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PLANT BREEDING

Agronomic potential of BC_1F_2 populations of Santa Cruz dwarf tomato plants

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ABSTRACT. The use of dwarf lines to obtain mini-tomato hybrid plants has led to agronomic and economic advantages. However, the benefits provided by dwarf parents in tomato hybrids of the Santa Cruz type remain unexplored. The aims of this study were to determine the agronomic enhancement in BC_1F_2 dwarf populations bearing characteristic fruit of the Santa Cruz type after the first backcross and to select populations with high agronomic potential and fruit quality. The experiment was conducted in a greenhouse using a randomized block design with 15 treatments and 4 replicates. Evaluated genetic materials included 11 BC_1F_2 dwarf tomato populations, both parents (recurrent and donor), and the cultivars (Santa Cruz Kada and Santa Clara). Traits evaluated included: mean weight, soluble solid concentration, number of locules, shape, pulp thickness, fruit longitudinal and transversal diameters, internode length, and plant height. Univariate, multivariate, correlation, and selection index analyses showed that mean fruit weight, transverse diameter, and pulp thickness increased significantly in dwarf populations after a single backcross, most of them exhibiting a fruit shape similar to that of the Santa Cruz type. The dwarf BC_1F_2 populations UFU-Sci#11 and UFU-Sci#12 showed high potential for obtaining lines and, subsequently, Santa Cruz type hybrids.

Keywords: *Solanum lycopersicum* L.; backcrossing; dwarf phenotype.

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Introduction

Tomato (*Solanum lycopersicum* L.) is the second most grown vegetable crop worldwide (FAO, 2016). In 2020, approximately 55000 hectares of land was dedicated to tomato production in Brazil, with an estimated yield of 4 million tons (IBGE, 2020). In Brazil, tomatoes are classified into five categories: Minitomate, Salada, Caqui, Santa Cruz, and Saladete (Alvarenga, 2013). Outside Brazil, these tomato types are known as cherry or grape (mini-tomatoes), round, beefsteak, chonto, and saladette or roma, respectively (Finzi et al., 2020). Among them, the Santa Cruz fruit stands out with greater post-harvest durability, the highest yield potential, greater fruit uniformity, and a more intense red color (Shirahige, Melo, Purquerio, Carvalho, & Melo, 2010).

The cost of tomato production in Brazil is over 100,000 reals per hectare, and tomato cropping is considered a financially high-risk agricultural activity (Finzi et al., 2020). Future challenges in the sector include obtaining genotypes that are high yielding, resistant to pests and diseases, and show high fruit quality, thus requiring investments in innovation (Luz, Bittar, Oliveira, Nascimento, & Nogueira, 2016). The use of hybrid tomato plants has been the main strategy to achieve these objectives (Finzi, Maciel, Silva, Luz, & Borba, 2017a).

The use of dwarf plants is important for the development of tomato hybrids. Hybrid tomato plants obtained from a dwarf parent (obtained through crossing a normal plant with a dwarf plant) develop notably short internodes, thereby achieving a high yield by increasing the number of clusters per linear meter of stem (Finzi et al., 2017a). One cluster more per stem leads to a yield gain. As tomato is a crop that requires a high investment, adopting technologies aimed at increasing profit per hectare is fundamental to successful farming.

The dwarf line used by Finzi et al. (2017a) bears fruit that is incompatible for directly obtaining hybrids of the Santa Cruz tomato type, because it is small and oblong (Maciel, Silva, & Fernandes, 2015b). Finzi et al. (2020) performed the first backcross with a dwarf line mentioned aiming to obtain Salada type fruit. Similarly, backcrosses must be performed to obtain Santa Cruz type dwarf plant lines, which can then be used to obtain hybrids.

The aims of this study were to determine the agronomic enhancement in BC_1F_2 dwarf populations that bear fruit characteristic of the Santa Cruz type after the first backcross and to select populations with high agronomic potential and fruit quality. Thus, emphasis was given to comparisons between the dwarf populations and the donor parent.

Material and methods

The experiment was performed from March to September 2019 at the Hortaliças Experimental Station, Monte Carmelo, Minas Gerais State, Brazil (47º29'55.8" W; 18º42'43.19" S, 873 m asl). The plants were grown in an arch-type greenhouse (7 × 21 m) with a roof height of 4 m, covered with transparent, polyethylene film (150 microns) with additives to protect against ultraviolet radiation and with anti-aphid white screen lateral curtains.

The evaluated genetic material consisted of 15 treatments, including 11 populations of dwarf tomato plants obtained in the first backcross (BC_1F_2) after hybridization of a pre-commercial homozygous line bearing fruit of the Santa Cruz type (recurrent parent UFU-TOM-MOTHER-2) with the dwarf line (donor parent UFU MC TOM1; Maciel et al., 2015b), both parents, and the cultivars Santa Cruz Kada and Santa Clara.

The BC_1F_2 populations and the parents belong to the tomato germplasm bank of UFU. The recurrent parent and the cultivars (Santa Cruz Kada and Santa Clara) are characterized by an indeterminate growth habit and red Santa Cruz fruit type. The homozygous line UFU MC TOM1, used as the donor parent, includes dwarf plants with an indeterminate growth habit and oblong mini-tomato (cherry tomato) fruit type (Finzi, Maciel, Luz, Clemente, & Siquieroli, 2017b; Maciel et al., 2015b). Since expression of the dwarf phenotype is of recessive and monogenic origin (Maciel et al., 2015b), the backcrosses were performed for transferring the recessive allele.

Seeds were sown in 200 cell polystyrene trays on March 2nd, 2019, and the seedlings were transplanted to 5 L plastic pots after 31 days. Seedlings of the respective dwarf tomato plant populations were selected within the BC_1F_2 populations before transplanting, as they were identified early because of their reduced structure and smaller, denser leaves, with dark green color. A coconut fiber-based commercial substrate was used in the trays and pots. Crop treatments were performed as recommended for the tomato crop grown in a protected environment (Alvarenga, 2013). The recurrent parent and the cultivars were oriented vertically with two stems in the polypropylene-cord-training system.

A randomized block experimental design was used, with 15 treatments and 4 replicates. Each experimental plot consisted of six plants distributed in double rows with a 0.3 × 0.3 m spacing. A spacing of 0.8 m was used between the double rows for a total of 360 plants.

Tomatoes were harvested weekly (a total of nine harvest time points) from June 5th to August 2nd, 2019. The fruit from each experimental plot was harvested at full maturity stage, and the following agronomic traits were evaluated:

Mean fruit weight (MFW) (g)*:* the ratio of the sum total of individual fruit weights to the total number of fruit harvested from the plot.

Total soluble solid concentration (SSC) (ºBrix): the mean of all the fruit harvested in the plot, obtained using a portable digital refractometer (Atago PAL-1 3810).

Fruit transverse diameter (TD) (cm): the horizontal length measured with a ruler after cutting the fruit vertically in the middle.

Fruit longitudinal diameter (LD) (cm): the vertical length measured with a ruler after cutting the fruit vertically in the middle.

Fruit shape (FS): the ratio of the transverse diameter to the longitudinal diameter (TD/LD). The recurrent parent and the cultivars were used as references for the Santa Cruz segment to allow classification of the fruit.

Pulp thickness (PT) (cm): the length between the fruit peel and the beginning of the locule, measured with a ruler after cutting the fruit vertically in the middle.

Number of locules (NL) (locules fruit^{-1}): the number of locules counted after cutting the fruit horizontally in the middle.

Internode length (IL) (cm): obtained by the equation [(plant height/number of nodes)] based on the mean values of the two center plants of the plot.

Plant height (PH) (cm)*:* determined by the vertical length of the plant as measured with a ruler and obtaining the mean value of the two center plants of the plot.

After verifying normality assumptions (Kolmogorov-Smirnov Test), homogeneity (O'Neil and Mathews Test), and additivity (Tukey's Non-additivity Test), data transformation $\sqrt{x + 0.5}$ was used for mean fruit weight, number of locules, internode length, and plant height, registering the real values of these variables.

In addition, the data obtained were analyzed with four independent models: means test, multivariate analyses, selection index, and correlations among traits. In the means test, analysis of variance was used (F = 0.05), and the mean values were compared using Tukey's test (p = 0.05).

Multivariate analyses were performed solely for the purpose of determining the genetic dissimilarity between the dwarf populations and the donor parent; the dissimilarity matrix was obtained by measuring the generalized Mahalanobis distance. Genetic dissimilarity was represented by analyzing the canonical variables shown by scatter plot, with the axes represented by the first canonical variables (Cruz, Regazzi, & Carneiro, 2012).

The selection index was calculated by the rank-sum index of Mulamba and Mock (1978), using only the dwarf populations and the donor parent. Five populations were chosen for estimates of gains from selection. The selection criterion adopted was used to reduce internode length while increasing all other variables. The economic weight adopted was the genetic coefficient of variation of each variable, as recommended by Cruz et al. (2012). Analyses were performed using the Genes software (Cruz, 2016). The qgraph (Epskamp, Cramer, Waldorn, Schmittmann, & Borsboom, 2012) was used to obtain correlations that were processed by the R software version 3.6.3 (R Core Team, 2020).

Results and discussion

The BC_1F_2 dwarf tomato populations differed from the parents and the cultivars for all evaluated traits (Table 1), as per the F test ($\alpha = 0.05$). Such traits exhibited heritability greater than 70% and a CVg/CVe ratio higher than 0.90 (Table 1), indicating the reliability of the selection process.

Table 1. Agronomic traits evaluated in BC_1F_2 populations of dwarf plants, recurrent parent, donor parent, and cultivars (Santa Cruz Kada and Santa Clara).

Treatments	MFW*	SSC	TD	LD	FS	PT	NL	IL	PH
UFU-Sci#2	7.25 de	9.66 ab	2.24 cd	3.04 de	0.74 cde	0.32 b	2.08 bc	1.30 ab	26.30 b
UFU-Sci#3	6.47 de	9.03 abc	2.30 cd	2.45 e	0.94 b	0.33 b	2.13 bc	1.30 ab	22.65 ab
UFU-Sci#5	5.98 de	8.39 bcd	2.43 c	2.70 e	0.90 bc	0.33 b	2.23 bc	1.22 ab	23.35 ab
UFU-Sci#6	4.46 e	8.95 abc	2.24 cd	2.39 e	0.93 b	0.31 b	2.29 bc	1.21 ab	24.45 ab
UFU-Sci#8	11.35 bc	8.96 abc	2.48 c	3.53 cd	0.70 de	0.35 b	2.35 bc	1.44 b	23.82 ab
UFU-Sci#11	8.29 cd	9.60 ab	2.35 cd	2.77 e	0.85 bcd	0.32 b	2.17 bc	1.25 ab	23.08 ab
UFU-Sci#12	8.34 cd	10.26 ab	2.20 cd	2.70 e	0.82 bcd	0.32 b	2.22 bc	1.11 ab	19.13 ab
UFU-Sci#16	7.22 de	9.86 ab	2.28 cd	2.60 e	0.88 bcd	0.30 b	2.10 bc	1.23 ab	23.88 ab
UFU-Sci#18	6.14 de	9.62 ab	2.17 cd	2.41 e	0.91 bc	0.32 b	2.03 c	1.27 ab	21.45 ab
UFU-Sci#20	6.19 de	9.59 ab	2.03 d	2.36 e	0.86 bcd	0.30 b	2.00 c	1.30 ab	21.03 ab
UFU-Sci#25	7.71 cd	8.97 abc	2.37 cd	2.71 e	0.87 bcd	0.32 b	2.11 bc	1.25 ab	26.58 b
Recurrent parent	13.90 ab	6.94 de	4.40 ab	4.82 a	0.91 bc	0.45 a	3.14 a	5.41 c	135.25 c
Donor parent	1.75 f	10.87 a	1.48 e	2.44 e	0.60 e	0.20 c	2.00 c	0.89 a	16.68 a
Kada	13.95 ab	7.32 cde	4.06 b	4.54 ab	0.89 bc	0.49 a	2.54 bc	5.65 c	185.00 d
Santa Clara	17.75 a	6.27 e	4.62 a	4.02 bc	1.16 a	0.45 a	2.55 ab	5.72 c	185.00 d
KS[2]	4.40	2.80	2.30	5.10	0.30	1.20	1.70	0.70	9.10
F (OM)[3]	0.90	1.90	0.30	8.60	1.80	0.40	1.50	0.90	1.40
F (Additivity)[4]	1.30	4.60	0.20	0.40	2.50	7.10	0.10	1.40	8.60
CV (%)	8.25	8.42	5.85	8.95	8.32	7.28	4.62	5.30	5.68

*MFW: mean fruit weight (g), SSC: soluble solid concentration (°Brix), TD: transverse diameter (cm); LD: longitudinal diameter (cm); FS: fruit shape; PT: pulp thickness (cm); NL: number of locules (locules fruit^{-1}); IL: internode length (cm); PH: plant height (cm). [1]Mean values followed by different letters within columns differ as per the Tukey test at 0.05 significance. KS[2], F (OM)[3], F (Tukey)[4]: statistics of the Kolmogorov, O'Neil and Mathews, and Tukey tests, respectively. For all the variables evaluated, the residues exhibited normal distribution, homogeneous variances, and additivity between blocks and treatments.

Mean fruit weight and total number of tomatoes harvested are primary production components and have equal importance in determining total fruit production (Rodrigues, Marim, Silva, Mattedi, & Almeida, 2010). In the present study, fruit of the BC_1F_2 populations exhibited a considerable (312.6%) increase in mean weight, especially for the UFU-Sci#8 population (548.6%). This result shows the success of the first generation of backcross and the restoration of part of the genetic constitution of the recurrent parent. Similarly, Maciel et al. (2017) reported positive results after the first backcross in mini-tomato (cherry tomato).

Regarding soluble solid concentration, except for population UFU-Sci#5 (which scored a mean of 8.39°Brix), all other BC_1F_2 populations were similar to the donor parent, with a mean value of 9.45°Brix.

Environmental, physiological, and genetic factors can modify the concentration of soluble solids. In this study, all evaluated genotypes were managed equally under greenhouse conditions, thus minimizing any environmental effect. Therefore, the low soluble solid concentration in UFU-Sci#5 is most likely because of genetic factors affecting fruit capacity to import photoassimilates. Finzi et al. (2019) evaluated the genetic variability for soluble solid concentration in mini-tomato hybrids derived from dwarf lines and mainly attributed the variation for the trait to genetic factors, consistently with our results.

For *in natura* consumption, soluble solid concentrations of 3.0°Brix is considered ideal (Kader, Morris, Stevens, & Albright-Holton, 1978; Schwarz et al., 2013). Thus, the BC_1F_2 populations are promising for the development of dwarf lines belonging to the Santa Cruz type, with high soluble solid concentration, and they can be used in enhancing current tomato plant varieties because the greater the soluble solid concentration, the greater the fruit sweet flavor, which is preferred by consumers (Maciel, Fernandes, Hillebrand, & Azevedo, 2015a; Schwarz et al., 2013).

Fruit size is represented in this study by transverse and lateral fruit diameters, which are important parameters related to the uniformity of the final product (Siddiqui, Ayala-Zavala, & Dhua, 2015). The mean increase in the transverse diameter of the fruit in the BC_1F_2 population (54.0%) suggests restoration of part of the genetic constitution of the recurrent parent, as observed for mean fruit weight. However, in the case of longitudinal diameter, except for the UFU-Sci#8 genotype (i.e., 3.53 cm), the BC_1F_2 populations did not differ from the donor parent, with mean values of 2.60 cm.

One of the factors for variability within the traits evaluated is the genotypic and phenotypic segregation after selection and subsequent self-fertilization of different BC_1F_1 plants (normal phenotype). To obtain the BC_1F_2 populations, BC_1F_1 plants were selected, followed by collection of seeds from BC_1F_2 populations. Thus, self-fertilization of the BC_1F_1 plants changed the genetic composition and reduced the number of heterozygous loci and, consequently, the expression of the traits. Consistently with the results reported herein, García-Fortea et al. (2019) reported segregation for the traits evaluated in the first two backcross generations in an eggplant crop, except for the number of flower parts.

Fruit transverse and lateral diameters also indicate an important trait of the tomato fruit shape, namely, the TD/LD ratio. All BC_1F_2 populations were similar to the recurrent parent and Santa Cruz Kada in this respect, exhibiting a slightly oblong shape. Therefore, clearly, the fruit borne by the evaluated BC_1F_2 populations were mostly similar to those of the Santa Cruz group. Fruit shape and size are related to firmness; consequently, when a fruit with an oval shape has increased pericarp thickness, it holds firm during post-harvest for a long period (Chakrabort, Vanlalliani, Chattopadhyay, & Hazra, 2007).

Pulp thickness in all BC_1F_2 populations was greater than that in the donor parent, showing an increase ranging from 55.0% (UFU-Sci#16 and UFU-Sci#20) to 75.0% (UFU-Sci#8). This trait is of fundamental importance to fruit quality, as a thicker pulp generally results in fruit with longer shelf life and better survival rate after long-distance transport (Chakrabort et al., 2007; Siddiqui et al., 2015). In this study, the BC_1F_2 populations exhibited a mean increase of 60.0% for PT in relation to the donor parent. In this step of the breeding program, the genotypes derived from the first backcross generation (BC_1F_2) are expected to exhibit a mean of 75.0% of the recurrent parent genome (Borém, Miranda, & Fritsche-Neto, 2017). Thus, this percentage is an indication of the success of the first backcross. However, other backcrosses are still necessary to increase the percentage of the genome of the recurrent parent in future lines.

Another factor affecting fruit quality is the number of locules; specifically, a higher number of locules is negatively associated with fruit firmness. Therefore, tomatoes with a small number of locules are desirable (Siddiqui et al., 2015). The number of locules did not differ among the individuals of the BC_1F_2 populations and the donor parent, which expressed a mean of 2.14 locules per fruit, thus, exhibiting a reduction in locules.

In addition to desirable fruit production and quality traits, obtaining compact plants, i.e., those with short internodes, should be one of the aims of tomato breeding programs. With a mean internode length of 1.20 cm and a mean plant height of 22.00 cm, all BC_1F_2 populations were similar to the donor parent, except for UFU-Sci#8 (1.44 cm) for internode length and UFU-Sci#2 and UFU-Sci#25, at 26.30 and 26.58 cm, for plant height, respectively. Phenotypic and genotypic segregation after selection and later self-fertilization of BC_1F_1 plants to obtain BC_1F_2 populations explained the variability observed among the different populations.

The reduced internode length of the dwarf populations is advantageous because it allows compact plants to be obtained in hybrid combinations, together with a large number of clusters per linear meter of stem (Finzi et al., 2017a). This trait facilitates pruning and vine training practices, thereby, reducing labor expenses and inputs (Marim et al., 2009; Figueiredo et al., 2015).

In general, one backcross was effective in increasing agronomic performance of the BC_1F_2 dwarf populations (Figure 1).

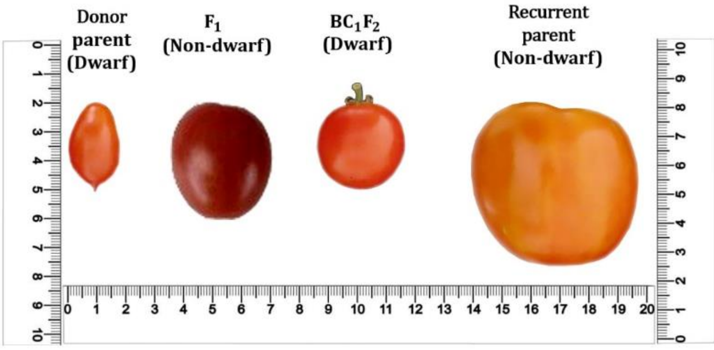

Figure 1. Comparison between the phenotypes of the donor and recurrent parents and the UFU-Sci#11 population with respect to agronomic parameters.

Other satisfactory results derived from the first backcross were observed in passion fruit (Melo, Souza, Sousa, Viana, & Santos, 2015), eggplant (García-Fortea et al., 2019), and tomato (Finzi et al., 2020). Thus, as in a previous study performed by Gonçalves Neto et al. (2010), performing two more backcrosses is suggested, as this will result in lines with commercial standard fruit and subsequent attainment of hybrids of the Santa Cruz type from dwarf lines, as obtained by Finzi et al. (2017a). This finding underlines the importance of using selection strategies as measurements of genetic dissimilarity, selection indices, and correlation among traits that allow superior dwarf lines to be obtained.

The dissimilarity estimated by the generalized Mahalanobis distance between dwarf plants ranged from 1.78 (UFU-Sci#11 and UFU-Sci#16) to 125.99 (donor parent and UFU-Sci#20), indicating genetic diversity among dwarf plants (data not shown). Visualization of the genetic dissimilarity was attained by a scatter plot of the canonical variables (Figure 2).

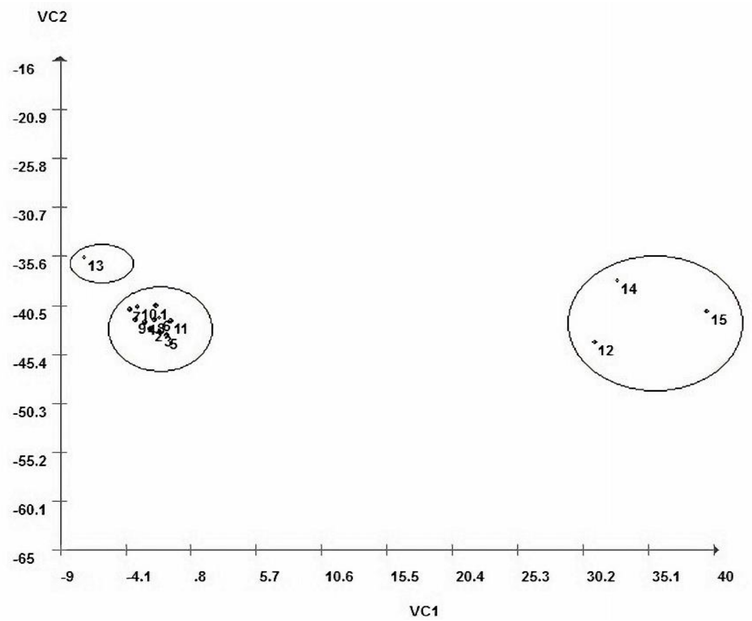

Figure 2. Scatter plot of the scores in relation to the two axes representing the first two canonical variables (VC1 and VC2). VC1 (95.23%) and VC2 (1.84%). 1 = UFU-Sci # 2; 2 = UFU-Sci # 3; 3 = UFU-Sci # 5; 4 = UFU-Sci # 6; 5 = UFU-Sci # 8; 6 = UFU-Sci # 11; 7 = UFU-Sci # 12; 8 = UFU-Sci # 16; 9 = UFU-Sci # 18; 10 = UFU-Sci # 20; 11 = UFU-Sci # 25; 12 = UFU-TOM-MOTHER-2 (recurrent parent); 13 = UFU MC TOM1 (donor parent); 14 = Santa Cruz Kada; and 15 = Santa Clara.

Using a scatter plot of the canonical variables, it was possible to identify three distinct groups (Figure 2). Group I was composed of the donor parent, Group II comprised all BC_1F_2 populations, and Group III consisted of the recurrent parent and the cultivars (Santa Cruz Kada and Santa Clara). The choice of the 2D graph was supported by the high percent values obtained from the first two canonical variables, which explained a great proportion of the variation within and among groups. For a satisfactory interpretation of the variability, it is necessary that the first two principal components explain over 80.0% of all the variability observed for the set of traits under study (Cruz et al., 2012). Here, the first two principal components explained 97.1% of the total variation.

The fact that all BC_1F_2 populations differed from the donor parent and had to be placed in different groups indicates the success of the first backcross. The two-dimensional plots have been widely used in different studies and explain the genetic variability among groups to a large extent (Gonçalves, Rodrigues, Amaral Junior, Karasawa, & Sudré, 2009; Oliveira, Silva, Brasileiro, Medeiros, & dos Anjos, 2013).

Normally, agronomic traits are subject to complex genetic control schemes affected by the environment, and strongly correlate with each other (Costa et al., 2004; Nick et al., 2013). Thus, selection considering only one trait is not very efficient when evaluating traits of polygenic inheritance and may result in gain for a certain trait but loss in other traits of agronomic importance (Cruz et al., 2012). According to Rezende et al. (2014) and Vasconcelos et al. (2010), selection of superior genotypes should be performed simultaneously for several traits, aiming at simultaneous genetic gain for the greatest possible number of traits. In this respect, the selection index is an excellent alternative, as it allows for simultaneous selection in an efficient manner (Cruz et al., 2012; Rosado, Santos, Bruckner, Nunes, & Cruz, 2012).

By the rank-sum index (Table 2), satisfactory gains were obtained for mean fruit weight (46.8%), soluble solid concentration (51.2%), fruit shape (10.5%), and number of locules (27.4%). Moreover, we estimated that there was a reduction in internode length (-30.4%), a trait favorable for tomato (Finzi et al., 2017a), as an additional aim was to obtain more compact plants. Finzi et al. (2020) evaluated selection of tomato lines using the Mulamba and Mock selection index and, consistently with our results, reported a reduction in internode length (-2.39%). The greatest genetic gain, evenly distributed among all the evaluated traits, were obtained through selection of five populations: UFU-Sci#3, UFU-Sci#11, UFU-Sci#12, UFU-Sci#20, and UFU MC TOM1 (Table 2).

Table 2. Estimate gain from selection (GS%) obtained for nine traits among 12 dwarf tomato populations (11 BC_1F_2 populations and the donor parent UFU MC TOM1) by the Mulamba and Mock rank-sum index.

Selected genotypes	
Traits	%GS
MFW	46.8
SSC	51.2
TD	-26.5
LD	-10.9
FS	10.5
PT	-39.0
NL	27.4
IL	-30.4
PH	-58.0
%GS Total	-28.9
Selected Populations	UFU-Sci#3 UFU-Sci#11 UFU-Sci#12 UFU-Sci#20 UFU MC TOM1

MFW: mean fruit weight (g), SSC: soluble solid concentration (°Brix), TD: transverse diameter (cm); LD: longitudinal diameter (cm); FS: fruit shape; PT: pulp thickness (cm); NL: number of locules (locules $fruit^{-1}$); IL: internode length (cm); and PH: plant height (cm).

Additional important information was obtained from the relationship among traits, i.e., genotypic, phenotypic, and environmental correlations (Ferreira, Queiróz, Braz, & Vencovsky, 2003; Valadares et al., 2017). This estimate is emphasized especially when difficulties emerge in the selection for a desirable trait because of low heritability and/or difficult measurement and identification, thus, allowing for gains to be obtained for one trait through indirect selection for another (Cruz et al., 2012; Valadares et al., 2017). Positive correlation coefficients indicate the tendency for a variable to increase when a correlated variable increases, whereas negative values indicate the tendency for a variable to decrease when another increases (Nogueira et al., 2012). In the present study, strong, positive genetic correlations were observed between the pairs: (NL × LD), (TD × LD), (IL × LD), (IL × TD), (PH × IL), (MFW × LD), (MFW × TD), and (PT × TD) (Figure 3). However, all traits had a negative correlation coefficient when correlated with soluble solid concentration. According to Falconer and Mackay (1996), and Nogueira et al. (2012), pleiotropy (i.e., the same gene affects the expression of more than one trait), is one of the causes for high correlations.

This information can contribute to advances in tomato breeding programs by increasing the efficiency of the selection process and facilitating the choice of parents for future crosses.

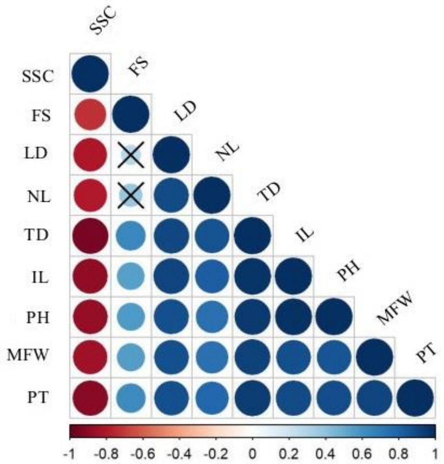

Figure 3. Genotypic correlations among nine traits in tomato. MFW: mean fruit weight (g), SSC: soluble solid concentration (ºBrix), TD: transverse diameter (cm); LD: longitudinal diameter (cm); FS: fruit shape; PT: pulp thickness (cm); NL: number of locules (locules fruit^{-1}); IL: internode length (cm); PH: plant height (cm). X: non-significant correlation. The area in blue represents positive correlation, whereas that in red represents negative correlation. The darker the color, the greater the correlation.

Backcross populations UFU-Sci#11 and UFU-Sci#12 were prominent in both, univariate analysis and in the estimate of genetic gain. In addition, the scatter plot for the canonical variables helped confirm genetic dissimilarity in relation to the donor parent. This indicates that UFU-Sci#11 and UFU-Sci#12 have a high agronomic potential. Thus, we propose using these populations for further backcrossing to obtain hybrids from dwarf lines of the Santa Cruz tomato type.

Conclusion

A single backcross allowed us to obtain dwarf plant populations with a significant increase in agronomic performance for the Santa Cruz tomato type. Positive and strong genetic correlations were observed between the traits (NL × LD), (TD × LD), (IL × LD), (IL × TD), (PH × IL), (MFW × LD), (MFW × TD), and (PT × TD). The populations UFU-Sci#11 and UFU-Sci#12 are recommended for obtaining lines and, subsequently, for hybrids of the Santa Cruz type of tomato.

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