb light and perform photosynthesis (Sarlikioti et al., 2011), thereby interfering in the production of photoassimilates and consequently, availability in sink regions. Therefore, it follows that some of the photoassimilates that might have supported internode growth or a stem diameter, instead supported tomato growth. It is important to emphasize that not all hybrids from dwarf lines showed shorter internodes, higher fruit weight and higher productivity in relation to the commercial hybrid (Mascot). This can be explained by genetic factor, where some parents (female parents) have lower productive potential, greater length of internodes and varied diameter of fruits compared to control (Mascot). In this sense, achieving better performance of hybrids obtained by minitomato dwarf lines also depends of the parental genetic potential.

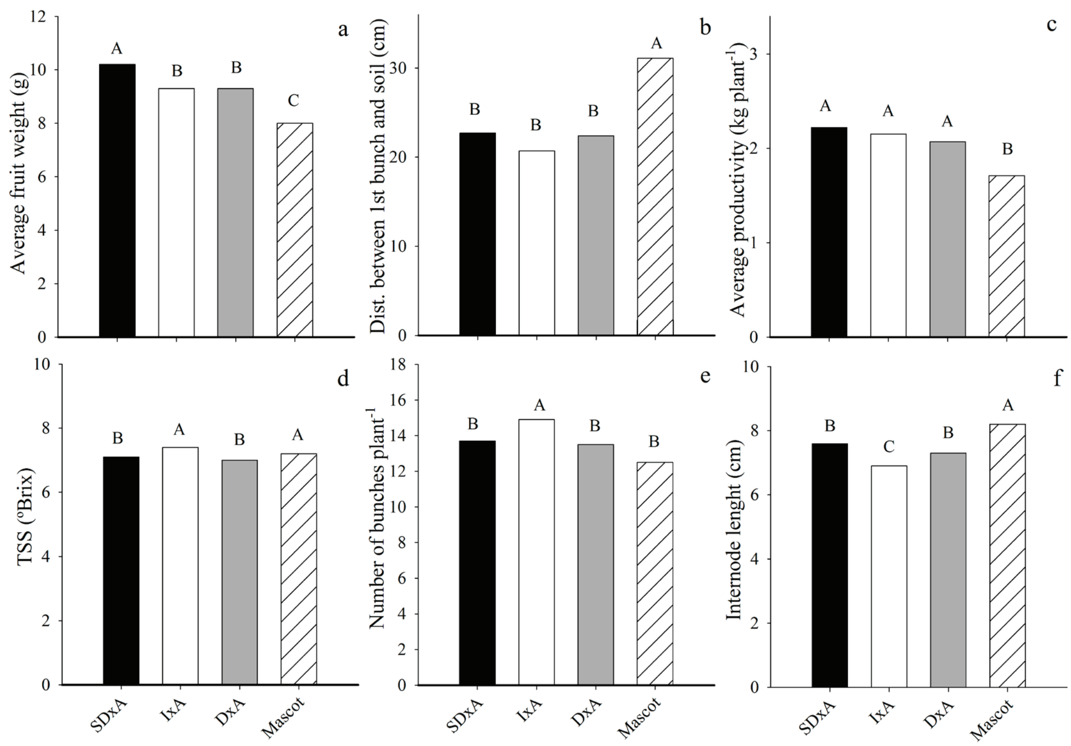

Figure 1: Agronomic performance of mini-tomato hybrids of dwarf lines where D: normal lines with determinate, (SD) semi-determinateand (I) indeterminate growth habits; and (A) dwarf line. Means followed by distinct letters differ by the Scott-Knott test at 0.05 significance.

The internode length of tomato plants can also be influenced by temperature, the quantity and quality of the light intercepted by the leaf (Chen et al., 2014), growth regulators (Figueiredo et al., 2015), moisture stress (Sibomana; Aguyoh; Opiyo, 2013), higher concentrations of atmospheric ozone (Thwe et al., 2013), among others. Nevertheless, shorter internodes caused by these factors hindered plant development, which differs from the results found in the current study. Gardner and Panthee (2012) and Panther and Gardner (2013a, 2013b) also observed shorter internodes in hybrids from dwarf lines. According to these authors, one of the main advantages of internode reduction for the growth of indeterminate mini-tomatoes is plant compaction, which allows the use of shorter plant supports. Furthermore, shorter indeterminate tomatoes may also facilitate pruning and staking practices (Figueiredo et al., 2015) and also facilitate harvesting.

Internode length also influenced the distance between the first bunch and the soil for hybrids from dwarf lines. In general, the first tomato bunch of hybrids from dwarf lines was 30% closer to the soil than for the commercial hybrid (Mascot) (Figura 1.b). The distance for these hybrids varied from 18.0 to 27.6 cm.

Regarding the influence of parent growth habit, hybrid fruit obtained from the cross SDxA was, on average, 9% heavier than hybrid fruit from IxA and DxA. Hybrid tomatoes from the IxA cross had internodes that were 7% shorter, soluble solids that were 5% higher and 1 more bunch per plant than hybrids from SDxA and DxA parentage.

Some reports show that small changes in the expression levels, different allelic combinations or mutations in growth habit genes can influence plant performance (Krieger; Lippman; Zamir, 2010; Park et al., 2014.). Thus, we can surmise that there were different expressions in the growth habit genes of these hybrids, especially in IxA versus DxA and SDxA, despite having the same indeterminate growth habit.

Presumably, hybrids derived from IxA had stronger gene expression related to reproductive development to the detriment of vegetative development, which explains the shorter internodes, greater numbers of bunches and higher soluble solids in the fruit. The weight of the fruit coming from SDxA parentage may have been higher due to the expression of other genes linked to flowering (Krieger; Lippman; Zamir, 2010). Soluble solid levels may have been affected not only indirectly by plant morphology, but also directly by biochemical mechanisms (Piotto and Peres, 2012).

Levels of soluble solids in mini-tomatoes are fundamental to the commercialization of the fruit. Thus, high levels of soluble solids and high productivity are two of the most important characteristics in hybrid mini-tomatoes. In this regard, the hybrid UFU-1510 (IxA) stood out from the rest with high productivity (2.2 kg plant^{-1}) and high soluble solids (8.0 ºBrix) (Table 1).

In tomato generally there is an inverse correlation between productivity and soluble solids (Favati et al., 2009), corroborating to the results found in this study (r = -0.41) (Table 2). However, Preczenhak et al. (2014) did not observe these results in minitomato genotypes, justifying that the reduced fruit size and huge size of the plant may be responsible for the positive relation between productivity and soluble solids. The hybrid UFU-1510 was the only one that maintained high productivity and soluble solids in this study.

The increase in productivity was confirmed by increases in fruit weight (r= 0.67). In addition, the number of bunches (r= 0.25), diameter (r= 0.24) and number of fruits (r= 0.58) also showed a positive correlation with productivity. The internodes length had an inverse correlation with the number of bunches (r= -0.44) and number of fruits (r= -0.40) per plant, as well as a positive correlation with the distance between the first bunch and the soil (r= 0.49), corroborating to the findings of this study.

Table 1: Agronomic performance of mini-tomato hybrids from dwarf lines where, D: normal lines with determinate, (SD) semi-determinate and (I) indeterminate growth habit; and (A) dwarf. I: internode length (cm); TSS: total soluble solids in fruit (ºBrix); DS: distance between first bunch and the soil (cm); CPL: number of bunches plant^{-1}; DI: stem diameter (cm); FC: Number of fruits bunch^{-1}; P: Productivity (kg plant^{-1}); F: Fruits plant^{-1}; FW: Fruit weight (g).

Hybrids	Growth habit of the parents	I	TSS	DS	BPL	DI	FB	P	F	FW
UFU-1502	SDxA	7.9 a	7.1 c	23.9 c	13.3 b	9.9 a	29.1 a	2.0 b	384.6 b	10.5 a
UFU-1503	SDxA	8.0 a	7.1 c	23.3 c	13.8 b	10.1 a	31.8 a	2.4 a	435.3 b	10.9 a
UFU-1504	SDxA	6.9 b	6.7 d	18.0 d	13.8 b	10.2 a	36.5 a	2.5 a	500.0 a	10.2 a
UFU-1505	SDxA	7.8 a	7.3 c	22.1 c	13.9 b	10.8 a	31.1 a	2.0 a	431.8 b	9.4 b
UFU-1506	SDxA	7.9 a	7.0 c	27.6 b	14.5 a	10.7 a	30.4 a	2.3 a	438.8 b	10.3 a
UFU-1513	SDxA	7.3 b	7.5 b	19.8 d	13.4 b	10.2 a	32.4 a	2.0 b	427.0 b	9.4 b
UFU-1507	SDxA	7.5 a	7.2 c	24.5 c	13.3 b	10.4 a	33.3 a	2.3 a	441.8 b	10.5 a
UFU-1509	IxA	6.7 b	7.3 c	21.3 c	14.8 a	11.1 a	29.6 a	2.2 b	435.4 b	9.7 b
UFU-1510	IxA	6.7 b	8.0 a	21.4 c	15.1 a	10.8 a	33.1 a	2.2 a	498.6 a	8.9 c
UFU-1511	IxA	6.8 b	7.2 c	22.8 c	14.9 a	10.7 a	30.7 a	2.3 a	456.2 a	10.1 a
UFU-1512	IxA	7.4 b	7.1 c	19.5 d	14.4 a	10.5 a	31.7 a	2.2 a	453.3 a	9.6 b
UFU-1514	IxA	6.7 b	7.6 b	18.5 d	15.1 a	10.2 a	31.2 a	1.9 b	467.8 a	8.3 d
UFU-1516	DxA	7.3 b	6.8 d	22.1 c	13.4 b	10.7 a	34.5 a	2.3 a	459.4 a	10.0 a
UFU-1518	DxA	7.7 a	7.1 c	23.9 c	13.1 b	10.2 a	32.0 a	2.1 b	418.8 b	10.1 a
UFU-1519	DxA	7.2 b	6.6 d	22.7 c	12.8 b	10.1 a	35.5 a	2.0 b	450.9 a	8.8 c
UFU-1520	DxA	7.2 b	7.4 b	20.9 d	14.8 a	10.3 a	31.7 a	1.9 b	466.9 a	8.2 d
Mascot	-	8.2 a	7.2 c	31.1 a	12.5 b	9.3 a	35.8 a	1.7 b	431.3 b	8.0 d
KS[1]		**0.094**	**0.116**	0.147	**0.073**	**0.062**	**0.086**	**0.066**	**0.053**	**0.064**
F (Levene)[2]		**1.275**	**1.952**	**1.415**	**1.115**	**1.122**	**2.149**	**1.048**	**1.508**	**1.165**
CV (%)		6.39	4.08	10.24	9.48	8.31	5.45	8.92	7.57	5.41

[1]Means followed by distinct letters within a column differ by the Scott-Knott test at 0.05 significance; [2]KS, F: statistics of the Kolmogorov-Smirnov and Levene tests, respectively; bold values indicate residuals with normal distributions and homogenous variance at the 0.01 level of significance.

Table 2: Pearson correlation coefficients (r) between the agronomic performance variables of mini-tomato hybrids.

Variables	BPL	DI	FB	TSS	F	P	DS	I
FW	-0.06^{ns}	0.23^{ns}	-0.16^{ns}	-0.41^{**}	-0.21^{ns}	0.67^{**}	0.22^{ns}	0.15^{ns}
I	-0.44^{**}	-0.15^{ns}	0.09^{ns}	-0.23^{ns}	-0.40^{*}	-0.17^{ns}	0.49^{**}	
DS	-0.17^{ns}	-0.13^{ns}	-0.43^{ns}	0.35^{ns}	-0.28^{*}	-0.19^{ns}		
P	0.25^{*}	0.24^{*}	0.20^{ns}	-0.33^{**}	0.58^{**}			
F	0.40^{**}	0.68^{ns}	0.44^{**}	0.37^{ns}				
TSS	0.40^{**}	0.01^{ns}	-0.28^{*}					
FB	-0.63^{**}	-0.19^{ns}						
DI	0.24^{*}							

** indicates significance at 1%; ns indicates not significant.
BPL: Number of bunches plant^{-1}; DI: Stem diameter; FB: Average number of fruits bunch^{-1}; TSS: Total soluble solids of the fruit; F: Average fruits plant^{-1}; P: Average productivity; DS: Distance between the first bunch and the soil; I: Internode length; FW: Average fruit weight.

The internodes lenght had no significant correlation with the fruit weight (r= 0.15), but it does not mean that these variables are not related. The Pearson's test measures only the linear correlations. In this way, productivity had no significant direct correlation with internode length. However, shorter internodes are correlated significantly with the increase of the number of fruits, which is correlated with productivity.

In general, the results found in this work indicated greater effect in internodes shortening and genetic factor as better hybrid's performance. The exploitation of hybrids from dwarf line (male parental) proved to be viable, which could occur using this strategy in another cultures.

CONCLUSIONS

The growth habit of parents influences the performance of hybrids from dwarf lines. Hybrids from IxA parents have shorter internodes and consequently higher content of soluble solids in the fruit and higher number of bunches plant^{-1}. Dwarf lines can be used to produce mini-tomato hybrids with agronomic potential. In this way, UFU-1510 (IxA) was selected as the most promising hybrid based on productivity and total soluble solids.

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