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Identification of promising tomato breeding lines with determinate growth by selection index

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Abstract: Source of important vitamins, fibers, and minerals, the tomato (*Solanum lycopersicum* L.) stands out in the world agricultural scenario for its economic and social relevance and versatility. The Brazilian market is dominated by multinationals companies, and this market segment obtains cultivars from other countries, with genetics accurate to climatic conditions and cultivation method very different from those used in Brazil. As a result, the local cultivation of tomatoes plants becomes dependent on market variations and has required a material that has limited production efficiency. This study aimed to estimate genetic parameters from agronomic traits and to select industrial tomato lines using the selection index. A randomized block experimental design with three replications was used. Eighty-five industrial tomato lines from the germplasm bank of the Vivati Plant Breeding Ltda were evaluated. Each plot had 12 plants. The two central plants of each plot were evaluated. The evaluations were carried out using adapted morphological descriptors described in the guidelines for carrying out the distinguishability, homogeneity, and stability (DHE) tests of the Ministry of Agriculture, Livestock, and Supply of Brazil (MAPA). The genotypic determination coefficient (H^2) of the traits related to fruit pericarp thickness, fruit firmness, fruit yield, average cycle, average number of fruits per plant, and soluble solids was high. The base index and the classic index presented the largest gain from selection for the fruit yield trait. Rank summation index and genotype-ideotype distance index had the highest total selection gain values. The tomato lines PXT-601 and PXT-610 stood out as superior genotypes by the methods of direct selection and by selection indexes.

1. Introduction

Tomato is grown in different regions of the world and stands out as the most produced vegetable in the world, second only to potatoes in the cultivated area (Geraldini *et al.*, 2018). Part of the success of tomatoes comes from its diversity in food and nutritional aspects that help human health. The fruit is rich in vitamins A and C and lycopene, substances that help prevent cancer of the gastrointestinal tract (Simão and Rodriguez, 2008).

Brazil is in ninth place in the world tomato production ranking. At the top is China, accounting for 31% of production, followed by India with 11%, and the United States with 8% of global production (Dossa and Fuchs, 2017). In 2017, 36.688 hectares of tomato were grown in Brazil, 47.40% of the production was destined for fresh consumption, and 52.60% for processing industries (Marcomini and Molena, 2018).

The Brazilian national market is dominated by multinationals and acquires imported cultivars, with genetic characteristics adapted to climatic conditions and cultivation systems very different from those found in Brazil. As a result, the Brazilian cultivation of tomato becomes dependent on market swings. It obtains cultivars with productive potential restricted if compared to the yields reached in the environment that they were developed. Also, the plants may suffer losses by climate intolerances and plant diseases, when facing the Brazilian growing conditions.

Due to the economic importance of the crop, tomatoes produced for processing industries have been the focus of research, especially in genetic breeding with the aim of produce cultivars that possess genes able to assist in the adaptation and tolerance to biotic and abiotic stresses, which can result in important contributions to the sector (Parmar *et al*., 2017).

In a breeding program, the objective is to enhance the main phenotypic trait and conserve or improve the expression of secondary traits at the same time (Nogueira *et al*., 2012). However, the direct selection of quantitative traits is influenced by the environment, which may cause unfavorable changes in other traits (Vasconcelos *et al*., 2010).

One way to improve this process is to use the simultaneous selection of a group of important agronomic traits, that is, to use the selection indexes. These indexes relate information of different traits and make it possible to perform a selection effectively, which increases the probability of success in a plant breeding program (Cruz *et al*., 2012; Vianna *et al*., 2013; Rezende *et al*., 2014).

Considering the importance of the industrial processing of tomatoes and the market demand for cultivars that meet the requirements of this industrial chain, it is indispensable to know the relationship between agronomic traits and the study of the indexes. This makes it possible to obtain the best prediction of gains and yields and greater efficiency in the selection process. Given the above, this aimed to estimate genetic parameters for agronomic traits and to select industrial tomato lines using the selection index.

2. Materials and Methods

The study was conducted in the experimental area of Vivati Plant Breeding Ltda, in Abadia de Goiás Unit, Goiás, Brazil, at 16°45’26” S, 49°26’15” W, and 898 m of altitude. The climate, according to Koppen, is classified as tropical humid, characterized by rainy summer with high temperatures and dry winter, with an average annual rainfall of 1.575 mm.

The genotypes analyzed in this study are owned by Vivati Plant Breeding Ltda, which use their own selection and maintain methods. The seeds were sown in 450-cell polystyrene trays, filled with a substrate composed of coconut fiber, rice husk, and peat and covered with vermiculite. The trays were kept in a greenhouse for 35 days when the seedlings had from two to three true leaves, and they were able to transplant to the field.

The soil preparation was carried out with a tractor and rotary tiller. Seedbeds were prepared with 1.0 m wide, 0.20 m high, with 1.0 m spacing between beds. At the transplanting, 1.500 kg ha^{-1} of the NPK formulation 04-30-10 was applied. As topdressing fertilization, 20 kg ha^{-1} of MAP, 75 kg ha^{-1} of ammonium sulfate, 100 kg ha^{-1} of ammonium nitrate, and 200 kg ha^{-1} of potassium chloride were divided into four applications with a 20-day interval after transplanting.

The seedlings were manually transplanted to the field 35 days after sowing (DAS), with 0.40 m between plants and 1.0 m between rows. Irrigation was performed by a drip system, supplying the water requirement based on the parameters for crop irrigation management.

Weed control was performed weekly to avoid competition. Insecticide baits were placed throughout the field to identify the insect infestation rate and help the decision of pesticide application. Phytosanitary control was carried out whenever necessary, to maximize fruit production (FAO, 2006).

The tomato lines were characterized by morphological traits contemplated in the guidelines for performing the distinguishability, homogeneity, and stability (DHE) assays by the MAPA, which were modified by the authors. A randomized block experimental design with three replications was used. Eighty-five industrial tomato lines were evaluated. Each plot had 12 plants. The two central plants of each plot were evaluated. The descriptors analyzed are shown in Table 1.

It was estimated the genotypic determination coefficient (H^2), according to the estimator below:

$$H^2 = \frac{\hat{\emptyset}g}{QMT/_r}$$

$$\hat{\emptyset}g = \frac{(QMT - QMR)}{r}$$

Where:
H^2 = genotypic determination coefficient;
$\emptyset$ = quadratic genetic component;
QMT = mean square of genotypes;
QMR = mean square of the residue; and
ϒ = number of replications.

Genotypes were grouped based on the Scott-Knott test at the 1% and 5% probability level. Subsequently, the selection gains estimates were reached by the aid of the selection index methodologies cited by Cruz (2006): direct and indirect selection; classic index proposed by Smith (1936) and Hazel (1943); rank summation index of Mulamba and Mock (1978); base index of Williams (1962); and genotype-ideotype distance index (GID). The selection criterion applied was to increase the traits: fruit pericarp thickness (FPT), fruit firmness (FF), yield (YLD), average number of fruits per plant (NFP), and soluble solids (SS).

The index proposed by Smith (1936) and Hazel (1943) was established by the selection index (I) and the genotypic aggregate (H) described below:

$$I = b_1 y_1 + b_2 y_2 + \ldots + b_n y_n = \sum_{i=1}^{n} b_i\, y_j = y'b$$

$$H = a_1 g_1 + a_2 g_2 + \ldots + b_n y_n = \sum_{i=1}^{n} a_i\, g_i = g'a$$

where:
n = number of traits evaluated;
b = vector of dimension 1 xn of the selection index weighting coefficients to be estimated;

Table 1 - Descriptors for industrial tomatoes (adapted from MAPA, 2005) and details on their analysis

Traits	Trait description	Description code	Comments
01. Fruit pericarp thickness	Slim	S	The analysis was performed using a digital caliper, measuring the diameter (mm) from the outer wall to the inner wall of the pericarp
	Average	A	
	Thick	T	
02. Fruit: firmness	Soft	S	The analysis was performed by subjecting the fruits to pressure at one point in the middle region, measuring the resistance of the pulp to penetration, using Instrutherm model PTR-300 digital penetrometer, and obtaining the values expressed in Newton (N)
	Medium	M	
	Firm	F	
03. Maturation cycle	Precocious	P	It was evaluated from the transplanting of seedlings
	Medium	M	
	Late	L	
04. Yield	Low	L	It was determined by the weight and number of fruits per plant
	Average	A	
	High	H	
05. Number of fruits per	Low	L	It was counted all fruits of each plant, including the green and damaged ones
	Average	A	
	High	H	
06. Soluble solids	Low	L	The analysis was performed by transferring a drop of the fruit juice to the Hanna Instruments model HI 96801 digital refractometer prism and then reading it, expressed in °Brix
	Average	A	
	High	H	

y = nxp dimension matrix (plants) of phenotypic values of traits;
a = is the 1 xn dimension vector of previously established economic weights;
g = nxp dimension matrix of unknown genetic values of the n traits considered.

The vector b = P -1 Ga, where P -1 is the inverse of the matrix, of dimension nxn of phenotypic variance and covariance between traits. G is the nxn dimension matrix of genetic variance and covariance between traits.

The expected gain for trait j was expressed by:

$$\Delta g_{j(i)} = DS_{j(i)} h_j^2$$

Where:
Ag j(i) = gj (i): expected gain for trait j, with selection based on index I;
DS j(i) = selection differential of trait j, with selection based on index I;
h^2j = heritability of trait j.

In the rank summation index of Mulamba and Mock (1978), the orders of each genotype were summed, resulting in the selection index, as described below:

$$I = r_1 + r_2 + ... + r_n$$

Where:
I = index value for a given individual or family;
r_n = an individual's rank (or rank) from the j^{th} trait;
n = number of traits considered in the index.

The weights were given by:

$$L = p_1 r_1 + p_2 r_2 + ... + p_n r_n$$

Where:
pj = economic weight attributed to the jth trait.

For the base index of Williams (1962), the following index was used as selection criteria:

$$I = a_1 y_1 + a_2 y_2 + ... + a_n y_n = \sum_{i=1}^{n} a_i y_i = y'a$$

Where:
y = are the means;
a = are the economic weights of the traits studied.

For the index of genotype-ideotype distance (Cruz, 2006), the mean and maximum and minimum values for each variable were calculated. Xij was considered as the mean phenotypic value of the ith genotype concerning the ith trait. As well, we considered the value Yij representing the transformed mean phenotypic value and Cj as a constant relative to the average genotype depreciation. Thus, we had: LIj as the lower limit to be presented by the genotype, relative to the characteristic j, LSj as the upper limit to be presented by the genotype and VOj as the optimal value to be presented by the genotype, under selection.
If LIj <Xij <LSj, then Yij = Xij;
If Xij <LIj, Yij = Xij + VOj - LIj - Cj;
If Xij> LSj, Yij = Xij + VOj - LSj + Cj.

In the methodology, it was considered Cj = LSj - LIj. The Cj value ensured that any value of Xij within the range of variation around the optimum resulted in a value of Yij of magnitude close to the optimal value (VOj), as opposed to the values of Xij outside this range. Thus, the Xij transformation was performed to ensure the depreciation of phenotypic values out of range. The Yij values obtained by transformation were later standardized and weighted by the weights assigned to each characteristic, obtaining the Yij values, as described below:

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

Where:
S (Yj) = standard deviation of the mean phenotypic values obtained by the transformation;
aj = weight or economic value of the characteristic.

Then, we calculated the GID index values expressed by the distances between the genotypes and the ideotype, as illustrated:

$$I_{GID} = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (y_{ij} - vo_j)^2}$$

From these indexes, the best genotypes were identified, and the selection gains were calculated. All genetic and statistical analyzes were processed through the Computational Program in Genetics and Statistics - GENES Program (Cruz, 2016).

3. Results and Discussion

Genetic variability was found for all traits by the F-test at 1% or 5% probability level, which evidenced the ability to perform the selection of superior tomato lines. It was verified by values of coefficient of variation (CV) ranging from 1.36% to 29.03% for MC and NFP, respectively. The highest CV values were observed in trait NFP (29.03%), SS (18.28%), and YLD (18.05%) (Table 2).

The genotypic coefficient of determination (H^2) allows us to define the estimate of genetic gain to be achieved and to establish the most appropriate strategy to be used in the breeding program (Baldissera *et al.*, 2014). H^2 values change according to each charac-

Table 2 - Mean square, coefficient of variation, and genetic parameters of agronomic traits and yield of 85 industrial tomato lines

Source of Variation	DF	Mean square					
		FPT	FF	YLD	CM	NFP	SS
Blocks	2	0.65	0.59	488.22	2.89	1663.12	37.75
Lines	84	2.08 **	0.56 **	698.53 **	8.16 **	1664.94 *	0.82 *
Residue	168	1.35	0.23	338.89	2.29	1175.83	0.55
CV (%)	-	15.96	16.69	18.05	1.36	29.03	18.28
CVg/CVe	-	0.42	0.68	0.59	0.92	0.37	0.41
H^2	-	34.84	58.30	51.48	71.93	29.38	33.29

FPT= fruit pericarp thickness, FF= fruit firmness, YLD= yield, MC= maturation cycle, NFP= number of fruits per plant, SS= soluble solids, H^2= genotypic coefficient determination, CV= coefficient of variation, CVg= coefficient of genetic variation, CVe= coefficient of experimental variation. ** and * significant by F-test at 1% and 5% probability, respectively.

teristic and are classified as high when they are higher than 0.7 (Alvares *et al.,* 2016).

The highest H^2 values were found for the maturation cycle (71.93%), fruit firmness (58.30%), and yield (51.48%). These values allow us to reach success by the phenotypic selection, which can be proven by the results found in the CVg/CVe ratio, which were close to 1.0 for these traits. The lowest H^2 values were observed for the number of fruits per plant (29.38%) and soluble solids (33.29%).

The medium and high results of the heritability coefficient and coefficient of genetic variation are related to higher selective accuracy, higher genetic variability, and the probability of successfully choosing genotypes with optimal agronomic traits (Storck and Ribeiro, 2011).

The CVg/CVe ratio was close to 1.0 only for the medium cycle. The CVg/CVe ratio can be accepted as an indicator of the obtaining of more relevant genetic gains in the selection of superior genotypes (Cruz *et al*., 2012).

The constitution of tomato fruits for the industry has been remodeled through genetic improvement, to select cultivars with desirable characteristics for processing. As a general rule, the desired tomato lines are those that combine higher yield with quality, and that meet the needs of the industry, which currently are firm fruits, with a high content of soluble solids, a shorter cycle, a higher number of fruits per plant and higher fruit pericarp thickness (Iglesias *et al*., 2015; Peixoto *et al*., 2017).

Fruit pericarp thickness ranged from 5.36 to 9.04 mm (Table 3). Only 3.7% of the tomato lines had a

Table 3 - Fruit pericarp thickness (FPT), fruit firmness (FF), yield (YLD), maturation cycle (MC), number of fruits per plant (NFP), and soluble solids (SS) of 85 industrial tomato lines

Lines	Traits					
	FPT mm	FF N	YLD t ha^{-1}	MC days	NFP n° plant^{-1}	SS °Brix
PXT-102	5.5 b	1.79 b	103.79 a	109 b	123.67 a	4.17 a
PXT-104	6.55 b	1.98 b	93.96 b	107 b	111 b	4.57 a
PXT-106	7.59 a	2.39 b	108.19 a	111 a	130.83 a	3.07 b
PXT-107	6.11 b	2.31 b	111.50 a	109 b	109 b	4.07 a
PXT-108	7.20 a	2.67 b	123.94 a	110 b	96.33 b	4.13 a
PXT-109	7.91 a	2.30 b	85.28 b	110 b	92.33 b	3.77 b
PXT-111	7.75 a	2.58 b	68.98 b	107 b	74.83 b	4.43 a
PXT-113	7.15 a	3.15 a	85.76 b	112 a	99.17 b	4.77 a
PXT-114	7.40 a	2.38 b	72.87 b	110 b	112.83 b	3.03 b
PXT-115	8.08 a	2.55 b	86.27 b	107 b	106.00 b	4.20 a
PXT-116	7.36 a	1.94 b	117.45 a	113 a	107.17 b	3.67 b
PXT-117	8.08 a	2.65 b	119.54 a	112 a	130.83 a	4.40 a
PXT-118	6.90 b	2.70 b	110.33 a	110 b	141.17 a	3.77 b
PXT-120	7.17 a	2.13 b	114.81 a	113 a	128.17 a	4.73 a
PXT-121	6.00 b	2.63 b	115.12 a	112 a	135.17 a	3.17 b
PXT-122	7.39 a	2.40 b	106.26 a	113 a	129.33 a	4.10 a
PXT-123	8.58 a	2.68 b	103.88 a	112 a	143.33 a	4.30 a
PXT-124	6.15 b	2.41 b	113.87 a	113 a	77.67 b	3.87 b
PXT-125	5.69 b	3.14 a	93.54 b	113 a	159.00 a	4.80 a
PXT-126	6.15 b	3.05 a	115.37 a	109 b	155.83 a	4.83 a

Means followed by the same letters belong to the same group by the Scott-Knott test at 5% probability level.

To be continued...

Table 3 - Fruit pericarp thickness (FPT), fruit firmness (FF), yield (YLD), maturation cycle (MC), number of fruits per plant (NFP), and soluble solids (SS) of 85 industrial tomato lines

Lines	Traits					
	FPT mm	FF N	YLD t ha^{-1}	MC days	NFP n° plant^{-1}	SS °Brix
PXT-401	5.37 b	3.08 a	95.68 b	113 a	173.83 a	3.60 b
PXT-402	5.90 b	2.74 b	107.19 a	112 a	139.00 a	4.57 a
PXT-403	6.37 b	3.33 a	122.89 a	112 a	146.00 a	4.00 b
PXT-404	6.74 b	2.11 b	118.68 a	113 a	93.67 b	3.37 b
PXT-405	5.50 b	2.88 b	117.25 a	112 a	115.50 b	4.30 a
PXT-406	6.37 b	3.30 a	100.62 a	110 b	156.17 a	4.40 a
PXT-407	6.43 b	2.85 b	103.61 a	111 a	99.33 b	3.80 b
PXT-408	6.01 b	2.62 b	90.30 b	112 a	126.00 a	4.87 a
PXT-409	6.03 b	3.22 a	99.00 b	111 a	100.33 b	4.87 a
PXT-410	7.42 a	2.80 b	106.20 a	112 a	112.00 b	4.63 a
PXT-411	7.81 a	2.46 b	101.26 a	113 a	96.83 b	4.00 b
PXT-412	7.58 a	2.65 b	110.89 a	113 a	80.92 b	4.63 a
PXT-413	7.95 a	3.12 a	111.25 a	113 a	116.83 b	3.10 b
PXT-501	9.04 a	2.85 b	90.56 b	110 b	120.00 a	4.63 a
PXT-502	8.44 a	3.35 a	116.72 a	110 b	101.67 b	3.57 b
PXT-503	7.72 a	3.35 a	100.34 a	113 a	124.67 a	4.17 a
PXT-504	7.10 a	3.48 a	95.05 b	112 a	122.83 a	4.17 a
PXT-505	7.44 a	2.84 b	113.92 a	108 b	127.00 a	4.37 a
PXT-506	6.79 b	3.06 a	114.68 a	111 a	110.83 b	3.97 b
PXT-551	6.66 b	2.97 a	95.56 b	112 a	128.33 a	4.07 a
PXT-552	7.16 a	2.68 b	112.40 a	111 a	109.00 b	3.47 b
PXT-553	6.92 b	2.99 a	112.46 a	111 a	146.83 a	3.63 b
PXT-554	8.69 a	2.67 b	83.15 b	112 a	69.50 b	4.47 a
PXT-555	6.96 b	2.65 b	104.99 a	108 b	154.17 a	4.10 a
PXT-556	8.49 b	3.06 a	101.46 a	109 b	91.83 b	4.63 a
PXT-557	6.92 b	3.08 a	104.24 a	112 a	96.67 b	3.60 b
PXT-558	7.53 a	3.69 a	102.49 a	109 b	164.00 a	4.23 a
PXT-559	7.31 a	3.77 a	103.30 a	112 a	98.76 b	3.26 b
PXT-560	6.88 b	2.50 b	109.27 a	109 b	93.00 b	4.50 a
PXT-561	8.22 a	2.70 b	85.59 b	109 b	102.50 b	3.63 b
PXT-562	7.73 a	2.88 b	102.51 a	110 b	94.00 b	5.03 a
PXT-563	7.22 a	3.05 a	111.74 a	113 a	90.50 b	4.07 a
PXT-564	6.95 b	2.50 b	131.20 a	113 a	98.33 b	3.26 b
PXT-565	7.12 a	3.07 a	104.29 a	111 a	114.83 b	4.10 a
PXT-566	8.44 a	3.38 a	114.83 a	111 a	128.17 a	4.43 a
PXT-567	8.35 a	2.84 b	91.36 b	112 a	148.83 a	3.83 b
PXT-568	7.23 a	3.42 a	105.30 a	111 a	122.50 a	3.80 b
PXT-569	8.06 a	2.87 b	76.93 b	112 a	121.83 a	4.13 a
PXT-570	8.02 a	3.34 a	88.84 b	113 a	139.33 a	3.40 b
PXT-571	7.23 a	2.80 b	90.29 b	112 a	94.17 b	3.96 b
PXT-572	8.14 a	2.76 b	83.28 b	110 b	104.33 b	4.76 a
PXT-601	6.4a b	3.31 a	137.92 a	112 a	154.66 a	4.26 a
PXT-602	7.59 a	2.76 b	122.97 a	110 b	114.17 b	5.26 a
PXT-603	6.19 b	3.08 a	98.68 b	112 a	136.67 a	3.66 b
PXT-604	7.60 a	2.98 a	117.62 a	109 b	105.33 b	3.37 b
PXT-605	7.82 a	2.94 a	77.11 b	111 a	116.17 b	3.60 b
PXT-606	7.67 a	2.82 b	99.15 b	112 a	144.50 a	4.03 a
PXT-608	8.82 a	2.79 b	93.17 b	110 b	84.33 b	3.03 b
PXT-609	7.29 a	2.78 b	97.48 b	109 b	104.17 b	3.77 b
PXT-610	7.69 a	3.08 a	145.98 a	113 a	132.67 a	4.27 a

Means followed by the same letters belong to the same group by the Scott-Knott test at 5% probability level.

To be continued...

Table 3 - Fruit pericarp thickness (FPT), fruit firmness (FF), yield (YLD), maturation cycle (MC), number of fruits per plant (NFP), and soluble solids (SS) of 85 industrial tomato lines

Lines	Traits					
	FPT mm	FF N	YLD t ha^{-1}	MC days	NFP n° $plant^{-1}$	SS °Brix
PXT-611	7.94 a	2.84 b	104.42 a	113 a	110.67 b	4.00 b
PXT-613	7.75 a	3.03 a	92.45 b	109 b	106.50 b	4.40 a
PXT-614	7.46 a	3.31 a	99.55 b	112 a	107.00 b	3.50 b
PXT-615	7.37 a	2.67 b	83.69 b	110 b	79.33 b	3.73 b
PXT-616	7.69 a	3.91 a	98.75 b	111 a	122.50 a	4.87 a
PXT-617	8.27 a	3.04 a	85.38 b	113 a	92.83 b	3.97 b
PXT-618	8.68 a	3.04 a	114.23 a	110 b	96.33 b	4.57 a
PXT-619	6.61 b	3.57 a	97.11 b	111 a	152.00 a	4.17 a
PXT-651	7.45 a	3.37 a	56.63 b	109 b	125.83 b	3.60 b
PXT-652	8.16 a	4.10 a	74.64 b	109 b	157.67 a	3.57 b
PXT-653	8.39 a	3.31 a	82.29 b	112 a	103.83 b	2.93 b
PXT-654	6.84 b	3.43 a	84.09 b	111 a	166.17 a	3.87 b
PXT-655	7.55 a	2.35 b	108.04 a	109 b	124.17 a	4.27 a
PXT-656	6.90 b	3.43 a	114.19 a	110 b	149.50 a	3.90 b
PXT-687	6.70 b	2.95 a	98.99 b	109 b	113.83 b	4.77 a

Means followed by the same letters belong to the same group by the Scott-Knott test at 5% probability level.

high thickness of the pericarp. According to Vieira *et al.* (2019), the thickness of the pericarp, together with the resistance of the epidermis and the texture of the placenta tissue, influences the firmness of the fruit (the relationship between the volume of the pericarp and volume of the locular material).

Only 3.7% of the tomato lines had high values of fruit firmness. Firmer fruits present less degradation of the cell wall and increase the resistance of the fruits during the transport process. The fruit firmness ensures resistance to mechanical damage during mechanized harvesting and bulk transport. Fruits that are not firm are more susceptible to the transformation and breakage of the skin, releasing cellular juice and causing fermentation and deterioration of the fruits before the arrival in the industry (Vieira *et al*., 2019). The fruit firmness is extremely important for the industry, because, between the harvest and the unloading process in the industry, there are many losses, due to a large number of disintegrated fruits, related to excessive compression (Moura and Golynski, 2018).

One of the main characteristics to be used in the selection of the ideal genotype for the tomato processing industry and mainly for the producers is fruit yield. Among the tomato lines evaluated, again, 3.7% of them obtained high values, above 131 t ha^{-1}. The average yield of the state of Goiás, where the tomato lines were evaluated, were 85 and 94 t ha^{-1} in the 2017 and 2018 harvests, respectively (Globo Rural, 2018).

The average cycle ranged from 106 to 113 days. Only 5.88% of tomato lines evaluated had a short cycle. Most cultivars marketed by seed companies have a cycle between 95 and 125 days (Kelley *et al*., 2010), which demonstrates that all tomato lines evaluated are classified between the short and middle cycles. The use of short-cycle genotypes is desirable in breeding programs, as it allows for a shorter stay in the field, where they will be subject for a shorter time to effects of biotic and abiotic factors such as disease and drought stress (Gatut-Wahyu *et al*., 2014).

The number of fruits per plant ranged from 69.50 for PXT-554 to 173.83 for PXT-401. Cultivars with a low number of fruits per plant are not recommended because they have lower yield during the harvesting process (Santos, 2015).

High soluble solids content is one of the main characteristics that an industrial tomato material must-have. According to Figueiredo *et al*. (2015), the higher the soluble solids content, the higher the efficiency of industrial production, and the lower the energy expenditure during the pulp concentration procedure. In practice, for each addition of a °Brix in the pulp, there is a 20% increase in industrial production. Values above 4.5°Brix are higher than the Brazilian average. Among 85 tomato lines evaluated, 23.17% is above this value, reaching the maximum value of 5.23 °Brix.

Direct selection resulted in higher individual gains (Table 4). This selection is directed only for one trait of interest and comprises the obtention of maximum gains of a single trait for which selection is practiced. According to how this trait is associated with others, favorable or unfavorable results may occur in traits of secondary importance (Cruz, 2016).

Direct selection for FPT, NFP, and SS resulted in direct gains for fruit firmness, with values of 1.97%, 8.69%, and 2.93%, respectively. Noteworthy was the direct selection for the number of fruits per plant, which resulted in the largest indirect gain for fruit firmness.

The indexes of selection consist of an alternative that allows the simultaneous selection to perform effectively by combining different traits (Rosado *et al*., 2012). In general, the index of the rank summation index of Mulamba and Mock (1978) showed the largest gain of yield (7.89%) and soluble solids (4.02%), followed by the Smith (1936) and Hazel (1943) index, with 7.20% of the gain of yield. However, these two indexes had low selection gain values for the other traits (Table 5).

Table 4 - Genetic gain estimates obtained for five traits evaluated by direct and indirect selection for 85 industrial tomato lines

Traits	Genetic gain (%)				
	FPT	FF	YLD	NFP	SS
FPT	**6.21**	0.43	-0.43	-3.25	-1.94
FF	1.97	**14.41**	-3.34	8.69	2.93
YLD	-1.41	-1.51	**12.05**	-0.67	-1.47
NFP	-2.32	5.05	-0.05	**10.26**	0.2
SS	-0.12	-0.23	-0.44	1.06	**6.81**
Total	4.33	18.15	7.79	16.09	6.53

FPT= fruit pericarp thickness, FF= fruit firmness, YLD= yield, NFP= number of fruits per plant, SS= soluble solids.

The rank summation index of Mulamba and Mock (1978) had the highest gain for all the traits and the highest total gain, with values of 22.92%. The genotype-ideotype distance index obtained the second-highest total gain value, with 22.54%. These indices presented a balanced distribution of selection gains. In the research carried out by Rosado *et al.* (2012), the authors reported that the rank summation index of Mulamba and Mock (1978) was the most appropriate, allowing for a balanced distribution of selection gains for a larger number of yellow passion fruit progenies.

Table 5 - Genetic gain estimates obtained for five traits by selection by the classical index proposed by Smith (1936) and Hazel (1943), rank summation index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index for 85 industrial tomato lines

Traits	Genetic gains (%)			
	Smith (1936) and Hazel (1943)	Mulamba and Mock (1978)	Williams (1962)	Genotype-ideotype distance
FPT	-4.55	1.88	-2.98	2.31
FF	5.34	5.12	5.83	7.07
YLD	7.20	7.89	6.71	6.69
NFP	7.22	4.01	8.77	4.12
SS	0.29	4.02	0.57	2.35
Total	15.50	22.92	18.90	22.54

FPT= fruit pericarp thickness, FF= fruit firmness, YLD= yield, NFP= number of fruits per plant, SS= soluble solids.

The top ten genotypes, selected by all selection methods used in this study and their values of fruit pericarp thickness (Table 6), fruit firmness (Table 7), yield (Table 8), number of fruits per plant (Table 9), and soluble solids (Table 10) are shown in the tables below. The lines PXT-601 and PXT-610 were selected in all selection methods applied, verifying the superiority of these genotypes.

4. Conclusions

The rank summation index of Mulamba and Mock (1978) and the classical index proposed by Smith (1936) and Hazel (1943) applied to agronomic traits of eighty-five industrial tomato lines turned out to the largest selection gain for the yield trait.

Rank summation index of Mulamba and Mock (1978) has the highest total genetic gain values.

The lines of tomato PXT-601 and PXT-610 stand out as superior genotypes by the direct selection method and selection indexes.

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Table 6 - Fruit pericarp thickness (FPT) in mm from ten superior genotypes selected by direct selection for fruit pericarp thickness, and classic index proposed by Smith (1936) and Hazel (1943), rank summation index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index (GID)

Selection indexes							
Williams (1962) and direct selection of fruit pericarp thickness		Smith (1936) and Hazel (1943)		Mulamba and Mock (1978)		Genotype-ideotype distance	
Lines	FPT	Lines	FPT	Lines	FPT	Lines	FPT
PXT-601	6.44	PXT-601	6.44	PXT-566	8.44	PXT-566	8.44
PXT-610	7.69	PXT-403	6.37	PXT-610	7.69	PXT-558	7.53
PXT-126	6.15	PXT-610	7.69	PXT-558	7.53	PXT-616	7.69
PXT-403	6.37	PXT-126	6.15	PXT-616	7.69	PXT-601	6.40
PXT-558	7.53	PXT-401	5.37	PXT-601	6.44	PXT-117	8.08
PXT-401	5.37	PXT-656	6.90	PXT-117	8.08	PXT-656	6.90
PXT-656	6.90	PXT-405	5.50	PXT-126	6.15	PXT-610	7.69
PXT-555	6.96	PXT-121	6.00	PXT-602	7.59	PXT-123	8.58
PXT-553	6.92	PXT-406	6.37	PXT-618	8.68	PXT-503	7.72
PXT-406	6.37	PXT-619	6.61	PXT-123	8.58	PXT-618	8.68

Table 7 - Fruit firmness (FF) in Newton from ten superior genotypes selected by the direct selection for fruit firmness, and classic index proposed by Smith (1936) and Hazel (1943), rank index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index (GID)

Selection Indexes							
Williams (1962) and direct selection of fruit firmness		Smith (1936) and Hazel (1943)		Mulamba and Mock (1978)		Genotype-ideotype distance	
Lines	FF	Lines	FF	Lines	FF	Lines	FF
PXT-601	3.31	PXT-601	3.31	PXT-566	3.38	PXT-566	3.38
PXT-610	3.08	PXT-403	3.33	PXT-610	3.08	PXT-558	3.69
PXT-126	3.05	PXT-610	3.08	PXT-558	3.69	PXT-616	3.91
PXT-403	3.33	PXT-126	3.05	PXT-616	3.91	PXT-601	3.31
PXT-558	3.69	PXT-401	3.08	PXT-601	3.31	PXT-117	2.65
PXT-401	3.08	PXT-656	3.43	PXT-117	2.65	PXT-656	3.43
PXT-656	3.43	PXT-405	2.88	PXT-126	3.05	PXT-610	3.08
PXT-555	2.65	PXT-121	2.63	PXT-602	2.76	PXT-123	2.68
PXT-553	2.99	PXT-406	3.30	PXT-618	3.04	PXT-503	3.35
PXT-406	3.30	PXT-619	3.57	PXT-123	2.68	PXT-618	3.04

Table 8 - Yield (YLD), in Mg ha-1, of ten superior genotypes selected by direct selection for yield, and classic index proposed by Smith (1936) and Hazel (1943), rank summation index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index (GID)

Selection Indexes							
Williams (1962) and direct selection of yield		Smith (1936) and Hazel (1943)		Mulamba and Mock (1978)		Genotype-ideotype distance	
Lines	YLD	Lines	YLD	Lines	YLD	Lines	YLD
PXT-601	137.92	PXT-601	137.92	PXT-566	114.83	PXT-566	114.83
PXT-610	145.98	PXT-403	122.89	PXT-610	145.98	PXT-558	102.49
PXT-126	115.37	PXT-610	145.98	PXT-558	102.49	PXT-616	98.75
PXT-403	122.89	PXT-126	115.37	PXT-616	98.75	PXT-601	137.92
PXT-558	102.49	PXT-401	95.68	PXT-601	137.92	PXT-117	119.54
PXT-401	95.68	PXT-656	114.19	PXT-117	119.54	PXT-656	114.19
PXT-656	114.19	PXT-405	117.25	PXT-126	115.37	PXT-610	145.98
PXT-555	104.99	PXT-121	115.12	PXT-602	122.97	PXT-123	103.88
PXT-553	112.46	PXT-406	100.62	PXT-618	114.23	PXT-503	100.34
PXT-406	100.62	PXT-619	97.11	PXT-123	103.88	PXT-618	114.23

Table 9 - Number of fruits per plant (NFP) of ten superior genotypes selected by direct selection for number of fruits per plant, and classic index proposed by Smith (1936) and Hazel (1943), rank summation index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index (GID)

Selection Indexes							
Williams (1962) and direct selection of number of fruits per plant		Smith (1936) and Hazel (1943)		Mulamba and Mock (1978)		Genotype-ideotype distance	
Lines	NFP	Lines	NFP	Lines	NFP	Lines	NFP
PXT-601	154.67	PXT-601	154.67	PXT-566	128.17	PXT-566	128.17
PXT-610	132.67	PXT-403	146.00	PXT-610	132.67	PXT-558	164.00
PXT-126	155.83	PXT-610	132.67	PXT-558	164.00	PXT-616	122.50
PXT-403	146.00	PXT-126	155.83	PXT-616	122.50	PXT-601	154.66
PXT-558	164.00	PXT-401	173.83	PXT-601	154.67	PXT-117	130.83
PXT-401	173.83	PXT-656	149.50	PXT-117	130.83	PXT-656	149.50
PXT-656	149.50	PXT-405	115.50	PXT-126	155.83	PXT-610	132.67
PXT-555	154.17	PXT-121	135.17	PXT-602	114.17	PXT-123	143.33
PXT-553	146.83	PXT-406	156.17	PXT-618	96.33	PXT-503	124.67
PXT-406	156.17	PXT-619	152.00	PXT-123	143.33	PXT-618	96.33

Table 10 - Soluble solids (SS), in °Brix, from ten superior genotypes selected by direct selection for soluble solids, and classic index proposed by Smith (1936) and Hazel (1943), rank summation index of Mulamba and Mock (1978), base index of Williams (1962), and genotype-ideotype distance index (GID)

Selection Indexes							
Williams (1962) and direct selection of soluble solids		Smith (1936) and Hazel (1943)		Mulamba and Mock (1978)		Genotype-ideotype distance	
Lines	SS	Lines	SS	Lines	SS	Lines	SS
PXT-601	4.27	PXT-601	4.27	PXT-566	4.43	PXT-566	4.43
PXT-610	4.27	PXT-403	4.00	PXT-610	4.27	PXT-558	4.23
PXT-126	4.83	PXT-610	4.47	PXT-558	4.23	PXT-616	4.87
PXT-403	4.00	PXT-126	4.83	PXT-616	4.87	PXT-601	4.26
PXT-558	4.23	PXT-401	3.60	PXT-601	4.27	PXT-117	4.40
PXT-401	3.60	PXT-656	3.90	PXT-117	4.40	PXT-656	3.90
PXT-656	3.90	PXT-405	4.30	PXT-126	4.83	PXT-610	4.27
PXT-555	4.10	PXT-121	3.17	PXT-602	5.27	PXT-123	4.30
PXT-553	3.63	PXT-406	4.40	PXT-618	4.57	PXT-503	4.17
PXT-406	4.40	PXT-619	4.17	PXT-123	4.30	PXT-618	4.57

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