Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 6 Issue 6 June 2022

Research Article

Selection of Mini Tomatoes in the Tomato Seed Collection of the Federal University of Goiás

Mariana Vieira Nascimento, Viviane Teixeira Rodrigues, Roberto Gomes Vital and Abadia dos Reis Nascimento

Phytotechnics Department, Federal University of Goiás, Brazil

***Corresponding Author:** Roberto Gomes Vital, Horticulture Department, Federal University of Goiás, Brazil.

DOI: 10.31080/ASAG.2022.06.1152

Received: May 12, 2022

Published: May 31, 2022

Abstract

Tomato is a vegetable originally from the Andes in South America, first domesticated in Mexico and later in Europe. The domestication process provoked genetic variability loss and the genetic base narrowing of the cultivated tomato. The seed collections are a conservation method that promotes species preservation and food security. Studies with morphological descriptors provide knowledge of the variability of accessions, allowing better management of germplasm banks, favoring the identification of suitable parents for the formation of populations through plant improvement. Thus, this study aimed to establish genetic parameters for agronomic traits and select mini tomatoes accessions through selection indexes. The experimental design consisted of 14 accessions of mini tomatoes in randomized complete blocks with three replications. The two central plants of each plot were analyzed. The evaluations carried out used morphological traits included in the methodology proposed by [23]. Selection indexes were used to choose the best accessions based on the evaluated characters. The base index of [22] and the classic index proposed by [32] and [14] present the most significant selection gain for the yield trait. Accession UFG 57 showed superior genotypes through all direct and indirect selection methods.

Keywords: *Solanum Lycopersicum*; Fruits Per Plant; Selection Index, Genetic Variability, Morphological descriptors.

Abbreviations

CYCLE: Reproduction Cycle; DAS: Days After Sowing; DAT: Days After Transplanting; FF: Fruit Firmness; FW: Fruit Weight; GDI: Genotype-Ideotype Distance Index; GS%: Estimates of Genetic Gains; IM: Improved Population; NFP: Number of Fruits Per Plant; OM: Original Population; SS: Soluble Solids Content; YD: Yield

Introduction

Tomato (Solanum lycopersicum) is cultivated in several regions of the world, standing out as the second most grown vegetable, surpassed only by potato (Solanum tuberosum) in the cultivated area [9]. The success of tomatoes results from its variations in food and production, thus forming an essential product for the fresh trade and processed food industry.

Brazil stands out as one of the largest tomato producers, ranking ninth globally, corresponding to 2.5% of world production. Brazilian yield ranks third, behind only the United States and Spain [6]. In 2018, 59,726 hectares of the crop were planted in the country, with 47.40% of the production destined for fresh use and 52.60% for industries, producing 4,084,910 tons [19]. In 2019, the state of Goiás had a planted area of 9,043 ha, representing 25% of national plantations, reaching 817,804 tons [15].

The tomato plant originated between northern Peru and southern Ecuador in the Andean region. In this territory, they naturally developed several species of the genus Solanum. Its domestication occurred initially in Mexico, later in Europe, around the 16th century, and in the United States, in the 17th century [1]. This domestication process resulted in genetic variability loss, reducing the genetic base of species [31,29].

The seeds collections are critical, as they provide researchers with a comprehensive source of genetic resources, which can furnish genes that provide adaptation to abiotic stresses and resistance to numerous insects and diseases [11]. These collections represent food security for the current and future generations [23]. However, accessions deposited in seeds collections are little used due to a series of adversities, such as lack of documentation, adequate description, and evaluation of collections, limiting the action of breeders [11].

The morphological characterization of accessions from the seeds collections contributes to their greater knowledge and recognizes possible genotypes, which can be used in plant breeding programs [15]. Research with morphological descriptors provides significant contributions to understanding the genetic variability of accessions and enabling better collections management, collaborating with the identification and selection of appropriate genotypes for the formation and management of populations in plant breeding programs [3].

Research related to genetic variation in seeds collections can be carried out based on quantitative or qualitative morphoagronomic descriptors [20]. The description of plant species in the collections has been carried out using botanical, morphological, and agronomic tables. In most cases, they are used without parameters referring to their effective collaboration for variability, thus causing an extension of time and labor during plant characterization [25].

Selection based on one or a few traits may prove inadequate as it does not lead to superior products regarding several characters [33]. An alternative would be adopting multiple information in the experimental units to select based on a group of characteristics. Therefore, breeding programs have used strategies that involve selection for several traits, such as selection index methods [27], providing more significant total gains, with distribution among the most suitable traits for genetic improvement purposes [27].

Thus, this study aimed to establish genetic parameters for agronomic traits and select mini tomatoes accessions through selection indexes.

Materials and Methods

The study was carried out in the experimental field of the Horta da Escola de Agronomia, at the Federal University of Goiás in Goiânia, Goiás. The climate, according to Köppen-Geiger, is classified as rainy summer and dry winter, with an average annual rainfall of 1,575 mm. The genotypes analyzed in this study are maintained in the tomato collection of Horta, which uses their own selection and conservation methods for these accessions.

The plants used in the experiment were sown manually in trays with 450 cells, filled with a substrate based on rice husk (Carolina Soil®), coconut fiber, and peat, and covered with vermiculite. Soon after, the trays had to be wrapped with polyethylene film (Stretch) to maintain a constant temperature and relative humidity to encourage uniform germination. The trays were directed to agricultural greenhouses with foot baths, antechambers, screens with a maximum mesh of 0.239 mm, and floating irrigation, as determined by the Ministry of Agriculture, Livestock and Supply (MAPA).

The soil preparation was carried out with a quarrying machine coupled to the tractor. Beds 1.0 m wide and 0.20 m high were prepared, with 1.0 m spacing between beds. A plastic mulching cover was used, and posts, bamboo, and wires were installed to stake the tomato plants. 1,500 kg of NPK 04-30-10 was incorporated into the soil. In the top dressing fertilization, 20 kg of MAP, 75 kg of ammonium sulfate, 100 kg of ammonium nitrate, and 200 kg of potassium chloride were applied at intervals of twenty days after transplanting totaling four applications. Calcium and boron-based foliar fertilizer were also applied weekly from the beginning of flowering.

Seedlings were transplanted to the field 35 days after sowing (DAS), with a spacing of 0.50 m between plants and 1.00 m between rows. Twenty-six days after transplanting (DAT), the plants were staking with polypropylene ribbon. The pruning (once a week) and topping (when the plants reached a significant height of 1.80m) were performed.

The drip irrigation system was adopted for water supply, obeying the water requirement and the irrigation management parameters of the crop. Manual weeding was carried out to avoid competition with weeds. Adhesive baits were used to identify the insect infestation rate for pesticide application decision-making.

Fourteen accessions of minitomatoes were used (UFG 02, UFG 03, UFG 04, UFG 05, UFG 06, UFG 07, UFG 33, UFG 48, UFG 49, UFG 50, UFG 56, UFG 57, UFG 61 and UFG 64). The experimental design adopted was a randomized complete block with three replicates, 14 plots with 12 plants each. The two central plants of each plot were analyzed during five harvests during the same reproductive cycle.

For the quantitative traits of each individual, the differences between accesses and the metric data of the descriptors most affected by the environment (quantitative traits) were analyzed. The plant material described above was evaluated using morphological traits included in the method of Nascimento [23], as shown in table 1.

Trait	Trait Description	Description Code	Observations
Fruit weight	Small Medium Big	S M B	The analysis was determined through each fruit weight in grams, carried out with a digital scale.
Average number of fruits per plant	Low Medium High	L M H	Fruit counting.
Soluble solids	Low Medium High	L M H	The analysis was performed by transferring a drop of fruit juice to the prism of a digital refractometer model HI 96801 from Hanna Instruments and then reading it, expressed in Brix degree.
Fruit: firmness	Soft Medium Firm	S M F	The analysis was performed by submitting the fruits to pressure at a point in the median region, measuring the resistance of the pulp to penetration, using an Instrutherm model PTR-300 digital penetrometer, and obtaining values expressed in Newton (N).
Yield	Low Medium High	L M H	The analysis was determined by the weight (kg/plant) and the number of fruits per plant.
Cycle to maturation	Early Medium Late	P M T	Counting days from transplanting until the beginning of fruit ripening.

Table 1: Tomato descriptors according to Birth methodology (2019).

To evaluate selection gains among accessions, selection indexes were used to identify the best genotypes. Genotypes were pooled at the 1% and 5% probability levels based on the Scott-Knott test. Subsequently, the selection gains estimates were reached with the help of the selection index methodologies mentioned by [5]: direct and indirect selection; classic index, proposed by [32] and [14];

rank-sum index of [22]; Williams base index [34]; and genotype-ideotype distance index (GDI).

The selection criterion applied was to increase the traits weight, fruit: firmness, yield, the average number of fruits per plant, and soluble solids. The index proposed by [32] and [14] was established by the selection index (I) and the genotypic aggregate (H) described below

$$I=b_1y_1+b_2y_2+...+b_ny_n=\sum_{i=1}^{n} b_i y_j = y'b$$

$$H=a_1g_1+a_2g_2+ ... + b_ny_n = \sum_{i=1}^{n} a_i g_i = g'a$$

Where

n: number of evaluated traits

b: 1 x n dimension vector of the weighting coefficients of the selection index to be estimated

y: n x p (plants) dimension matrix of phenotypic values of traits

a: is the 1 x n dimension vector of previously established economic weights

g: n x p 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 n x n, of phenotypic variances and covariances between the traits. G is the matrix of dimension n x n, genetic variances, and covariances 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) = g j(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

h2j: heritability of trait j.

In the rank-sum index of [22], each genotype orders of each genotype were added, resulting in the selection index, as described below

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

Where

I: index value for a specific individual or family

rj: classification (or "rank") of an individual concerning the j-th trait

n: number of traits considered in the index.

Weights were given by

$$I=p_1r_1+p_2r_2+...+p_nr_n$$

Where

pj: economic weight attributed to the j-th trait.

For the base index of [34], the following index was used as a selection criterion:

$$I=a_1y_1+a_2y_2+...+a_ny_n=\sum_{i=1}^{n} a_i y_i = y'a$$

Where

y: are the averages

a: are the economic weights of the studied traits.

Mean, maximum, and minimum values of each variable were calculated for the genotype-ideotype distance index [5]. Xij was considered the mean phenotypic value of the ith genotype regarding the j-th trait. Likewise, the Yij value represented the transformed mean phenotypic value, and Cj a constant relative to the genotype mean depreciation. Thus, we had: LLj as the lower limit to be presented by the genotype, related to the j trait, ULj as the upper limit to be presented by the genotype, and OVj as the optimal value presented by the genotype under selection.

If LLj < Xij < ULj, then Yij = Xij

If Xij < LLj, Yij = Xij + OVj - LLj - Cj

If Xij > ULj, Yij = Xij + OVj - ULj +Cj.

In the methodology, it was considered Cj = ULj - LLj. The Cj value ensured that any Xij value within the range of variation around the optimal would result in a Yij value with a magnitude close to the optimal value (OVj), as opposed to Xij values outside this range. Thus, the Xij transformation was performed to ensure the depreciation of phenotypic values outside the range. The Yij values obtained by transformation were later standardized and weighted by the weights assigned to each trait, 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, the index values (GDI) expressed by the distances between the genotypes and the ideotype were calculated, as illustrated

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

The best genotypes were identified from these indexes, and selection gains were calculated. The analyzes were processed through the Computational Program in Genetics and Statistics (GENES Program).

Results and Discussion

Results The Brazilian market is looking for an ideal mini tomato cultivar with the following traits: high soluble solids content, high firmness, very productive, early cycle, with an increased number of fruits per plant and heavier fruits. Therefore, the tomato collections accessions were tested for these traits.

Analysis of variance (ANOVA) was performed for different mini tomatoes accessions (Table 2). It was observed that there were no significant differences in weight between plants from the same block and between other blocks. Among the 14 different accessions of mini tomatoes, significant statistical differences were observed, at 1% probability, for fruit weight (Table 3), as well as between the five different harvests carried out (Table 4).

Variation Sources	DF	FW (g)	NFP	YD ($kg.ha^{-1}$)	FF (N)	SS (º Brix)	Cycle (Days)
Blocks	2	1.60 ^{ns}	2,547.0 ^{ns}	0.47 ^{ns}	1.47 ^{ns}	-	-
Plants	1	12.40 ^{ns}	-	0.85 ^{ns}	0.08 ^{ns}	-	-
Harvests	4	417.70*	525,161.0*	-	12.90*	1.42*	-
Accessions	13	4,048.0*	75,200.0*	1,808.87*	69.87*	14.6*	193.85*
Residue	387	27.20	2,770.0	0.03	1.42	0.06	0.06
Total	407	-	-	-	-	-	-

Table 2: Summary of ANOVA for fruit weight (FW), number of fruits per plant (NFP), yield (YD), fruit firmness (FF), soluble solids content (SS), and reproduction cycle (Cycle) for fourteen accessions of mini tomatoes. Goiania, 2021.
DF: Degrees of Freedom; SQ: Sum of Squares; MQ: Mean square; Fc: Calculated F Value, ns, and *: Non-Significant and Significant at 1% probability, respectively.

Among the accessions evaluated, UFG 57 was the one with the highest average weight, with 50.77 g, followed by accessions UFG 50 (38.40 g), UFG 56 (35.33 g), and UFG 49 (32, 83 g) (Table 3). Among the accessions with lighter fruits, UFG 61 and UFG 48 stand out, with 14.97 g and 14.80 g, respectively, inserted within the same grouping by the Scott-Knott test at 5% probability (Table 3).

The comparison between the harvests was carried out to verify how the evaluated traits behave along the productive cycle of the accessions. It is observed that the fruits harvested more at the end of the production cycle have the highest averages for fruit weight (FW), indicating that the mini tomato plants, in general, presented greater productive capacity at the end of their cycle.

Accessions	FW (g)	NFP	YD (kg. ha^{-1})	SS (ºBrix)	FF (N)	Cycle (Days)
UFG 57	50.77 a	85.47 c	35.51 a	5.96 f	6.44 c	108 b
UFG 50	38.40 b	66.67 c	26.88 b	6.12 e	4.95 e	108 b
UFG 56	35.33 c	90.25 c	19.79 c	5.90 f	7.03 c	115 a
UFG 49	32.83 c	118.75 b	18.39 c	5.75 e	5.07 e	115 a
UFG 33	18.70 d	80.60 c	13.09 d	7.72 a	6.13 d	108 b
UFG 48	14.80 e	107.67 b	10.36 e	6.52 c	4.37 f	108 b
UFG 64	9.63 f	191.00 a	6.74 f	7.22 b	3.78 g	108 b
UFG02	20.40 d	60.00 c	14.29 d	7.32 b	8.31 a	108 b
UFG03	19.37 d	114.00 b	13.55 d	6.34 d	7.72 b	108 b
UFG04	16.30 d	79.33 c	11.41 e	5.70 e	6.69 c	108 b
UFG05	11.10 f	205.87 a	7.77 f	7.00 b	5.87 d	108 b
UFG06	18.17 d	185.53 a	12.73 d	5.86 f	5.90 d	108 b
UFG07	19.23 d	61.47 c	13.46 d	7.24 b	8.36 a	108 b
UFG 61	14.97 e	83.20 c	10.48 e	5.76 e	3.66 g	108 b
Average	22.86	109.27	15.32	6.46	6.02	109
CV%	51.90	45.26	50.69	10.89	25.51	2.33

Table 3: Scott-Knott test at 5% probability for fruit weight (FW), number of fruits per plant (NFP), yield (YD), soluble solids content (SS), fruit firmness (FF), and reproduction cycle for different accessions of mini tomatoes. Goiania, 2021.

CV%: Coefficient of variation (%); Means followed by equal letters belong to the same group by the Scott-Knott test at 5% probability.

Table 2 shows no significant differences, at 1% probability, for the number of fruits per plant obtained between plants in the same accession. However, there were substantial differences between the different accessions of mini tomatoes evaluated, as well as for the five harvests carried out (Table 2). This finding is due to genetic differences between the accessions and the physiological state of plants during the harvests carried out. The number of fruits per plant ranged from 61.47 for the UFG 07 accession to 205.87 for the UFG 05 accession (Table 3).

The accessions UFG 05, UFG 64, and UFG 06 have the highest averages with 205.87, 191.00, and 185.53 fruits per plant, respectively, being in the same grouping by the Scott-Knott test at 5% probability (Table 3). Eight accessions are included in the group with the lowest average of fruits per plant by the Scott-Knott test at 5% probability, with accessions UFG 02 and UFG 07, with the lowest averages, 61.47 and 60.00 fruits per plant, respectively (Table 3).

Evaluating different mini tomato hybrids, [18] obtained more total and commercial fruits for the cultivars being assessed, unlike the current work. [13] observed that the genotype greatly influences fruit formation in mini tomato hybrids, influencing the number of fruits formed, as observed in this study.

One of the main traits of tomato improvement is the fruit yield. Thus, an analysis of variance for this trait was also carried out in the different accessions of mini tomatoes. It was observed that there were no significant differences in productivity between plants of the same accession, nor for different blocks, due to uniformity within the same access (Table 2).

Among the five different harvests performed, a statistically significant difference was observed for the number of fruits per plant, as well as for the different accessions evaluated (Table 2). These differences are due to the diverse genotypes in the accessions that make up the tomato collection of the UFG.

The accession with the highest yield was UFG 57 (35.51 kg. ha^{-1}), followed by accessions UFG 50 (26.88 kg.ha^{-1}), UFG 56 (19.79 kg.ha^{-1}) and UFG 49 (18.39 kg.ha^{-1}) (Table 3). Among the accessions with a lower yield, UFG 48, UFG 05, and UFG 64 stand out, with 10.36 kg. ha^{-1}, 7.77 kg.ha^{-1}, and 6.74 kg.ha^{-1}, respectively, inserted within the same grouping by the Scott-Knott test at 5% probability (Table 3).

Despite lower yields, these values are still above the average for the state of Goiás [4]. Within the 14 accessions, there was a yield range from 6.74 kg. ha^{-1} to 35.51 kg.ha^{-1}. Twelve of these accessions had yield values higher than the average for the state of Goiás, which was 8.50 kg. ha^{-1} in the 2017 harvest and 9.40 kg.ha^{-1} in the 2018 harvest [4].

Firmness is one of the main variables studied in post-harvest tomatoes, as it is associated with the time that the fruits will remain physically intact, maintaining their commercial aesthetics. Thus, the firmness analysis of the fruits of different mini tomato accesses was carried out. It was observed that there were no significant differences between plants of the same access and between blocks. In contrast, fruits of different accessions showed considerable variation for this character (Table 2).

The accessions with greater firmness were UFG 07 and UFG 02, with mean resistance of 8.36 N and 8.31 N, respectively, being in the same grouping by the Scott-Knott test at 5% probability. Accessions UFG 48, UFG 64, and UFG 61 presented the lowest firmness, with mean resistance values of 4.37 N, 3.78 N, and 3.66 N, respectively (Table 3). Even considering the lowest firmness values, these were higher than those [23] found when he worked with selection indexes in industrial tomato lines and found maximum fruit firmness values of 3.6 N.

There was also a statistically significant difference in fruit firmness among the five different harvests carried out (Table 2). Thus, the fruits harvested at the end of the cycle, in the fifth harvest precisely, showed increased resistance, on average 6.63 N (Table 3), indicating the plant produces heavier fruit towards the end of its cycle.

The soluble solids content is one of the main traits that must be evaluated in a tomato accession. The great advantage of the mini tomato is that it is delicious and sweet, being consumed as a fruit or appetizer. Traditional tomatoes have a Brix degree between 4 and 6. On the other hand, cherry or grape varieties have enough sweetness reaching between 9 and 12 º Brix, which shows the concentration of total soluble solids represented by the sugar content. This trait makes all difference for mini tomatoes being consumed like grapes around the world, decorating and giving a touch of class to salads [2].

Through analysis of variance (ANOVA), it was observed that there were significant differences in the content of total soluble solids between fruits from different harvests and different evaluated accessions (Table 2). These dissimilarities are most likely due to each accession's genetic makeup and the degree of physiological maturation at the time of harvest. The access with the highest soluble solids content was UFG 33 with 7.72 ºBrix, followed by UFG 02 (7.32 ºBrix), UFG 07 (7.24 ºBrix), UFG 64 (7.22 ºBrix), and UFG 05 (7.00 ºBrix), being these inserted within the same grouping by the Scott-Knott test at 5% probability (Table 3).

The cluster with the lowest concentration of soluble solids was constituted by the accessions UFG 57 (5.96 ºBrix), UFG 56 (5.90 ºBrix), and UFG 06 (5.86 ºBrix). Even these are considered suitable for commercialization since values above 4.50 ºBrix are considered higher than the national average in Brazil.

[20] evaluated 29 mini tomato accessions and observed values ranging from 2.73 to 4.50 °Brix, with an average of 3.66 °Brix. Similar values were observed in 11 mini tomato lines analyzed by [30], ranging from 3.73 ºBrix to 4.95 ºBrix (average 4.22 ºBrix). This was also observed by [12], whose mean value was 4.34 °Brix in cultivar Kyndio. Soluble solids can be influenced by several nutritional factors of the plant, climatic and, mainly, genetic. Regarding productivity, the concentration of soluble solids can be affected by the number of fruits of the plant. When directly related, soluble solids and productivity are inversely proportional, as emphasized by some authors [8,17,26].

Regarding the reproductive cycle time, two clusters were observed by the Scott-Knott test at 5% probability, one with an average duration of 115 days, consisting of accessions UFG 56 and UFG 49, and another group with an average development of 108 days, comprising the other accessions (Table 3). Most cultivars sold by seed companies have a cycle between 95 and 125 days [7]. In this way, all analyzed accessions fall within the average cycle. Cultivars with an early cycle are desirable in breeding programs. They allow the material to remain in the field for a shorter time, subject to lesser effects of biotic and abiotic factors, such as diseases and drought [10].

The comparison between the harvests that can be seen in Table 4 was to verify how the evaluated characters behave along the productive cycle of the accessions. It is observed that the fruits harvested towards the end of the production cycle had the highest means for fruit weight (FW) and fruit firmness (FF). This fact indicates that the mini tomato plants generally presented heavier fruits with greater firmness at the end of their cycle.

Harvests	**FW (g)**	**NFP**	**SS (ºBrix)**	**FF (N)**
Harvests 1	19.17 d	28.42 d	6.39 d	5.71c
Harvests 2	21.46 c	35.17 d	6.32 d	5.73 c
Harvests 3	22.63 b	108.74 c	6.52 b	5.80 c
Harvests 4	23.52 b	223.14 a	6.66 a	6.18 b
Harvests 5	25.37 a	140.02 b	6.47 c	6.63 a
Average	22.43	107.10	6.47	6.01
CV%	10.33%	75.16%	2.02%	6.59%

Table 4: Scott-Knott test at 5% probability for fruit weight (FW), number of fruits per plant (NFP), soluble solids content (SS), and fruit firmness (FF) for the different seasons of harvesting mini tomatoes. Goiania, 2021.

CV%: Coefficient of variation (%); Means followed by equal letters belong to the same group by the Scott-Knott test at 5% probability.

The genotypic and phenotypic correlation was performed to verify which traits are more associated with each other due to genetic influence (genotypic) and genetic interaction with the study environment (phenotypic). As expected, the estimates of the genotypic and phenotypic correlation coefficients, in averages of the accessions, were significant, except for the relationship between the number of fruits x fruit firmness.

The correlation between the characters fruit weight with fruit firmness, fruit weight, and yield, and soluble solids content with fruit firmness were positive and of high magnitude (Table 5). The correlations between the number of fruits and yield, soluble solids content and yield, fruit firmness and yield were negative and of small magnitude.

Yield, in many cases, is associated with plants that produce more fruit. The negative correlation between yield and the number of fruits per plant indicates the opposite in this work. Thus, heavier fruits can explain higher yields in this study, as indicated by the positive correlation between these two traits.

Negative correlations between traits indicate that when selection is made in one of these traits, a high negative correlated response is expected in another, which is a problem since the direction of selection is the same for such traits [25]. Correlations close to zero (null) or negative of small magnitudes, such as fruit firmness and yield (Table 2), demonstrate that selection for these traits in cherry tomatoes can be made independently and without a correlated response. There was a tendency for the genotypic correlation coefficients to surpass those of the phenotypic correlation, demonstrating that genetic factors are more important than environmental factors in expressing these traits in mini tomatoes.

Estimates of selection gains obtained for five traits evaluated by direct and indirect selection are shown in Table 6. Estimates of genetic gains were consistently higher for fruit weight and the number of fruits per plant compared to those of other traits when evaluated by the traditional selection indexes of Smith and Hazel, the basis of Williams and Genotype and Ideotype (Table 6). The direct selection index and the sum of Mulamba and Mock's ranks showed greater gains for weight and fruit firmness. Selection indexes consist of an alternative that makes it possible to perform simultaneous selection efficiently by combining different traits [28].

This is probably due to the higher estimates of the coefficients of variation (Table 3) and the estimates of heritability coefficients (Table 6). Considering the four plants with the best performance, direct selection provided positive gains in almost all traits, except for the number of fruits, ranging between -22.61% and 107.27%. Therefore, the selection performed for these fruit traits provided

Traits	FW (g)	NFP	SS (ºBrix)	FF (N)	YD (kg. ha^{-1})
Genotypic correlation					
FW (g)	1.00	0.161 ^{ns}	0.628*	0.663*	0.575*
NFP	-	1.00	0.371*	0.315 ^{ns}	-0.270*
SS (ºBrix)	-	-	1.00	0.967*	-0.252*
FF (N)	-	-	-	1.00	-0.164 ^{ns}
YD (kg. ha^{-1})	-	-	-	-	1.00
Phenotypic correlation					
FW (g)	1.00	0.162 ^{ns}	0.631*	0.667*	0.579*
NFP	-	1.00	0.372*	0.317 ^{ns}	-0.271*
SS (ºBrix)	-	-	1.00	0.969*	-0.252*
FF (N)	-	-	-	1.00	-0.165 ^{ns}
YD (kg. ha^{-1})	-	-	-	-	1.00

Table 5: Genotypic and phenotypic correlations at 5% probability for fruit weight (FW), number of fruits per plant (NFP), yield (YD), soluble solids content (SS), and fruit firmness (FF) for the different accessions of mini tomatoes. Goiania, 2021.
^{ns} and *: not significant and significant at 1% probability, respectively.

the positive displacement of the mean in almost all to obtain desirable gains. Through direct selection, the best cherry tomato accessions were UFG 57, UFG 50, UFG 02, and UFG 03.

Direct selection was used because it is aimed only at a variable of interest and comprises maximum gains from a single variable regarding the applied selection type. According to how this trait is associated with the others, favorable or unfavorable results may occur in characters of second importance [5].

Regarding the selection indexes, the classic index, proposed by [32] and [14], demonstrated the possibility of obtaining higher gains in weight and number of fruits, with good gains in the other traits, between 25.50% to 50.26%. Through this classic index, the cherry tomato lines UFG 05, UFG 57, UFG 50, and UFG 64 were selected as the best, respectively. The Williams Base Index obtained results equal to the indexes of [32] and [14], as shown in table 6.

The rank-sum index, proposed by Mulamba and Mock, obtained the greatest selection gains in fruit firmness and weight,

Traits	OM	h²	Direct selection		Smith and Hazel Index		Mulamba and Mock Index		Willians Based Index		Genotype-Idiotype Distance Index	
			IM	GS%	IM	GS%	IM	GS%	IM	GS%	IM	GS%
FW (g)	15.14	98.80	31.58	107.27	28.21	85.25	24.96	64.04	28.21	85.25	30.33	99.11
NFP	23.07	99.59	17.83	-22.61	57.50	148.61	21.67	-6.06	57.50	148.61	51.67	123.43
SS (ºBrix)	4.19	100.00	6.25	49.06	6.30	50.26	6.60	57.41	6.30	50.26	6.33	50.85
FF (N)	3.61	99.43	6.73	86.01	4.92	36.06	7.44	105.45	4.92	36.06	6.35	75.39
YD (kg. ha^{-1})	15.32	99.99	22.56	47.25	19.23	25.50	19.20	25.35	19.23	25.50	21.11	37.82

Table 6. Estimates of genetic gains (GS%), the mean from the original population (OM) and mean from the improved population (IM), using direct selection, Smith and Hazel classical index, Mulamba and Mock rank-sum index, Williams base index, and genotype-ideotype distance index (GIDI) in half-sib progenies for fruit weight (FW), number of fruits per plant (NFP), yield (YD), soluble solids content (SS), and fruit firmness (FF) for fourteen accessions of mini tomatoes. Goiania, 2021.

respectively. A negative selection gain for the number of fruits made a simultaneous selection for several traits difficult. Selection gains for the Mulamba and Mock index ranged between -6.06% and 105.45%. This rank-sum index selected cherry tomato accessions UFG 02, UFG 57, UFG 03, and UFG 07 as the best, respectively.

Regarding the genotype-ideotype distance index (GDI), there were positive gains for the traits under analysis. The main interest in this selection was to obtain balanced gains among all traits under evaluation. Genetic gains ranged between 37.82% and 123.43% for yield and number of fruits per plant, respectively. This rank-sum index selected the accesses of mini tomatoes UFG 57, UFG 50, UFG 02, and UFG 05 as the best, respectively.

The accession of mini tomato UFG 57 is the superior genotype, selected through all the selection methods used in this study, proving the superiority of this genotype for all evaluated traits

Conclusion

- The evaluated traits have high correlation values among them.
- The genotype-ideotype distance index and direct selection show the greatest selection gain for the fruit yield and weight.
- The classic index proposed by [32] and [14] and Williams base index have the highest values in selection gains for the number and weight of fruits.
- UFG 57 mini tomato accession is the superior genotype, selected through all direct and indirect selection methods.

Conflict of Interest

Declare if any financial interest or any conflict of interest exists.

Acknowledgments

To the National Council for Scientific and Technological Development (CNPq), for funding the project 423207/2018-0.

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