NOTE

Evaluation of families derived from backcrosses of processed tomato with dwarfism gene

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Abstract: *In comparison to tomato plants without the dwarfism gene, dwarf tomato plants were shorter, had a smaller canopy diameter and remained upright during maturation, thereby reducing the fruit-soil contact, resulting in healthier fruits. This study evaluated tomato families of a BC_1F_3 population carrying the dwarf gene for industrial yield. The 150 BC_1F_3 families and the two parents (hybrid H-9889 and accession BGH-9889) as controls were assessed in an augmented block design with four replications. The data were subjected to variance analysis and the F test. A selection index, based on the sum of ranks of Mulamba and Mock (1978), was used for the selection of genotypes, considering the most relevant traits, i.e., canopy diameter, yield, lodging and fruit firmness. Thus, selection resulted in a yield gain of 8.04%.*

Keywords: *Breeding, dwarf, Solanum lycopersicum.*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is considered one of the most important vegetables since it is not only used fresh, but also for industrial processing. The center of diversity of this herbaceous plant of the family Solanaceae is in South America, more precisely in the Andes, where the main domestication center lies between northern Chile and Ecuador. Another possible center of diversity is Mexico (Dupin et al. 2017, Palchetti et al. 2020).

The main countries producing processed tomato are the United States, Italy, China, Spain and Brazil (WPTC 2021). In Brazil, the states of Goiás, São Paulo, and Minas Gerais have the largest areas of tomato cultivation and produce high quantities for industrial processing (IBGE 2017). The increase in tomato yields in recent years was due to the favorable cultivation conditions in the cerrado region (Goiás and Minas Gerais), where mechanical operations can be used more intensely, facilitating e.g., transplanting and harvesting (Peixoto et al. 2017a, Silva et al. 2018, Almeida Neta et al. 2020). It is commonly acknowledged that hybrids and commercial lines should have: a) a high yield potential, b) concentrated maturation period, c) long durability of mature fruits on the plant, d) multiple disease resistance, e) a good canopy cover, f) smaller fruits (SST), and g) higher flesh firmness (Peixoto et al. 2017a, Peixoto et al. 2017b). The key challenge for Brazilian seed industries is to develop hybrids with these traits in breeding programs (Zeist et al. 2018).

In spite of the increase in processed tomato production, the Brazilian output does not meet domestic consumption, requiring imports of processed tomato

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from other countries, e.g., Argentina, Italy, the United States and especially Chile and China. One of the strategies to make tomato production economically more sustainable is the modification of the plant morphology to raise the yield efficiency and/or harvesting efficiency. Breeding for dwarfism is a strategy that can be exploited by researchers to adjust different crops to a particular cropping system and increase their productivity, without losses with regard to other traits.

The most famous case of the use of dwarfism in plants is that of wheat. The development of dwarf or semi-dwarf wheat cultivars allowed an increase in planting density and fertilization without the occurrence of lodging, thereby indirectly increasing productivity (Camargo 1984). Apart from wheat, a reduced plant size proved beneficial in the case of other crops as well. For rice and barley, the main advantage was a reduction in lodging, resulting, indirectly, in higher productivity (Bierbiger 1968, Rutger and Peterson 1976).

Several studies addressed the introgression of dwarfism genes into tomato, but most of them focused on the exploitation of dwarfism for the development of ornamental cultivars (Gerszberg el al. 2015, Yoshihiro and Tohru 2016). The dwarfism genes used in these cultivars usually lead to extremely small plants with a short cycle, intended for pot cultivation. Moreover, due to the ease of cultivation and the short cycle, these cultivars have also been widely used in studies of genetic transformation (Maciel et al. 2015).

Studies on the exploitation of dwarfism in cultivars for fruit production were also carried out. According to Finzi et al. (2017), dwarf lines planted at high densities were more productive than normal-sized cultivars. Yanokuchi and Okamoto (2001) evaluated different sources of dwarfism used in the breeding of cherry tomatoes. They recommended the use of the *bu* gene, due to the possibility of early identification of dwarf progenies, and found a higher fruit yield per plant. More compact plants, i.e., with shorter leaf and internode length, should be one of the objectives of breeding for processed tomato since such plants are better suited for mechanical harvesting (Finzi et al. 2017, Martínez-Gómez 2019, Finzi et al. 2020).

To remain competitive, tomato breeding programs for industrial processing should develop the agronomic traits of compact and small plants with concentrated fruit maturation, facilitating mechanical harvesting, and mainly with higher yields and improved disease resistance (Sun et al. 2019).

Fungi such as *Rhizoctonia solani, Sclerotium rolfsii*, *Sclerotinia sclerotiorum* and *Alternaria solani* are some of the main causes of damage on fruit in contact with wet soils (Grigolli et al. 2011, Ozkaya and Ergun 2017). Thus, the introgression of the dwarf gene into tomato for industrial processing can decrease the fruit quality loss at harvest by reducing the entry of soil particles into the tomato harvesting machine, and since the plants will stand upright for a longer time, thus reducing the time of fruit-soil contact (Sun et al. 2019).

Adequate fruit firmness confers resistance to damage during transportation, where tomato is currently handled entirely in bulk. Soft fruits, particularly those with low firmness, are more prone to deformation and to the rupture of the pericarp, leading to the release of cell juice and fermentation and deterioration during transportation from the field to the processing industry. Aside from the genetic factors, the effects of plant nutrition, soil water availability and maturation stage also affect this trait. The fruits must have a thick and firm pericarp and a compact pulp without any empty spaces (Clemente and Boiteux 2012).

The selection of genotypes with high fruit firmness is a rather challenging task, since a high number of genes are involved in the trait expression (Gerszberg et al. 2015, Li et al. 2020). In fact, in a study of Aragão et al. (2004), no difference was observed between experimental and commercial hybrids, indicating the difficulty of selecting superior genotypes.

Producers of tomato for industrial processing are not only in search for cultivars with a series of essential traits regarding field yield and industrial quality, but also with high yields. To this end, yield-related components must be studied to contribute as much as possible to yield optimization, without losing the industrial as well as the physical fruit quality. The objective of this study was to identify families of a RC_1F_3 tomato population for industrial processing that carry the dwarf gene, with potential for breeding superior lines.

MATERIAL AND METHODS

This field experiment was carried out in Viçosa-Minas Gerais, on an experimental field (lat 20° 45’14’’ S, long 42° 52’53’’ W and alt 648 m asl) of the Agronomy Department of the Federal University of Viçosa (DAA/UFV). Yield and morpho-agronomic traits were evaluated at the experimental location, while the industrial fruit quality was assessed in the Laboratory of Management of Plant Genetic Resources of the DAA/UFV. The soil of the experimental field was prepared by plowing, disking and furrowing. Fertilization, based on soil chemical analysis, was applied according to official recommendations for the crop (Ribeiro 1999) during soil tillage and by fertigation.

The seedlings were grown in a greenhouse, in polystyrene trays with 128 cells, filled with commercial substrate. The seedlings were transplanted to the field in the 4-5 leaf stage, approximately 30 days after sowing. Cultural practices and phytosanitary treatments were applied according to the crop requirements (Clemente and Boiteux 2012). Irrigation was applied as needed. The plants were grown on the ground, in other words, not on a trellis.

Hybrids were derived from a partial diallel cross between the commercial hybrids: UG 8169 (Agristar); HMX 7889 (Agrising); H 9553 (Heinz); AP 533 (Seminis); H 9992 (Heinz); H 9889 (Heinz); N 901 (Nunhens); and U 2006 (Nunhens) with accessions of dwarf-sized tomato of the vegetable germplasm bank, Federal University of Viçosa (BGH-UFV), namely BGH-1989, BGH-2006, BGH-2077 and BGH-2086. These accessions were chosen due to the dwarf size of the plant, i.e. they have a dwarf gene that confers this phenotype, without reducing the fruit size. The accessions, aside from having different morphological characteristics, generate great genetic variability. The F_1 hybrids were selected based on the general combining ability (GCA) (Griffing 1956, Cruz et al. 2012), according to the ranking of the traits for processed tomato, defined here: fruit yield, total soluble solids content, firmness, titratable acidity, and pH. The cross 'H 9889 x BGH 2006' was then selected as the most promising to breed populations with dwarf plants and fruits suited for processing.

To increase the frequency of favorable genes in the population, a backcross was performed after the initial cross (partial diallel), using F_1 plants as female and the commercial hybrid as male parents, to produce the RC_1F_1 seeds. A total of 600 plants were sown and the dwarf phenotypes were selected in the tray phase, i.e., 25% or 150 plants. The seeds of the selected plants were extracted separately (seeds RC_1F_3). To initiate the families, five RC_1F_3 plants of each RC_1F_2 plant were evaluated in an Augmented Block Design (ABD), with four replications. The parents were used as checks (H-9889 and BGH-2006). In the ABD, different from a randomized block design, only the checks are repeated, so that a higher number of genotypes can be tested in a smaller area.

For all evaluations, the data were measured separately per plant and the following morphological traits were evaluated: a) canopy diameter (averaging the distances between three canopy extremities, measured with a tape, in cm); and b) lodging (1-5 score scale; 1 - upright plants and 5 - fully lodged). Yield traits was estimated by the fruits yield per plant (weighed on an analytical balance, in kg plant^{-1}). Fruit quality was determined in a three-fruit-sample by the fruit firmness (using a digital penetrometer with a 4 mm diameter probe, model PTR-300, in N).

The data were subjected to variance analysis and to the F test to determine significance ($\alpha \leq 0.05$). From the resulting data, the genetic parameters genotypic variance, environmental variance and heritability were estimated. Heritability was calculated by dividing the genotypic by the phenotypic variance. The selection index, based on the sum of ranks of Mulamba and Mock (1978), was used for a selection of genotypes by taking all traits into consideration that were significant by the F test ($\alpha \leq 0.05$).

RESULTS AND DISCUSSION

In the analysis of variances, the traits tomato yield, canopy diameter, plant lodging and fruit firmness were significant ($\alpha \leq 0.05$) by the F test, indicating variability among families, thereby allowing the selection of the best ones. Further, the selection gains (SG%) by direct selection were estimated for these traits, to indicate possible gains in the others (Table 1). However, by this method, regardless of the selected trait, at a selection intensity of 10% (15 families), losses occurred for at least one of the traits. It is worth remembering that negative SG (%) values for lodging and canopy diameter are desirable, since the target values for these traits are lower due to dwarfism.

Alternatively, the ranking index based on the sum of ranks of Mulamba and Mock (1978) allows the use of economic weight for the traits. In several simulations of economic weights, the following proportion was found to be most adequate: 3 fruit yield: 3 canopy diameter: 2 lodging: 4 firmness, i.e., prioritizing firmness as determinant factor of fruit quality (Table 2). The trait fruit yield is essential, but the economic weight was equivalent to that of canopy diameter. A shorter canopy diameter and reduced lodging improve the fruit quality and reduce the fruit damage in the tomato harvesting

Table 1. Direct selection for four traits of RC_1F_3 tomato families with dwarfism gene to select plants with optimized genetic contribution

Direct Selection	X_0	h^2		Response in traits			
				Yield	**Canopy D.**	**Lod.**	**Fir.**
Yield (kg plant^{-1})	2,514.2	92.3	Xs	3,864.6	69.68	3.65	13.27
			SD	1,332.4	11.78	0.94	-1.04
			SG (%)	49.58	19.3	31.33	-6.74
Canopy diameter (cm)	57.90	94.9	Xs	1,667.9	40.83	1.76	15.75
			SD	-846.3	-17.07	-0.95	1.44
			SG (%)	-31.07	-27.98	-31.61	9.41
Lodging	2.71	89.9	Xs	2,110.5	48.44	1.16	13.77
			SD	-403.7	-9.46	-1.55	-0.54
			SG (%)	-14.82	-15.51	-51.39	-3.51
Firmness (N)	14.31	93.3	Xs	2,142.9	56.76	2.85	21.18
			SD	-371.3	-1.14	0.14	6.87
			SG (%)	-13.63	-1.87	4.77	44.84

X_o: population mean; h^2: heritability; Canopy D.: canopy diameter; Lod.: Lodging; Fir.: Firmness; Xs: Selected mean; SD: Selection differential; SG: selection gain (%).

Table 2. Selection indices of Mulamba and Mock (1978) for selected traits of RC_1F_3 tomato families carrying the dwarfism gene, to select plants with optimized genetic contribution

Traits	EcW	X_0	Xs	SG%	H9889
Yield per plant (g)	3	2,514	1,951	-20.64	3,724
Canopy diameter (cm)	3	57.90	45.21	-20.79	82
Lodging	2	2.71	1.49	-40.47	5
Firmness (N)	4	14.30	19.38	33.16	18.06
Yield (t ha^{-1})			49.06		45.41

EcW: Economic weight; X_0: Population mean; Xs: Selected mean; SG: selection gain (%); H9889: Values of the commercial hybrid; Canopy diameter, scored on a scale.

machine, but also allow a higher planting density, thereby compensating the reduction in yield per plant by an increase in productivity per area.

When comparing the values of economic weights of the selected families with the hybrid data (Table 2), a reduction in canopy diameter of 55.13%, a reduction in lodging of 72%, an increase in fruit firmness of 7.30% and a decrease in yield of 47.58% were observed. However, when increasing plant density, in an area of 0.82 m^2, previously required for one plant, 1.81 plants can be grown, thus increasing the productivity by 3.65 tons ha^{-1} (8.04%).

For the selection of superior families, higher values of genetic parameters such as heritability and genotypic variance are of great interest. When using the parents mentioned above, plants with significant gains could be selected for the traits canopy diameter, plant lodging as well as fruit firmness.

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