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Selection of F_2RC_1 saladette-type dwarf tomato plant populations for fruit quality and whitefly resistance[1]

Seleção de populações F_2RC_1 de tomateiro anão do tipo saladete para desenvolvimento de linhagens

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HIGHLIGHTS:

A backcross promoted recovery of recurrent parent characteristics in dwarf tomato plant populations.
Internodes of F_2RC_1 saladette-type dwarf tomato plants were four fold smaller than those of normal plants.
Selection indices were efficient in selecting dwarf tomato plant populations with potential for the saladette segment.

ABSTRACT: This study aimed to select promising F2RC1 populations of saladette-type dwarf tomato plants for the development of breeding lines based on agronomic characteristics, fruit quality, and whitefly resistance. The experimental design was randomized blocks containing 13 treatments (10 F_2RC_1 populations of dwarf tomato plants, both parents, and a commercial hybrid) with four replicates. The evaluations were performed included weight, length, diameter, shape, pulp thickness, number of locules, soluble solids, β-carotene, and lycopene concentration of the fruit; plant internode length; acylsugars concentration; and number of whitefly eggs, nymphs, and adults on the leaflets. The data were analyzed using ANOVA, selection indices, and multivariate analysis. The first backcross increased the agronomic characteristics of the populations in relation to the donor parent, especially for fruit weight (169.1%), fruit length (26.1%), and fruit diameter (16.6%). The UFU SDi 7, UFU SDi 9, and UFU-SDi 17 populations were selected using two selection indices and were therefore considered promising.

Key words: *Solanum lycopersicum*, dwarfism, backcrossing, plant breeding

RESUMO: O objetivo do estudo foi selecionar populações F2RC1 de tomateiro anão do tipo saladete promissoras para o desenvolvimento de linhagens baseado em características agronômicas, qualidade de fruto e resistência a mosca branca. O delineamento experimental foi em blocos casualizados contendo 13 tratamentos (10 populações F_2RC_1 de tomateiro anão, genitores e híbrido comercial) com quatro repetições. Foram avaliados: peso, comprimento, diâmetro, formato, espessura da polpa, número de lóculos, teores de sólidos solúveis, β-caroteno e licopeno do fruto; comprimento do entrenó da planta; teores de acilaçúcares, número de ovos, ninfas e adultos de mosca branca nos folíolos. Os dados foram analisados por ANOVA, índices de seleção e análise multivariada. O primeiro retrocruzamento aumentou as características agronômicas das populações em relação ao genitor doador, principalmente para peso de fruto (169.1%), comprimento do fruto (26.1%) e diâmetro do fruto (16.6%). As populações UFU SDi 7, UFU SDi 9 e UFU-SDi 17 foram selecionadas por dois índices de seleção e são consideradas promissoras.

Palavras-chave: *Solanum lycopersicum*, nanismo, retrocruzamento, melhoramento de plantas

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Introduction

Reduction in internode length through breeding may be a viable strategy to increase yield (Wu et al., 2018), as well as generation of plants with of compact architecture, facilitating harvesting and crop management practices, in addition to reducing production costs (Frasca et al., 2014).

Although this technology is rarely exploited in tomato (Sun et al., 2019), satisfactory results have been achieved by Finzi et al. (2017), who obtained hybrids originating from a cross between two mini-tomato lines (dwarf size vs. normal size) to agronomic advantage.

Direct use of the dwarf-size mini-tomato line to obtain saladette hybrids is unfeasible because this line produces small fruits (Maciel et al., 2015); therefore it is necessary to develop saladette-type dwarf lines to obtain hybrids with short internode lengths in the saladette segment.

Such lines can be obtained by backcrossing, which is the method used in the development of lines originating from interspecific crosses and in obtaining dwarf plants in salad-type tomatoes (Finzi et al., 2020). In addition, progenies agronomically superior to the donor parent with characteristics from the genetic constitution of the recurrent parent can be assured (Borém & Miranda, 2013).

In addition to the potential use of dwarf strains in tomato breeding programs, it is important to consider the susceptibility of the crop to pests and the demand for better looking and quality fruit (Andrade et al., 2014; Finzi et al., 2020).

The characterization of germplasm in terms of agronomic variables, fruit quality and resistance to pests provides relevant information for the selection of promising genotypes (Peixoto et al., 2019; Finzi et al., 2020; Londoño-Giraldo et al., 2020).

Selecting plants in an efficient manner in plant breeding programs requires adequate collection of field data and the use of effective statistical techniques. The use of multivariate techniques and selection indices has led to considerable efficiency in the selection process (Leite et al., 2018).

A study has reported obtaining dwarf tomato plant populations of the salad segment (Finzi et al., 2020); however, there are no studies on the use of introgression technology in saladette-type tomatoes, whose consumption has remarkably increased (CONAB, 2019).

Therefore, the aim of this study was to select F_2RC_1 populations of saladette-type dwarf tomato plants that show promise for the development of future lines based on agronomic characteristics, fruit quality, and whitefly resistance.

Material and Methods

The experiment was conducted at the Horticultural Experimental Station (18°42'43.19" S and 47°29'55.8" W, 873 m altitude) of the Universidade Federal de Uberlândia (UFU), Monte Carmelo, MG, Brazil, from 2017 to June 2019.

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.

First, hybridization was performed between the dwarf mini-tomato line UFU MC TOM1 (Maciel et al., 2015) and UFU MC TOM5 (a pre-commercial saladette-type line), both of which belong to the germplasm bank of UFU. With the F_1 seeds, a backcross (F_1 × UFU MC TOM5) was used to obtain F_1RC_1 plants after harvest and sowing.

All the F_1RC_1 seeds obtained were sown, and then F_2RC_1 seeds were collected from individual plants. The genotypes were sown in polyethylene trays (200 cells) filled with a coconut-fiber-based substrate.

The F_2RC_1 populations that had 100% normal plants, i.e., those that did not segregate to dwarf size, were discarded. In contrast, F_2RC_1 populations that segregated to dwarf sizes were identified and selected for the experiment.

The segregation (dwarf plants and normal plants) that occurred in the F_2RC_1 generation was expected, as previously reported by Maciel et al. (2015) and Finzi et al. (2017), allowing identification and selection in the seedling phase.

The experiment consisted of 10 previously selected F_2RC_1 dwarf populations (1 - UFU SDi 4; 2 - UFU SDi 5; 3 - UFU SDi 7; 4 - UFU SDi 8; 5 - UFU SDi 9; 6 - UFU SDi 10; 7 - UFU SDi 11; 8 - UFU SDi 13; 9 - UFU SDi 16; 10 - UFU SDi 17), a donor parent (UFU MC TOM1), a recurrent parent (UFU MC TOM5), and the commercial hybrid Pizzadoro as a control, for a total of 13 treatments.

In this study, the wild accession *Solanum pennellii* (LA-716) was used only for the comparison of variables related to whitefly resistance.

The genotypes were transplanted at 35 days after sowing (DAS) in 5 L plastic pots containing the same substrate as at sowing. Crop management practices were performed according to the recommendations for tomato crops (Alvarenga, 2013). Irrigation was performed manually according to the plant needs. During the experiment, the maximum and minimum temperatures were 34.6 and 8.4 °C, respectively.

The experiment was conducted in a randomized block design with four replicates. Each experimental plot consisted of six plants. Agronomic variables, fruit quality, and whitefly resistance were evaluated.

The fruit from each plot was collected at 80 DAS, counted, and weighed to determine the mean fruit weight (g) (MW). Subsequently, 10 tomatoes per plot were sampled and evaluated for the following characteristics:

Fruit length (FL) was measured with a graduated ruler from the pedicel scar to the blossom end of the fruit (cm);

Fruit diameter (FD) was measured with a graduated ruler in the cross section of the cut fruit (cm);

Fruit shape (FS) was determined by the ratio between the length of the fruit and the diameter of the fruit;

Pulp thickness (PT), measured with a graduated ruler, was determined by the greatest distance from the mesocarp of the fruit (cm); and

Number of locules (NL) was determined by direct counting of the locules in the fruit (locule per fruit).

Soluble solids (SS) concentration, expressed as °Brix (at 26 °C), was analyzed using a portable digital refractometer (Atago PAL-1 3810) (Finzi et al., 2017).

Internode length (IL) was determined by the ratio between the height and the number of nodes of the plant measured at the end of the crop cycle (135 DAS). Internode lengths were measured with a ruler on the two most central plants in each plot (cm).

Pigments were extracted from the fruit according to the method proposed by Nagata & Yamashita (1992), with modifications. For evaluation of carotenoids (β-carotene and lycopene), a 3 mL volume of 80% acetone solvent was added to 1.0 g of tomato homogenate and mixed in a test tube. The samples were placed in the dark in a refrigerator at 4 °C for 48 hours to avoid carotenoid oxidation.

Two phases were separated, and an aliquot was collected from the upper phase for optical density estimation at 450 and 470 nm using a spectrophotometer. The β-carotene (CβC) and lycopene (LC) concentrations were calculated according to Rodriguez-Amaya (2001) and Rodriguez-Amaya & Kimura (2004).

The acylsugar allelochemical concentration (AA) was determined at 75 DAS using a sample comprising eight leaf disks (equivalent to 4.2 cm^2) from each plant in the plot. The disks were collected from leaflets from the upper third of the plants and placed in test tubes. The extraction and quantification of the acylsugar allelochemical followed the methodology described Maciel & Silva (2014).

To measure the resistance of the genotypes to the whitefly (*Bemisia tabaci* biotype B), an insect population was reared in tomato plants 'Santa Clara' (susceptible to whitefly), from an adult population collected from under cultivated tomato leaves (*S. lycopersicum*) in the field.

Insect rearing was performed in an arch-type greenhouse with dimensions of 6 × 4 m and a ceiling height of 2 m, covered with transparent polyethylene film (150 microns), additive against ultraviolet rays, and side curtains.

Whitefly resistance was measured evaluated at 130 DAS. After infestation of the insects on the plants, the number of eggs (E) and nymphs (N) was counted with the aid of a magnifying glass (30× magnification).

Four leaflets were collected from the upper third of the plants, and whitefly eggs and nymphs were counted on 2 cm^2 of the leaf area (Maluf et al., 2010). To evaluate the number of whitefly adults (A), a mirror was used to count the insects on the abaxial surface of the leaves, avoiding the flight of the hemipterans (Maciel et al., 2017).

The normality of the residues of the models was confirmed using the Shapiro-Wilk test ($p \leq 0.01$). The Oneill Mathew test ($p \leq 0.01$) was used to determine the homogeneity of variances, and for block additivity, the Tukey test ($p \leq 0.01$) was used.

The number of whitefly eggs (E) and the internode length (IL) data were transformed ($\sqrt{X + 1}$). Subsequently, analysis of variance was performed using the F-test ($p \leq 0.05$).

The mean values were compared using the Scott-Knott test ($p \leq 0.05$) and Dunnett's test ($p \leq 0.05$). The dwarf donor line (UFU MC TOM1) was used as the control to verify the gains obtained by backcrossing.

In addition, the following genetic parameters were analyzed: genotypic determination coefficients (H^2) and the ratio between coefficients of genetic and environmental variation (CVg/CVe).

For estimates of gains from selection, only dwarf phenotypes were considered, with selection intensity of 45.4%. The methods used were used the classic index proposed by the sum of ranks index of Mulamba & Mock (1978) and the genotype-ideotype distance index (Cruz, 2006).

In the sum of ranks index, the orders of each genotype were added, resulting in the selection index, as follows:

$$I = r_1 + r_2 + \ldots + r_n$$

where:

I - value of the index for a given individual or family;

rj - classification (or "rank") of an individual in relation to the j-th character; and,

n - number of characters considered in the index.

The weights were given by:

$$I = p_1 r_1 + p_2 r_2 + \ldots + p_n r_n$$

where:

pj - economic weight attributed to the j-th character.

In the genotype-ideotype distance index, the average, maximum, and minimum values for each variable were calculated. X_{ij} was considered as the average phenotypic value of the i-th genotype in relation to the j-th trait. The Y_{ij} value, which represents the mean transformed phenotypic value, and C_j is a constant relative to the depreciation of the genotype average.

Therefore, LI_j is the lower limit to be presented by the genotype, relative to the characteristic j; LS_j is the upper limit to be presented by the genotype; and VO_j is the optimal value to be presented by the genotype, under selection:

$$\text{If: } LI_j < X_{ij} < LS_j LI_j < X_{ij} < LS_j \text{ then } Y_{ij} = X_{ij}$$

$$\text{If: } X_{ij} < LI_j \text{ then } Y_{ij} = X_{ij} + VO_j - LI_j - C_j$$

$$\text{If: } X_{ij} > LS_j \text{ then } Y_{ij} = X_{ij} + VO_j - LS_j - C_j$$

In the procedure, it was considered:

$$C_j = LS_j - LI_j$$

The Y_{ij} values obtained by transformation were standardized and weighted by the weights assigned to each characteristic, obtaining the Y_{ij} values as specified:

$$Y_{ij} = \sqrt{a_j \frac{Y_{ij}}{S(Y_j)}}$$

where:

S(Yj) - deviation standard of the average phenotypic values obtained by the transformation; and,

Aj - weight or economic value of the characteristic.

The values for VO_j were also standardized and weighted as:

$$VO_{ij} = \sqrt{a_j \frac{VO_j}{S(Y_j)}}$$

The index values (DGI) are expressed by the distances between the genotypes and the ideotype as follows:

$$I_{DGI} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(Y_{ij} - VO_j\right)^2}$$

The economic weight used in the selection indices was equal to the genetic variation coefficient (CVg), as recommended by Cruz et al. (2012). The selection criterion used was to reduce the internode length, number of locules, and number of whitefly eggs, nymphs, and adults, and increased the other characteristics evaluated in this study. For the genotype-ideotype distance index, the optimal values and the lower and upper limits were determined as the most desired values among the evaluations.

The genetic dissimilarity among the genotypes evaluated was obtained using the Mahalanobis generalized distance matrix. Genetic divergence was represented by the dendrogram obtained by the hierarchical unweighted pair-group method using arithmetic averages (UPGMA).

The validation of clustering by the UPGMA method was determined using the cophenetic correlation coefficient (CCC). All analyses were performed using the GENES software version 1990.2019.91(Cruz, 2016).

Results and Discussion

Significant differences were observed among the genotypes for all the characteristics evaluated (agronomic, fruit quality, and whitefly resistance), except for lycopene concentration in the fruit (F test, $p \leq 0.05$). As expected, the recurrent parent UFU MC TOM5 and the commercial hybrid Pizzadoro stood out, showing the highest mean values for most of the agronomic characteristics (Table 1).

It should be noted that one of the main aims of the study was to verify the increase the agronomic characteristics brought about in the F_2RC_1 populations, especially in comparison to that in the donor parent, after performing one backcrossing.

The plant internode lengths of the F_2RC_1 populations were comparable to those of the dwarf donor parent according to by the Scott-Knott ($p \leq 0.05$) and Dunnett's test ($p \leq 0.05$) tests. Dwarf populations showed an average internode length four times smaller than that of normal plants (recurrent parent and Pizzadoro) (Table 1). Maintaining short internodes is advantageous for obtaining tomato plants with a compact and high yielding structure (Frasca et al., 2014; Finzi et al., 2017).

The UFU SDi 4, UFU SDi 9, UFU SDi 13, and UFU SDi 17 populations differed from the donor parent in terms of mean fruit weight in both the Scott Knott ($p \leq 0.05$) and Dunnett ($p \leq 0.05$) statistical tests. These populations produced fruit that weighed on average three times more than that produced by UFU TOM 1 (donor parent) (Table 1).

An increase in fruit length and diameter was observed in 60% of the F_2RC_1 populations evaluated (Scott-Knott, $p \leq 0.05$) (Table 1). These populations had an average fruit length of 35.9% and fruit diameter of 24.6% greater than that of the donor parent.

The superiority of the populations in relation to the dwarf donor parent regarding mean fruit weight, length, and diameter shows the efficiency of this breeding method. Recovery of characteristics of interest in the first backcross cycle was reported previously in salad-type dwarf tomato plant populations (Finzi et al., 2020).

The donor parent (UFU TOM1) belongs to the mini-tomato segment and the recurrent parent (UFU MC TOM5) to the saladette segment, and both manifested elongated fruit, a recessive trait of monogenic inheritance (Maciel & Silva,

Table 1. Agronomic characteristics evaluated in 10 F_2RC_1 tomato populations, a recurrent parent (UFU MC TOM5), a donor parent (UFU MC TOM1), and a commercial control (Pizzadoro)

Genotypes	IL (cm)	MW (g)	FL (cm)	FD (cm)	FS	PT (cm)	NL (locules per fruit)
UFU SDi 4	1.41 c	4.71 d *	3.19 d *	1.83 b	1.75 a	0.26 b *	2.17 c
UFU SDi 5	1.50 c	3.09 e	2.95 d *	1.69 b	1.75 a	0.20 c	2.31 c
UFU SDi 7	1.41 c	3.90 d	3.14 d *	1.76 b	1.80 a	0.21 c	2.47 b *
UFU SDi 8	1.55 c	2.87 e	2.53 e	1.45 c	1.75 a	0.18 c	2.38 b
UFU SDi 9	1.53 c	5.07 d *	3.21 d *	1.66 b	1.96 a *	0.21 c	2.23 c
UFU SDi 10	1.49 c	3.81 d	2.69 e	1.52 c	1.76 a	0.19 c	2.26 c
UFU SDi 11	1.57 c	3.27 e	2.57 e	1.48 c	1.74 a	0.19 c	2.27 c
UFU SDi 13	1.54 c	4.03 d *	2.92 d *	1.71 b	1.71 a	0.22 c	2.26 c
UFU SDi 16	1.37 c	3.39 e	2.59 e	1.53 c	1.70 a	0.22 c	2.21 c
UFU SDi 17	1.59 c	7.57 c *	3.60 c *	2.04 b *	1.76 a	0.30 b *	2.05 c
UFU MC TOM5	6.23 a *	17.61 b *	6.28 a *	3.61 a *	1.64 a	0.52 a *	2.79 a *
PIZZADORO	5.36 b *	25.13 a *	5.86 b *	3.08 a *	1.63 a	0.52 a *	2.46 b *
UFU TOM 1	1.07 c	1.55 e	2.33 e	1.43 c	1.62 a	0.15 c	2.00 c
Mean	2.7	6.65	3.37	1.95	1.74	0.26	2.29
CV (%)	5.25	14.23	7.56	10.14	6.06	15.54	8.08
MSD Dunnett	0.19	1.95	0.53	0.41	0.22	0.08	0.38
H^2	98.67	99.52	98.96	98.34	58.26	89.87	78.69
CVg/CVe	4.31	7.22	4.87	3.85	0.59	2.97	0.96

IL - Internode length; MW - Mean fruit weight; FL - Fruit length; FD - Fruit diameter; FS - Fruit shape; PT - Pulp thickness; NL - Number of locules per fruit; CV - Coefficient of variation; H^2 - Genotypic determination coefficients; (CVg/CVe) - Ratio between coefficients of genetic and environmental variation. [1]Mean values followed by different letters in the column differ from each other by the Scott-Knott test at $p \leq 0.05$; [*]Mean values in the column differ from the dwarf donor line control UFU MC TOM 1 by the Dunnett test at $p \leq 0.05$

2008), which explains the similarity of these populations to the parents.

The fruit of these populations exhibited a mean of 1.77 for shape (Table 1), which characterizes them as elongated (length/diameter > 1.5) and allows them to be placed in the Italian/Saladette segment (Andrade et al., 2014).

The UFU SDi 17 population stood out in relation to the others by expressing the highest average for mean fruit weight (7.57 g), fruit length (3.60 cm), fruit diameter (2.04 cm), and pulp thickness (0.30 cm), an indicating the potential for inclusion in the saladette segment (Table 1).

Except for the UFU SDi 4 and UFU SDi 17 populations, which exhibited pulp thickness (73.3 and 100%, respectively) greater than the donor parent UFU MC TOM1, the other populations had pulp thicknesses that ranged from only 0.18 to 0.22 cm.

The smallest number of locules was observed in the fruit produced by the dwarf line (two locules). Among the populations evaluated, UFU SDi 7 exhibited an average of 2.47 locules and differed from the donor line UFU MC TOM1 (Scott-Knott, $p \leq 0.05$) (Table 1).

Tomato fruits with high pulp thickness and a small number of locules are firm and consequently, have extended post-harvest conservation (Siddiqui et al., 2015).

In general, with only one backcross, it was possible to obtain expressive increases related to agronomic characteristics in the F_2RC_1 dwarf populations, especially compared to the dwarf donor parent (Figure 1).

The donor parent produced fruits that expressed the highest averages for soluble solids and β-carotene concentrations, 9.91 °Brix and 3.55 mg per 100 g, respectively (Table 2).

The F_2RC_1 dwarf populations, UFU SDi 5, UFU SDi 7, UFU SDi 9, UFU SDi 10, and UFU SDi 17, were promising with regard to fruit quality variables because they did not differ from the donor parent for soluble solids and β-carotene concentrations (Dunnett $p \leq 0.05$) (Table 2).

High soluble solid concentrations accentuate the sweet flavor in tomato fruit, and consequently, having

Figure 1. Comparison of agronomic characteristics between the phenotypes of the donor and recurrent parents and F_2RC_1 populations

Table 2. Fruit quality characteristics evaluated in 10 F_2RC_1 tomato populations, a recurrent parent (UFU MC TOM5), a donor parent (UFU MC TOM1), and a commercial control (Pizzadoro)

Genotypes	SS (°Brix)	CβC	LC
		(mg 100g^{-1})	
UFU SDi 4	6.67 b *	2.66 b	2.55 a
UFU SDi 5	9.40 a	2.44 b	2.16 a
UFU SDi 7	9.38 a	2.49 b	2.75 a
UFU SDi 8	7.55 b *	3.02 a	2.47 a
UFU SDi 9	9.04 a	3.31 a	3.01 a
UFU SDi 10	8.69 a	2.95 a	2.18 a
UFU SDi 11	9.18 a	2.43 b	3.05 a
UFU SDi 13	8.73 a	2.16 b *	2.38 a
UFU SDi 16	8.22 a*	1.86 b *	1.78 a
UFU SDi 17	9.39 a	2.87 a	2.87 a
UFU MC TOM5	5.94 b *	2.01 b *	1.94 a
PIZZADORO	6.76 b *	2.28 b *	1.77 a
UFU MC TOM1	9.91 a	3.55 a	2.95 a
Mean	8.37	2.62	2.45
CV (%)	9.03	21.08	30.95
MSD Dunnett	1.56	1.14	1.56
H^2	90.91	69.99	31.92
CVg/CVe	1.58	0.76	0.34

SS - Soluble solids concentrations; CβC - β-carotene concentrations; LC - Lycopene concentrations; CV - Coefficient of variation; H^2 - Genotypic determination coefficients; (CVg/CVe) - Ratio between coefficients of genetic and environmental variation; [1]Mean values followed by different letters in the column differ from each other by the Scott-Knott test at $p \leq 0.05$; *Mean values in the column differ from the dwarf donor line control UFU MC TOM 1 by the Dunnett test at $p \leq 0.05$

good consumer preference (Schwarz et al., 2013). For tomatoes intended for in natura consumption, soluble solid concentrations of 3 °Brix are considered acceptable (Schwarz et al., 2013). Saladette-type fruits have a sweet flavor and are characterized by a soluble solid concentration greater than 4 °Brix (Andrade et al., 2014).

The lycopene concentration was similar between the dwarf populations, parents, and the commercial hybrid Pizzadoro. The populations UFU SDi 8, UFU SDi9, UFU SDi10, and UFU SDi 17 stood out among the others for the expression of the highest β-carotene concentrations that ranged from 2.87 to 3.31 mg per 100 g.

The β-carotene and lycopene concentrations observed in this study were higher than those reported by Avdikos et al. (2021) who evaluated the quality of fruit in tomato hybrids. They observed concentrations of β-carotene and lycopene that ranged from 0.78 to 157 mg per 100 g and varied between 1.50 and 2.74 mg per 100 respectively.

Additionally, the enrichment of nutritional and antioxidant properties by increasing the concentrations of β-carotene and lycopene in tomatoes for fresh consumption should be prioritized (Londonõ-Giraldo et al., 2020).

The recurrent parent UFU MC TOM5 and the Pizzadoro hybrid exhibited the lowest acylsugar concentrations, 22.42 and 21.94 nmols cm^{-2}, respectively, as well as greater preference by whitefly for oviposition, nymph development, and presence of adults than in the other populations.

In contrast, the wild accession *S. pennellii* expressed approximately double the acylsugar concentration compared to the recurrent parent and commercial control (Pizzadoro hybrid), as well as the smallest mean numbers of whitefly eggs, nymphs, and adults (Table 3).

Table 3. Characteristics related to whitefly (*Bemisia tabaci*) resistance evaluated in leaves of 10 F_2RC_1 tomato populations, a recurrent parent (UFU MC TOM5), a donor parent (UFU MC TOM1), wild accession *Solanum pennellii*, and a commercial control (Pizzadoro)

Genotypes	AA (nmol cm^{-2})	E (eggs cm^{-2})	N (nymphs cm^{-2})	A (adults per leaf)
UFU SDi 4	37.54 b	2.25 c	6.5 b	0.63 b
UFU SDi 5	32.35 c	2 c	6.81 b	1.94 b
UFU SDi 7	30.71 c	2.31 c	9.19 b	2.5 b
UFU SDi 8	32.96 c	3.44 b *	5.19 b	1.44 b
UFU SDi 9	32.64 c	2.06 c	5.94 b	1.19 b
UFU SDi 10	35.12 c	2.19 c	6.44 b	1 b
UFU SDi 11	32.81 c	2 c	6.63 b	1.81 b
UFU SDi 13	34.71 c	1.38 c	3.69 b	1.25 b
UFU SDi 16	35.26 c	1.88 c	7.44 b	1.81 b
UFU SDi 17	34.83 c	1.69 c	5 b	0.69 b
UFU MC TOM 5	22.42 d *	3.63 b *	11 b *	20.56 a *
PIZZADORO	21.94 d *	5.88 a *	19.75 a *	20 a *
UFU TOM 1	37.94 b	0.69 d	3.88 b	0.5 b
Solanum pennellii	43.96 a	0 d	0 b	0.25 b
Mean	33.22	2.24	6.95	3.96
CV (%)	12.16	16.4	42.38	82.66
MSD Dunnett	8.3	0.59	6.06	6.74
H^2	87.37	85.01	89.22	94.41
CVg/Cve	1.31	1.19	1.43	2.06

AA - Acylsugar allelochemical concentration; E - Number of eggs of whitefly; N - Number of nymphs of whitefly; A - Number of adults of whitefly; CV - Coefficient of variation; H^2 - Genotypic determination coefficients; CVg/CVe - Ratio between coefficients of genetic and environmental variation; [1]Mean values followed by different letters in the column differ from each other by the Scott-Knott test at p ≤ 0.05; [*]Mean values in the column differ from the wild accession *S. pennellii* by the Dunnett test at p ≤ 0.05

The acylsugars, secondary metabolites present in the type IV glandular leaf trichomes in tomato, are responsible for conferring resistance to whitefly and other pest arthropods by the antixenosis mechanism (Rodriguez-Lopez et al., 2012; Maciel et al., 2018).

Among the F_2RC_1 populations, only UFU SDi 4 was comparable to the dwarf donor parent, with an acylsugar concentration of 37.54 nmol cm^{-2}. However, this genotype did not differ from the donor parent regarding the number of whitefly eggs, nymphs, and adults on its leaves (Dunnett, $p \leq 0.05$) (Table 3).

Although the donor line and F_2RC_1 populations exhibited acylsugar concentrations lower than those found in *S. pennellii*, these genotypes were superior to the recurrent parent and to the Pizzadoro hybrid in all the variables related to whitefly resistance. These results are promising for minimizing damage caused by the action of the insects, which increases costs and significantly reduces tomato production (Maciel et al., 2017).

Univariate analyses showed that with only one backcross, it was possible to obtain dwarf populations superior to the dwarf donor parent. However, using these as a selection method is not a very efficient strategy because, in addition to allowing isolated gains, they may result in undesirable gains for characteristics of interest (Cruz et al., 2012).

Among the attributes evaluated, fruit shape, lycopene concentration, and β-carotene can be considered characteristics of low heritability because they exhibited genotypic determination coefficients lower than 70% and a CVg/CVe ratio lower than one (Tables 1 and 2). Owing to the low heritability, the selection of genotypes based only on these variables is not favorable for to promoting gains in selection (Leite et al., 2016).

Selection indices allow linear and simultaneous combinations of agronomic characteristics, fruit quality, and whitefly resistance, as well as help to maximize gains from selection in all the attributes considered (Cruz et al., 2012). The highest total gains of 94.2 and 125% were estimated using the Mulamba & Mock (1978) and genotype-ideotype distance (Cruz, 2006) selection indices, respectively (Table 4).

According to Leite et al. (2018), the efficiency of the selection indices can be determined through predicted genetic gains or coincidence in the selection of superior genotypes.

Therefore, the coincidence of the populations UFU SDi 7, UFU 9, and UFU 17 being selected by the indices based on the sum of ranks of Mulamba & Mock (1978) and the genotype-ideotype distance (Cruz, 2006), shows the efficiency of applying these methods in the selection of promising populations to obtain a saladette-type dwarf tomato plant line.

Based on knowledge of the genotypes and visual analysis of the dendrogram, a cutoff point of 6% was established, the region in which an abrupt change in representation occurred, and four distinct groups were obtained (Figure 2).

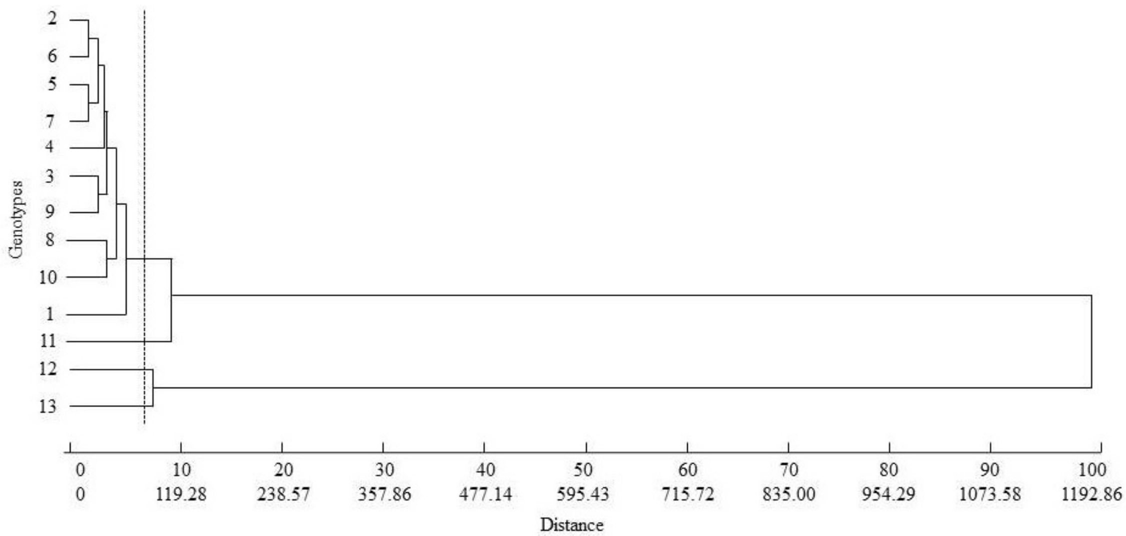
Group I was formed by all the F_2RC_1 populations, group II by the donor parent UFU MC TOM1, group III by the recurrent parent UFU MC TOM5, and group IV by the Pizzadoro hybrid. The fact that the F_2RC_1 dwarf populations did not group with the UFU MC TOM1 donor line indicates that the first backcross increases the differences within dwarf populations to the point of distinguishing them.

The genetic dissimilarity among the genotypes evaluated was well represented by the UPGMA cluster method, which exhibited a cophenetic correlation coefficient of 0.96. In other studies on the tomato crop, the variability of the genotypes was also represented in an efficient manner using this method (Peixoto et al., 2019; Finzi et al., 2020).

Table 4. Estimate of gains from selection (GS%) for 14 characteristics evaluated using two selection indices

Variables	Selection indices	
	Mulamba & Mock	Genotype-ideotype
IL (cm)	35.8	26.0
MW (g)	71.3	70.3
FL (cm)	-40.7	-15.5
FD (cm)	6.8	17.7
FS	5.7	11.4
PT (cm)	1.6	-17.4
NL (locules per fruit)	-5.9	23.0
SS (°Brix)	35.2	32.1
CβC (mg per 100 g)	-39.2	-23.6
LC (mg per 100 g)	-1.3	-1.2
AA (nmol cm^{-2})	0.0	0.0
E (eggs cm^{-2})	-13.1	-25.7
N (nymphs cm^{-2})	-11.9	-8.4
A (adults per leaf)	49.8	36.2
%GS	94.2	125.0
Selection	UFU TOM 1	UFU TOM 1
	UFU SDi 17	UFU SDi 17
	UFU SDi 9	UFU SDi 10
	UFU SDi 13	UFU SDi 7
	UFU SDi 7	UFU SDi 9

IL - Internode length; MW - Mean fruit weight; FL - Fruit length; FD - Fruit diameter; FS - Fruit shape; PT - Pulp thickness; NL - Number of locules per fruit; SS - Soluble solids concentration; CβC - β-carotene concentration; LC - Lycopene concentration ; AA - Acylsugar allelochemical concentration; E - Number of eggs of whitefly; N - Number of nymphs of whitefly; A - Number of adults of whitefly



Genotypes: 1- UFU SDi 4; 2 - UFU SDi 5; 3 - UFU SDi 7; 4 - UFU SDi 8; 5 - UFU SDi 9; 6 - UFU SDi 10; 7 - UFU SDi 11; 8 - UFU SDi 13; 9 - UFU SDi 16; 10 - UFU SDi 17; 11- UFU MC TOM1; 12 - UFU MC TOM5; 13 - commercial hybrid Pizzadoro

Figure 2. Dendrogram in reference to genetic dissimilarity obtained by the unweighted pair-group method with arithmetic mean (UPGMA) as a dissimilarity measurement

Conclusions

1. With one backcross, it is possible to obtain expressive increases in characteristics of interest in the dwarf tomato plant populations for the saladette segment.

2. The UFU SDi 7, UFU SDi 9, and UFU SDi 17 populations are the most promising for obtaining saladette-type dwarf tomato plant lines, with potential for fruit quality and whitefly resistance.

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