horticultura brasileira

Research

OLIVEIRA, CS; MACIEL, GM; FRAGA JÚNIOR, EF; PEIXOTO, JVM; ASSUNÇÃO, VB; MARQUES, DJ. 2021. Selection of tomato genotypes for drought tolerance and agronomic potential through different selection indexes. *Horticultura Brasileira* 39: 102-111. DOI: http://dx.doi.org/10.1590/s0102-0536-20210115

Selection of tomato genotypes for drought tolerance and agronomic potential through different selection indexes

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ABSTRACT

The selection of genotypes with agronomic potential associated with drought tolerance is considered of high complexity. An alternative could be the use of selection indexes that can evaluate multiple characteristics simultaneously. This study aimed to select tomato genotypes with agronomic potential and drought tolerance by selection indexes. The experiment was conducted in a randomized block design with three replications. Ten treatments were evaluated: seven genotypes F_2RC_3, donor genitor (*Solanum pennellii*), recurrent genitor (UFU-040), and cv. Santa Clara. The irrigation was suspended until the substrate reached a matric potential of ≤-25 kPa for water stress simulation during the tomato cycle at 45, 60, 80 and 100 days after sowing. The control treatment (donor genitor) and cv. Santa Clara, were resistant and susceptible to water deficit, respectively. The UFU-102-RC3#91335 genotype presented agronomic potential and satisfactory tolerance level to water deficit and presented 58.2% higher production than the recurrent genitor (UFU-040). The genotype-ideotype distance selection index was the most appropriate for the selection of tomato genotypes for agronomic potential allied to drought tolerance.

Keywords: *Solanum lycopersicum*, abiotic stress, selection gains, backcross, water deficit.

RESUMO

Seleção de genótipos de tomateiro para deficiência hídrica e potencial agronômico por meio de diferentes índices de seleção

A seleção visando obtenção de genótipos com potencial agronômico aliado a tolerância a déficit hídrico é considerada de alta complexidade. Uma alternativa poderia ser o uso de índices de seleção pois é capaz de avaliar múltiplas características. Objetivou-se com este trabalho selecionar genótipos de tomateiro com potencial agronômico e tolerância a déficit hídrico por diferentes índices de seleção. O experimento foi conduzido em delineamento de blocos ao acaso com três repetições. Foram avaliados dez tratamentos sendo sete genótipos F_2RC_3, genitor doador (*Solanum pennellii*), recorrente (UFU-040) e cv. Santa Clara. Para a simulação de vulnerabilidade hídrica durante o ciclo foram realizados quatro sucessivos déficit hídricos (45, 60, 80 e 100 DAS) até que as parcelas atingissem potencial matricial ≤-25 kPa. As testemunhas, genitor doador (*S. pennellii)* e cv. Santa Clara foram de fato resistente e suscetível ao déficit hídrico, respectivamente. O genótipo UFU-102-RC3#91335 apresentou potencial agronômico e níveis satisfatórios de tolerância ao déficit hídrico sendo 58,2% superior em produção em relação ao genitor recorrente UFU-040. O índice de seleção de distância genótipo-ideótipo é o mais apropriado para seleção de genótipos de tomateiro visando potencial agronômico aliado a tolerância à seca.

Palavras-chave: *Solanum lycopersicum*, estresse abiótico, ganhos de seleção, retrocruzamento, déficit hídrico.

Received on May 6, 2020; accepted on December 1, 2020

The tomato is a widely cultivated crop and presents good adaptability to different climatic conditions. However, tomato plants demand high water volumes throughout their lifecycle (Alvarenga & Coelho, 2013). Water deficit during the tomato cycle negatively affects crop development and production (Celebi, 2014). In conditions of low water availability, plants can present diverse responses like the rise of the leaf temperature (Simões *et al.*, 2015); the decrease of stomatal conductance (Nascimento *et al.*, 2011), photosynthesis (Lopes *et al.*, 2011), leaf water potential, plant size, biomass, and productivity; and the increase of leaf abscission and the root:shoot ratio, besides favoring the incidence of rot apical disorder (Morales *et al.*, 2015).

In this context, factors such as efficient water use, water restrictions, and irrigation costs (Telles & Costa, 2010) increase the need for drought tolerant cultivars. Additionally, tomato cultivation is considered a high-risk culture, with production costs exceeding US$19.000 per hectare (Hortifruti Brasil, 2019), indicating the need to improve tomato crop management. In high-risk crops, even small irrigation management errors reflect in high impact on the agronomic characteristics

(Alvarenga & Coelho, 2013).

The cost of irrigation in tomato production represents more than 10% of the total cost. Climatic events such as *El niño* and *La niña* and global warming have leveraged the vulnerability of the crop cultivars, primarily due to the susceptibility to water stresses (Pereira *et al*., 2015). Aggravating this scenario, more than 85% of the soil in the world is subject to drought periods (Pérez, 2007). Thus, any measure to reduce the high costs with water supply to tomato crop is important.

An alternative to this reality could be the breeding of tomato genotypes with tolerance to drought stresses (Morales *et al*., 2015; Borba *et al*., 2017). However, the majority of the plant characters related to water stress tolerance is of polygenic nature and low heritability. This situation makes the evaluation of such traits much more complex (Egea *et al*., 2018), creating the need for alternatives during the genotype selection programs.

The evaluation of genotypes with different levels of drought tolerance requires a test able to select multiple characteristics simultaneously. The use of selection indexes has been a potent tool in breeding programs in several crops (Cruz, 2013), especially when the intention is to combine superior agronomic performance and drought tolerance in the same genotype. These indices allow an optimal linear combination between the set of information from the experimental unit, making it possible to carry out the simultaneous selection of characters efficiently (Cruz *et al*., 2014), increasing the chance of success in the breeding program. Additionaly, results in tomato are still scarce. This study aimed to select tomato genotypes with agronomic potential and tolerance to water stresses by different selection indexes.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station of Vegetables (18º42'43"S and 47º29'56"W, 873 m altitude) and at the Laboratory of Soil and Water Engineering from the Federal University of Uberlândia (UFU), Campus Monte Carmelo, Brazil. In June 2014, an interspecific cross was performed between the lineage UFU-040 (*Solanum lycopersicum*, recurrent genitor) versus wild access LA716 (*Solanum pennellii*, donor genitor). UFU-040 is a pre-commercial lineage of Santa Cruz type with high agronomic potential and determined growth habit, belonging to the germplasm bank of the UFU. The wild *S. pennellii* has genes responsible for conferring high water use efficiency (WUE) (Atarés *et al*., 2011). This access is considered tolerant to water deficit (Rocha *et al*., 2016). After hybridization, three successive backcrosses were performed, followed by self-pollination (F_2RC_3). The resulting genotypes (G) were G1 = UFU-102-RC3#91333; G2 = UFU-102-RC3#91321; G3 = UFU-102-RC3#91341; G4 = UFU-102-RC3#91325; G5 = UFU-102-RC3#91335; G6 = UFU-102-RC3#91343, and, G7 = UFU-102-RC3#91322). All these genotypes were obtained from the selection of agronomic characteristics in previous generations aiming commercial background (UFU-040).

In June 2017,the seven F_2RC_3 genotypes obtained, the recurrent genitor (UFU-040), donor genitor (*S. pennellii*), and Santa Clara cultivar were sown in polystyrene trays (200 cells) filled with a commercial substrate based on peat moss, vermiculite and limestone (Carolina Soil, Kingston, NY, USA) totaling ten treatments. Thirty five days after sowing (DAS), the seedlings were transplanted to 5-L plastic pots (one seedling per pot) and filled with the same substrate used for sowing. The experimental design was in randomized blocks with three replications. Six plants represented each plot parcel, totaling 18 plants evaluated per treatment. Tensiometers (HID32; Hidrosense, Jundiaí, SP, Brazil) were installed in one pot per plot at 10 cm depth to monitor the substrate matric potential daily (Figure 1). Irrigation was carried out in a controlled manner by using a graduated container, with individual control of each plot, keeping the substrate moisture in an optimum level for plant development (≥-10 kPa).

The experiment was conducted in a greenhouse (arc type, with 7x21 m, 4 m height), covered with transgenitor polyethene film, 150 microns, with ultraviolet protection and side curtains with anti-aphid white screen. The weather conditions were monitored using an automatic weather station (model CM3 Kipp & Zonen; Campbell Scientific, Logan, UT, USA). The flow density of the global solar radiation (Qg) estimated by a silicon photodiode pyranometer (LP02-L12; Campbell Scientific), the air temperature, and the relative humidity of the air estimated by a temperature and humidity sensor (HMP45C-L12; Campbell Sci.) (Figure 2) were evaluated. The sensors were installed in the central area of the greenhouse, above the crop at a canopy height of 2 m. The data were taken every 30 seconds and integrated every 15 minutes using the datalogger.

Water deficit was simulated during tomato crop cycle in four successive drought periods at 45, 60, 80 and 100 DAS. The matric potential threshold to irrigate was from -25 kPa. In each event the water matric potential in the soil was -25; -35; -31 and -32 kPa.

The physiological, morphological and agronomic characteristics were assessed at 104 DAS. The following physiological characteristics were determined: SPAD index, measured with a portable chlorophyll meter (SPAD-502; Minolta, Ramsey, MN, USA) using the average of two readings on leaves of the canopy middle third; leaf water potential, quantified before dawn (±5 h) using a Scholander-type pressure chamber (model 3000; Soil Moisture, Santa Bárbara, CA, USA) using the average of two readings on leaves of the canopy middle third; the leaf temperature (average of two readings measured in the period between 12:30 and 14 h) was assessed on leaves of the canopy middle third using an infrared thermometer (NUB8380; Nubee, Burbank, CA, USA).

The morphological characteristics studied were plant height, measured using a graduated metallic tape from the apical meristem and the cervical region of the plant to the soil level; number of leaves, determined by direct count of developed and vivid leaves in each plant; distance to the insertion of the first fruit bunch, length between the first fruit bunch and the substrate level measured with a graduated metallic tape.

For the agronomic traits, harvests were performed until the plants have ceased production (130 DAS). The fruits were collected, identified and subsequently counted and weighed using a precision scale (Mark 500; Bel Engineering, Monza, Lombardia, Italy). The following characteristics were measured: number of fruit per plant (ratio between total fruit accounted and number of plants in each plot); fruit average weight (ratio between the weight and the number of all the fruit harvested in the plot); production per plant (ratio between the weight of fruit harvested and the number of plants of the plot); incidence of apical rot (percentage of the total number of fruit with symptom in relation to the total number of fruit harvested).

At the end of the crop cycle, the plants were removed from the substrate, and the roots were washed. The root and shoot parts were weighed separately to obtain the fresh weight. The dry weights were obtained by drying the parts of the plants in a forced air circulation oven at 65ºC for 72 hours. The shoot, root and total dry weight were obtained by $DW = (W_{dry}*100)/W_{fresh}$, where: DW = percentage of dry weight; W_{dry} = dry weight obtained after drying each part of the tomato plant, and W_{fresh} = fresh weight obtained from each plant part.

Analysis of variance was performed, and the mean squares were compared by the F test (α= 0.05). The averages were compared by the Tukey's and Dunnett's test (α= 0.05). The *S. pennellii* accesses considered the drought-tolerant control was used for comparison of the Dunnett test (Atarés *et al.*, 2011; Morales *et al.*, 2015). The following parameters were determined: genetic coefficient of genotypic determination (h^2), coefficient of genetic variation (CVg) and variation index (CVg/CVe).

For the estimates of selection gains, five genotypes were selected (50% of the studied genotypes) using the following direct and indirect selection methodologies (Cruz *et al.*, 2012): classic index, proposed by Smith (1936) and Hazel (1943); Mulamba & Mock (1978) sum of ranks index and genotype-ideotype distance index (Cruz, 2013). The selection criterion used was the reduction of plant height, distance from the insertion of the first bunch of fruit, leaf temperature and incidence of apical rot, and the increase of shoot dry weight, root dry weight, total dry weight, number of leaves, SPAD index, leaf water potential, number of fruit per plant, fruit weight, and production per plant. All analyzes were processed using a computational software for genetics and statistics (Genes version 5.0; UFV) (Cruz, 2016).

RESULTS AND DISCUSSION

Efficient simulation of drought stress imposed on 45, 60, 80 and 100 DAS was confirmed (Figure 1). This result was important to ensures an optimal simulation of water vulnerability imposed to the tomato genotypes. There are reports that several physiological changes in tomatoes start after the matric potential of - 5 KPa (Borba *et al.*, 2017; Hott *et al.*, 2018).

The average temperature within the greenhouse was 21.24ºC ranging between 16.4 and 24.6°C during the entire period of the experiment, considered within the range from 10 to 34ºC, which is the extent tolerable temperature for the development of tomato plants (Alvarenga & Coelho, 2013). The air relative humidity was 47.2%, ranging from 42.5 to 70.1% and the average global radiation was 106.88 W m^{-2}.

On the date of leaf water potential, leaf temperature, SPAD index, number of leaves, plant height, distance from the insertion of the first bunch of fruit evaluations, the average air temperature was 24.5ºC, ranging between 13.91 and 37.12ºC; the air relative humidity average was 47.20%, ranging between 21.24% and 84.1%; the average global radiation and the vapor pressure deficit reached values of 123.03 W m^{-2} and 2.02 kPa, respectively (Figure 2).

There was significant difference among the genotypes in relation to the variables analyzed, except for the number of leaves and number of fruit per plant (Table 1). The highest coefficients of variation were found for the variables: production per plant (22.8%); incidence of apical rot (33.5%); shoot dry weight (33%); root dry weight (30%) and total dry weight (30%) (Table 1). These results may be an indicative of high dispersion of the experimental data regarding the genetic and phenotypic differences or because those variables

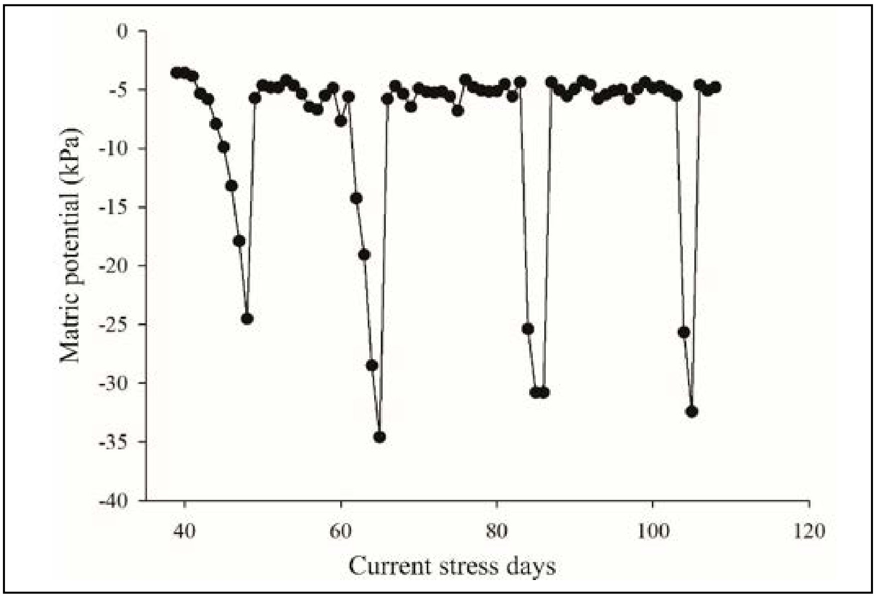

Figure 1. Water matric potential in the substrate during the tomato crop cycle. Monte Carmelo, UFU, 2017.

are highly influenced by environmental conditions (Leite *et al*., 2016).

The estimation of the coefficients from genotypic determination (h^2) were higher for leaf water potential (76.1%), SPAD index (76.8%), fruit weight (79.0%), production per plant (80.7%), root dry weight 81.6%), shoot dry weight (86.4%), incidence of apical rot (89.9%) and plant height (90.1%) (Table 1). The phenotypic selection was successful, which can be confirmed with the values obtained in the ratio CVg/CVe exceeding one for these characters (Table 1) (Ramalho *et al*., 2012).

The *S. pennellii* access presented leaf temperature around 31°C, which was similar ($p>0.05$) to the other genotypes (Table 2). However, *S. pennellii* showed the highest averages for SPAD index (66.4) and leaf water potential (-1.9 MPa), distinguishing from other genotypes, excepting G5 genotype (-2.1 MPa) which showed

Table 1. Mean square, averages, coefficients of variance and the genetic parameters of the physiological, morphological and agronomic characteristics of the tomato genotypes under water stress conditions. Monte Carmelo, UFU, 2017.

Source of variation		MS			MS		
		Physiological characters			Morphological characters		
	gl	LT (°C)	SPAD	WP (MPa)	NL (leaf plant^{-1})	PH (cm)	DF (cm)
Block	2	9.5	4.7	0.1	1.7	40.9	26.7
Treatment	9	3.6*	116.3*	0.4*	4.4*	780.3*	39.8*
Genotypes	8	2.3*	31.2*	0.3*	0.5^{ns}	417.4*	43.4*
Genotype vs *S. pennellii*	1	14.0*	797.0*	1.2*	35.6*	3683.7*	11.1^{ns}
Residue	18	0.8	7.2	0.1	0.7	41.1	5.9
Overall average		33.0	50.9	-2.5	9.7	68.1	18.3
Average genotypes		33.3	49.2	-2.5	9.4	64.5	18.1
Average *S. pennellii*		31.0	66.4	-1.9	13.0	101.4	20.1
CV(%)		2.7	5.3	9.5	8.8	9.4	13.0
h^2(%)		66.0	76.8	76.1	0	90.1	86.4
CVg(%)		2.1	5.7	10.4	0	17.4	19.5
CVg/CVe		0.8	1.1	1.1	0	1.7	1.4

Source of variation		MS						
		AgronomicCharacters						
	gl	NFP (fruit plant $^{-1}$)	FAW (g)	PPP (kg plant^{-1})	AR (%)	SDW (%)	RDW (%)	TDW (%)
Block	2	14.1	23.1	1175.0	577.3	259.6	27.4	156.6
Treatment	9	52.8*	160.7*	90777.4*	929.1*	753.5*	983.1*	637.2*
Genotypes	8	21.7^{ns}	42.3*	45250.6*	759.4*	530.0*	730.6*	400.2*
Genotypes *vs S. pennellii*	1	301.6*	1108.4*	454991.6*	2286.0*	2540.8*	3003.3*	2533.1*
Residue	18	11.8	8.9	8711.1	77.0	166.5	138.3	131.3
Overall average		21.7	19.5	410.1	26.2	39.1	39.2	38.2
Average genotypes		20.7	21.6	451.2	29.1	42.1	42.6	41.3
Average *S. pennellii*		31.2	1.3	40.7	0.0	11.5	9.2	10.7
CV(%)		15.8	15.2	22.8	33.5	33.0	30.0	30.0
h^2(%)		45.5	79.0	80.7	89.9	68.6	81.06	67.2
CVg(%)		8.8	15.5	24.5	51.9	26.1	32.99	22.9

*differs at 0.05 level of significance by the F test. ns = not significant. CV = coefficient of variation; h^2= coefficient of genotypic determination; CVg= coefficient of genetic variation; CVg/CVe = index of variation between the coefficient of genetic variation and the coefficient of experimental variation; gl = degree of freedom; LT = leaf temperature ; SPAD = SPAD index; WP = leaf water potential ; NL = number of leaves; PH = height of the plants ; DF = distance from the insertion of the first bunch of fruit ; NFP = number of fruit per plant; FAW = fruit average weight ; PPP = production per plant; AR = incidence of apical rot; SDW = shoot dry weight ; RDW = root dry weight ; TDW = total dry weight.

Table 2. Physiological, agronomic and morphological characteristics evaluated in tomato genotypes after water stress conditions. Monte Carmelo, UFU, 2017.

Genotypes	**Physiological characteristics**		
	LT (°C)[1]	**SPAD**	**WP (MPa)[1]**
G1	33.1 a	49.7 b*	-2.4 b
G2	33.4 a*	44.4 c*	-2.6 c*
G3	32.9 a	53.3 b*	-2.4 b
G4	33.0 a	50.0 b*	-2.8 c*
G5	32.5 a	51.2 b*	-2.1 a
G6	33.0 a	52.1 b*	-2.4 b
G7	32.3 a	51.2 b*	-2.3 b
UFU-040	33.9 a*	45.5 c*	-2.8 c*
cv. Santa Clara	35.2 a*	45.7 c*	-3.1 c*
S. pennellii	31.0 a	66.4	-1.9 a
DMS Dunnett	2.1	6.5	-0.6

Genotypes	**Agronomic characteristics**			
	NFP (fruit plant $^{-1}$)[1]	**FAW (g)[1]**	**PPP (kg plant^{-1})[1]**	**AR (%)[1]**
G1	24.0 b	24.9 a*	0.603 a*	19.5 b
G2	18.8 b*	22.6 a*	0.423 b*	20.4 b
G3	18.7 b*	19.2 b*	0.359 b*	22.9 b*
G4	21.4 b*	20.8 b*	0.439 b*	26.3 b*
G5	23.0 b	27.4 a*	0.634 a*	12.2 c
G6	22.8 b*	20.1 b*	0.457 b*	27.3 b*
G7	21.2 b*	24.6 a*	0.512 a*	31.0 b*
UFU-040	20.7 b*	19.7 b*	0.401 b*	34.6 b*
cv. Santa Clara	15.3 b*	14.8 b*	0.231 c	67.7 a*
S. pennellii	31.2 a	1.3 c	0.041 d	0.0
DMS Dunnett	8.4	7.2	0.227	21.3

Genotypes	**Morphological characteristics**					
	SDW (%)[1]	**RDW (%)[1]**	**TDW (%)[1]**	**NL (leaf plant^{-1})[1]**	**PH (cm)[1]**	**DF (cm)[1]**
G1	53.6 a*	35.3 a	48.1 a*	9.3 b*	66.7 b*	14.4 b
G2	39.5 a	56.1 a*	41.4 a*	9.7 b*	59.5 b*	17.8 b
G3	51.8 a*	55.1 a*	52.3 a*	9.3 b*	64.9 b*	15.6 b
G4	51.0 a*	59.1 a*	52.1 a*	10.0 b*	59.9 b*	19.0 b
G5	49.0 a*	18.6 b	40.4 a*	9.3 b*	59.8 b*	15.1 b
G6	51.7 a*	39.3 a*	49.3 a*	9.3 b*	59.5 b*	16.3 b
G7	42.2 a	47.3 a*	42.9 a*	8.7 b*	56.2 b*	20.3 b
UFU-040	19.9 b	53.4 a*	25.1 b	9.0 b*	58.7 b*	17.4 b
cv. Santa Clara	20.5 b	19.0 b	20.0 b	9.7 b*	94.7 a	26.9 a*
S. pennellii	11.5 b	9.2 b	10.7 b	13.0 a	101.4 a	20.1 b
DMS Dunnett	31.4	28.6	27.9	2.1	15.6	5.9

[1] Averages followed by different letters in column differ by the Scott Knott test at 5% probability.*averages in column differ from the *S. pennellii* control by Dunnet's test at 5% probability LT = leaf temperature ; SPAD = SPAD index; WP = leaf water potential . NFP = number of fruit per plant; FAW = fruit average weight; PPP = production per plant ; AR = incidence of apical rot; SDW = shoot dry weight; RDW = root dry weight ; TDW = total dry weight; NL = number of leaves; PH = plant height ; DF = distance from the insertion of the first bunch of fruit.

Table 3. Estimate of selection gains (SG %) obtained for the 13 characters evaluated, by direct and indirect selection in tomato genotypes after water stress conditions. Monte Carmelo, UFU, 2017.

CHARAC[1]	GS (%)						
	LT (°C)[1]	**SPAD**	**WP (MPa)[1]**	**NFP (fruit plant^{-1})[1]**	**FAW (g)[1]**	**PPP (kg plant^{-1})[1]**	**AR (%)[1]**
LT	-1.4	-1.4	-1.2	-1.0	-0.4	-0.5	-0.9
SPAD	5.2	5.9	3.2	4.4	-2.5	-0.2	3.1
WP	-5.7	-8.1	-8.1	-4.0	-1.1	-1.4	-5.8
NFP	2.9	3.5	3.6	5.8	-0.1	1.6	3.0
FAM	-3.5	-4.1	-1.4	-2.6	18.3	16.3	-1.8
PPP	-2.5	-1.8	0.7	4.9	22.1	23.4	0.4
AR	-26.5	-25.8	-27.5	-31.3	-14.8	-10.1	-38.4
SDM	3.6	3.8	-0.5	7.5	14.0	18.3	3.5
RDM	-2.9	-11.0	-10.6	-14.3	8.4	1.4	-9.0
TDM	2.5	1.6	-2.3	3.3	11.9	14.6	0.6
PH	0.4	0.3	-1.1	1.8	-10.2	-10.2	3.1
DF	-1.3	-3.8	-1.8	-6.2	-4.7	-6.1	-8.0
Total	-30.6	-42.4	-48.2	-32.8	40.7	46.8	-51.2
Gen. Selec.	*S. pennellii*	*S. pennellii*	*S. pennellii*	*S. pennellii*	G5	G5	*S. pennellii*
	G7	G3	G5	G1	G1	G1	G5
	G5	G6	G7	G5	G7	G7	G1
	G3	G5	G6	G6	G2	G6	G2
	G4	G7	G2	G4	G4	G4	G3

CHARAC[1]	GS (%)					
	SDW (%)[1]	**RDW (%)[1]**	**TDW (%)[1]**	**NL (leaf plant^{-1})[1]**	**PH (cm)[1]**	**DF (cm)[1]**
LT	-0.3	0.1	-0.4	0.2	0.0	0.1
SPAD	0.5	-3.1	0.5	0.4	-3.1	-0.9
WP	-0.5	2.2	0.6	2.2	-2.2	-0.2
NFP	0.6	-3.3	-0.2	0.9	-0.9	0.4
FAM	12.0	7.5	9.7	-10.8	13.5	11.0
PPP	17.4	3.3	12.6	-12.4	14.9	16.0
AR	-15.6	2.9	-2.7	2.1	-3.8	-9.9
SDM	21.7	3.2	19.3	-6.8	2.5	10.8
RDM	4.6	30.9	16.5	-7.2	7.6	2.2
TDM	17.9	8.0	18.8	-6.6	2.8	8.4
PH	-7.9	-11.0	-8.8	11.0	-12.4	-8.2
DF	-10.5	-1.2	-5.6	6.4	-4.3	-11.9
Total	39.7	39.6	60.0	-20.3	-14.6	17.7
Gen. Selec.	G1	G4	G3	G10	G7	G1
	G3	G2	G4	G4	UFU-040	G5
	G6	G3	G6	G2	G2	G3
	G4	UFU-040	G1	cv. Santa Clara	G6	G6
	G5	G7	G7	G1	G5	UFU-040

[1] Characters: gen. selec.: genotype selected. LT = leaf temperature ; SPAD = SPAD index; WP = leaf water potential ; NFP = number of fruit per plant; FAW= fruit average weight; PPP = production per plant ; AR = incidence of apical rot; SDW = shoot dry weight; RDW = root dry weight; TDW = total dry weight ; NL = number of leaves; PH = plant height ; DF = distance from the insertion of the first bunch of fruit.

Table 4. Estimates of the selection gains (SG %) obtained for twelve characteristics and three selection indexes. Monte Carmelo, UFU, 2017.

Characters^1	**Selection gains (%)**		
	Smith (1936) & Hazel (1943)	**Mulamba & Mock (1978)**	**Genotype-ideotype distance**
LT (ºC)^1	0.7	-0.5	-0.5
SPAD	-3.4	0.8	-0.2
WP (MPa)^1	3.5	-3.5	-1.4
NFP (fruit plant $^{-1}$)^1	-3.8	0.5	1.6
FAW (g)^1	4.2	15.0	16.3
PPP (kg plant^{-1})^1	0.5	20.3	23.4
AR (%)^1	28.6	-12.4	-10.1
SDW(%)^1	3.3	18.6	18.3
RDW (%)^1	10.2	-0.2	1.4
TDW (%)^1	5.1	14.7	14.6
PH (cm)^1	-2.9	-8.9	-10.2
DF (cm)^1	8.3	-9.3	-6.1
Total	55.2	34.6	46.8
Selected genotypes	G2	G5	G7
	cv. Santa Clara	G1	G6
	G7	G6	G5
	G6	G7	G4
	G4	G3	G1

^{1}Characters: LT = leaf temperature; SPAD = SPAD index; WP = leaf water potential ; NFP = number of fruit per plant; FAW = fruit average weight; PPP = production per plant ; AR = incidence of apical rot; SDW = shoot dry weight ; RDW = root dry weight; TDW = total dry weight; PH = plant height; DF = distance from the insertion of the first bunch of fruit.

similarity regarding the leaf water potential (Table 2). These results reveal the great tolerance of *S. pennellii* to water deficit.

The leaf water potential of the G2 and G4 genotypes were similar to UFU-040 genotype and cv. Santa Clara; the G2 genotype also resembled these later genotypes for SPAD index (Table 2). The leaf temperature increases with the stress caused by the water deficit, and mainly occurring due to the lower leaf transpiration caused by the stomata closure; this situation also impairs the CO$_2$ assimilation and negatively affects the photosynthetic activity (Morales *et al.*, 2015).

The G1, G3, G4, G5, G6 and G7 genotypes were similar to the *S. pennellii* access for the leaf temperature characteristic. These same genotypes, except G4, were similar to *S. pennelli* for leaf water potential. The G5 genotype showed leaf water potential of -2.1 MPa, similar to the resistant genotype in both evaluations (Table 2). In cowpea, the leaf water potential was an excellent parameter to detect genotypes more susceptible to water stress (Nascimento *et al.*, 2011). In the present study, this parameter has distinguished the genotypes that showed higher and lower water deficiency.

The wild access *S. pennellii* presented averages 16.6 and 11.08 times lower than the other genotypes for fruit weight and production per plant, respectively. These lower results were expected because *S. pennellii* is a wild genotype without agronomic improvements, only used as a gene-donor source for water deficit resistance. This genotype produced a high quantity of fruit (31 fruit plant^{-1}). Among other genotypes, only G1 and G5 were similar in fruit production per plant to *S. pennellii* (Table 2). In terms of substrate, at water tensions below -25 kPa, the number of fruit per plant tended to decrease due to flower abortion and low formation of fruits due to water restrictions (Hott *et al.*, 2018).

The G1, G2, G5 and G7 genotypes presented heavier fruits, being 26.26% higher in relation to the recurrent genitor (UFU-040), and 68.07% higher than the cv. Santa Clara (Table 2). The extent of the water deficit may have negatively impacted the fruit weight in this study. Moreover, there are reports of Santa Cruz fruit weight exceeding 120 g (Matos *et al.*, 2012).

The genotypes G1, G5 and G7, yielded an average of 0.206 kg plant^{-1}, more than the recurrent genitor (UFU-040). The production of the cv. Santa Clara was two times lower than the average of the other genotypes, not differing from the wild access *S. pennellii* (Table 2).

The wild access *S. pennellii* (donor genitor) also showed no fruit with apical rot, similarly to the G1, G5 and G2 genotypes. The incidence of fruit with apical rot in the other genotypes was superior to 20%, except G1 (19.5%) and G5 (12.20%) genotypes. Cultivar Santa Clara showed a high percentage of fruit with apical rot (67.7%), demonstrating to be very sensitive to water deficit (Table 2). Apical rot is a common physiological disorder that causes a necrotic symptom in *Solanaceae* plant species fruit and is associated to water in soil and low calcium absorption by plants (Cantuário *et al.*, 2014).

The smallest increases in shoot and total dry weight were observed with the wild access *S. pennellii* (11.5 and 10.7%). This low increase may be due to the divergent morphology of the *S. pennellii* plants compared to the other genotypes. However, the recurrent genitor (UFU-040) and cv Santa Clara were similar to *S. pennellii* access. The genotypes G2 and G7 were similar to *S. pennellii* shoot dry weight (Table 2).

The shoot dry weight decreased with the increase in the matric potential of the substrate (Viol *et al.*, 2017). This reduced weight accumulation shows that despite the water restriction, the tomato genotypes G1, G3, G4, G5 and

G6 were the least impacted on the shoot dry weight accumulation (Table 2).

The wild access *S. pennellii*, the cv. Santa Clara and the G5 genotype showed the lowest root dry weight, averaging 15.6%. The G1 genotype was also considered of low root dry weight accumulation, averaging 35.3% (Table 2). For tomato (Morales *et al.*, 2015) and beet (Silva *et al.*, 2015), this parameter was not efficient to distinguish tolerant genotypes to water deficit. The wild access (*S. pennellii*) also presented 13 leaves, while the others displayed, on average, 9.4 leaves.

On the other hand, cv. Santa Clara presented the highest plant height, the number of leaves produced were similar to other genotypes, which are of determined growth habit (Table 2). This fact accelerates leaves' senescence due to the water deficit, as a plant strategy to reduce transpiration and the metabolic activity (Padilha *et al.*, 2016).

The wild access *S. pennellii* and the cv. Santa Clara presented plant heights of 101.4 and 94.7 cm, respectively, distinguishing from the other genotypes (Table 2). This result was already expected since these genotypes have indeterminate growth habit. The recurrent genitor UFU-040 expressed an average of 58.7 cm for plant height and determined growth habit. The genotypes from the interspecific crossing did not differ from UFU-040, showing the efficiency of the backcross in the recovery of this characteristic (Table 2).

The distance from the substrate surface to the insertion of the first fruit bunch in cv. Santa Clara was 26.9 cm; in the other genotypes, except the wild access (*S. pennellii*), this height was 64.31% lower (Table 2). This result demonstrates that the tomato genotypes were more compact when compared to cv. Santa Clara, facilitating crop management.

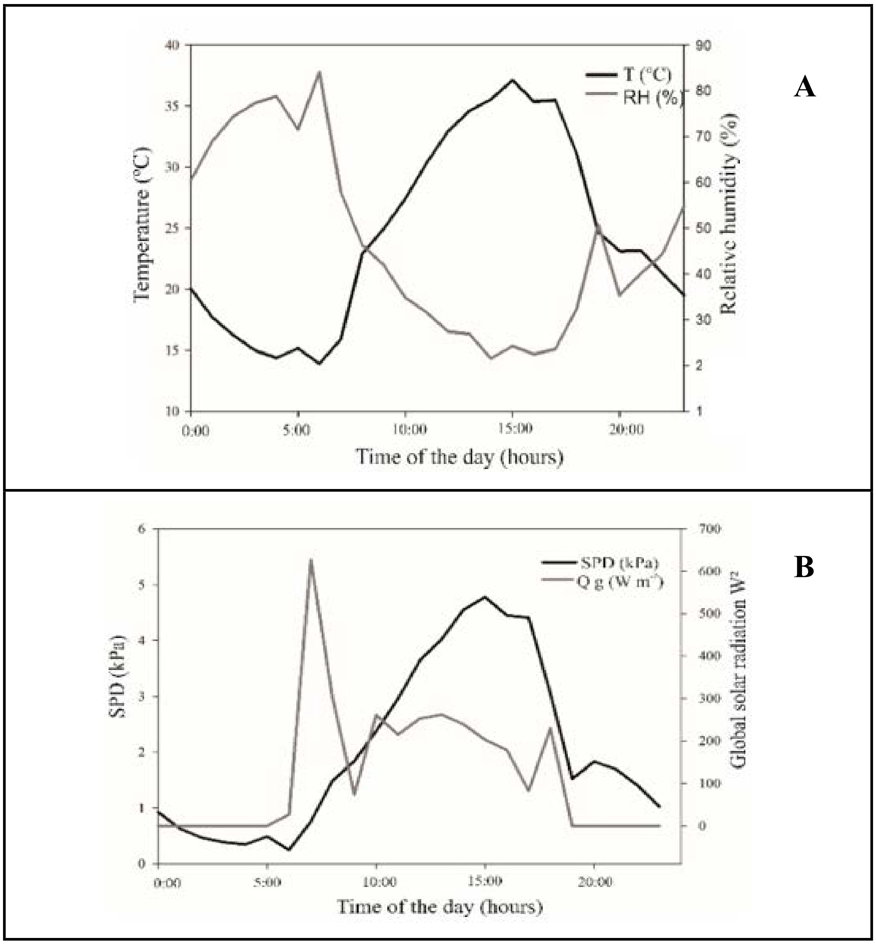

Figure 2. Climatic conditions observed 108 days after sowing: environment temperature and relative humidity (A); global solar radiation, and the deficit of vapor pressure (B). Monte Carmelo, UFU, 2017.

The direct selection based on the physiological characteristics: leaf temperature, SPAD index and leaf water potential is advantageous to the indirect selection aiming to reduce the incidence of fruit apical rot and generated gains exceeding 25%. Moreover, the selection for these variables favors the increase of fruit number. However, little influence on the production was observed. The direct selection aiming leaf temperature decrease, the increase of the SPAD index and the leaf water potential was efficient, especially to select the G5 and G7 genotypes, which were similar to the wild access (*S. pennellii*) for these characteristics (Table 3).

The direct selection for agronomic characters indicated 18.3% gains for fruit average weight, 5.8% for the number of fruit per plant, 23.4% for production, and 38.4% to reduce the incidence of fruit apical rot. The selection based on these characteristics majorly selected the G1 and G5 genotypes. However, the G4 and G7 genotypes, despite being selected for the fruit average weight and production, do not have the potential to reduce the incidence of apical rot. Rodrigues *et al.* (2017) demonstrated the efficiency of the direct selection under agronomic characters for cowpea genotypes tolerant to drought and the direct selection efficiency.

The gains to increment of dry weight using the direct selection ranged from 18.8 to 30.9%; however, the efficiency of selection is more magnificent when based on shoot dry weight (21.7%) and total dry weight (18.8%), selecting the genotypes that had better responses in conditions of water deficiency (G5, G1, G6 and G7) (Table 3).

The direct selection aiming at the reduction of plant height and height of the insertion of the first fruit bunch indicated gains of 12.4 and 11.9%, respectively. The selection of genotypes for these traits is efficient allowing the selection of genotypes similar to the recurrent genitor; thus, the G5 and G6 genotypes were selected for both characteristics (Table 3).

The genotype-ideotype distance index assumed the most expressive gains for production (23.4%) (Table 4) and obtained similar gains to the method of direct selection (Table 3). These indexes selected the genotypes: G1, G4, G5, G6, and G7 (Tables 3 and 4). Luz *et al.* (2014) found that the genotype-ideotype distance used in the selection of intraspecific progenies in peanuts features increased chances of success during the selection process.

The index of Mulamba& Mock (1978) indicated gains in the production of 20.3%; this index is also more efficient than the genotype-ideotype distance index in the gain to reduce the incidence of apical rot (12.4%). In this way, the selection of genotypes using this methodology follows G5, G1, G6, G7, and G3 (Table 4). Bizari *et al.* (2017) found that the method of Mulamba & Mock (1978) provides a balanced distribution of gains from selection, enabling more significant gains in a selection based on agronomic traits in the soybean crop.

In the present study, however, the genotype-ideotype distance presented a higher overall gain (46.8%), in comparison to Mulamba & Mock (1978) (34.6%). The selection index of Smith (1936) and Hazel (1943) was the only index to select the cv. Santa Clara, a genotype known to be susceptible (Borba *et al.*, 2017); this index had low power of selection when multiple characteristics of agronomic potential and drought tolerance were considered (Table 4).

The G5=UFU-102-RC3#91335 genotype resisted well to the water stresses imposed, keeping its agronomic performance superior to the cv. Santa Clara and similar physiological parameters compared to the wild access (*Solanum pennellii*). Our results indicate that the selection index of genotype-ideotype distance was the most appropriate for the selection of tomato genotypes with agronomic potential and drought tolerance.

ACKNOWLEDGMENTS

The authors thank the Federal University of Uberlândia, PROPP, CAPES, CNPQ and FAPEMIG for the financial and administrative support.

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