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ORIGINAL RESEARCH ARTICLE

Selection criteria for tomato lines with defined growth habit

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ABSTRACT

Introduction: The selection of genotypes with determinate growth habit in tomato should contemplate adequate selection criteria to increase the efficiency of the breeding program. **Objective:** The objective of this work was to estimate selection criteria for "chonto" type tomato lines with determined growth habit. **Materials and methods:** This work was carried out at the Universidad Nacional de Colombia (Palmira Campus), in 2016, with seven lines with determinate growth habit and a control with indeterminate growth. Heritability in a broad sense (h^2 g), coefficient of environmental variation, coefficient of genetic variation, selection efficiency and genetic gain were determined in parameters of morphological, phonological, fruit quality, fruit shape and production, using the RELM/BLUP procedure of the SELEGEN software. **Results:** There were three ranges of h^2 g, the first with values of h^2 g greater than 0.76, the second between 0.53 and 0.38, and the third with a value less than 0.38. The highest values of h^2 g were for final plant height with 0.92, plant height at harvest with 0.88, yield per plant with 0.83, days to flowering with 0.83, number of fruits per plant with 0.82, and days to harvest with 0.82. For genetic gain it was found that the control had the highest values for final plant height, plant height at harvest, internode length, days to harvest, harvest duration, soluble solids content, number of fruits per plant, fruit weight and yield per plant; however, in some parameters such as height and phenology for selection by determined growth habit, the lowest values were better. **Conclusion:** There was evidence of genetic parameters that could be considered as selection criteria for "chonto" type tomato lines with determinate growth habit.

Keywords: Plant Breeding; Heritability; Genetic Parameters; *Solanum Lycopersicum*

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1. Introduction

The tomato crop (*Solanum lycopersicum* L.) is widely distributed in the world and represents one of the most consumed foods, due to its traditional participation in the diet and its important intervention in promoting food security[1]. The exploitation of the genetic variability of S. lycopersicum originates from a strong pre-improvement process, in which conservation, characterization and identification of promising genes for genetic improvement programs represent the main components[2–5], which allows the identification of characters of interest that confer adaptation to adverse biotic and abiotic conditions[6,7]. For this, it is necessary to know the genetic parameters that contribute to the identification of traits that can be heritable between generations and that constitute aspects of interest in genetic improvement programs[8,9].

Nowadays, genetic parameters have been estimated within research focused on determining the effect of the genetic component on the expression of a certain trait[10–14], becoming one of the fundamental steps for the selection of promising genotypes for traits of interest[3,15].

Genetic variation can be influenced by additive, non-additive and non-allelic interaction effects; therefore, parameters such as heritability (h^2) indicate how much of the phenotypic expression is associated with the genetic component[16].

The determination of these parameters can be carried out using different methodologies; however, one of the most widely used is the analysis using the RELM/BLUP procedure[17]. This procedure corresponds to a mixed model methodology of great interest for the interpretation of results and possible identification of characteristics with potential for genotype selection[9], in addition, within a breeding program it is essential to estimate variance components and genetic values[18].

A parameter with high heritability and genetic gain can be an important selection criterion and an indicator of the additive genetic component of the trait[19].

The objective of this work was to estimate selection criteria for "chonto" type tomato lines with determinate growth habit.

2. Materials and methods

2.1 Study site

The study was conducted at the Experimental Center of the National University of Colombia, Palmira Campus (CEUNP), located in the municipality of Candelaria, village of Carmelo at 3°25′34″ N and 76°25′53″ E, at 951 masl, department of Valle del Cauca, Colombia, during 2016.

2.2 Plant material

The genetic material corresponded to seven lines of tomato type "chonto", characterized by having "green shoulder", bi or tri-locular fruits, average weight between 70 and 100 g and uniform ripening, mainly[20], with determinate growth habit (D2, D3, D5, D6, D7, D8 and D9), in fourth generation of backcrossing (RC4), plus the commercial control (UNAPAL Maravilla) of indeterminate growth, selected for its desirable characteristics and wide adoption by producers. In addition, there are no low-growing "chonto" cultivars adapted to the region. The lines were obtained by the Vegetable Breeding Research Group of the Universidad Nacional de Colombia, Palmira, from the cross between the commercial variety UNAPAL Maravilla, also created by the Universidad Nacional de Colombia, Palmira, and the Brazilian variety IPA-4, created by the Instituto Pernambucano Agropecuario.

2.3 Genetic parameters

Based on results generated in the research conducted by Burbano and Vallejo[21], genetic parameters were estimated for (1) morphological characteristics: final plant height (FPH), obtained from the average plant height (cm) of the six plants of the useful plot at the end of harvest; plant height at harvest (PHH), was taken from the average plant height (cm) of the six plants of the useful plot at the beginning of this work; stem diameter (SD), corresponding to the average diameter of the main stem (mm) of the six plants of the useful plot; internode length (IL), average measured in the main stem (cm) of the six plants of the useful plot; (2) phenological: days to flowering (DTF), number of days when 60% of the plants in the useful plot presented the first open flower; days to harvest (DTH), days when 60% of the plants in the useful plot initiated the harvest period; harvest duration (HDU), difference between the starting and final day of harvest; (3) fruit quality and format, soluble solids content in Brix degrees (BD), measured in five fruits of the useful plot using the manual refractometer 35HP-Brix scale 0–35°; fruit dry matter (DM) obtained as a percentage by extracting the difference between dry weight and fresh weight in five fruits from the useful plot; fruit diameter (FD) measured in mm, using five fruits from the useful plot; fruit weight (FW), ratio between total fruit weight and the number of fruits harvested per plant in the useful plot; and (4) yields: number of bunches per plant (NB), sum of all bunches produced per plant within the useful plot; number of fruits per plant (NFP), sum of all fruits produced per plant within the useful plot; and production per plant (PP), product of the average fruit weight (kg) by the number of fruits per plant.

2.4 Statistical analysis

The information obtained in this research was analyzed using the Statistical System of Computerized Genetic Selection SELEGEN REML/BLUP (Version, 2014), which uses the RELM/BLUP procedure for variance estimation (REML) and data balancing (BLUP)[17]. Model 20 (Equation 1) was used for the evaluation of genotypes (accessions, cultivars, clones, hybrids, lines and families) in several replications and one observation per plot[17], given that the experiment was developed under a randomized complete block experimental design with three replications[21] and in a single location:

$$y = Xr + Zg + e \tag{1}$$

Where: "y" is vector of data, "Xr" vector of repetition effects added to the overall mean, "Zg" vector of genotypic effects and "e" vector of the error or residual.

The parameters estimated by the analysis corresponded to: Vg: genetic variance, Ve: environmental variance, h^2 g: broad sense heritability, h^2 ml: mean linear heritability, AcL: efficiency of line selection, CVgi%: coefficient of individual genetic variation and CVe%: coefficient of variation associated with environments.

3. Results

The coefficient of variation associated with the environment (CVe%) varied between 2.29 and 18.79%; these values are considered low and show the importance of the genetic component in the expression of the evaluated characters. The highest value was presented in the DM parameter and the lowest in FW. The lowest value of the coefficient of genetic variation (CVg%) was for FW and the highest for PHH, with values of 0.55% and 21.16%, respectively (**Table 1**). Traits with greater individual genetic variation offer a greater possibility of selection in the group of individuals evaluated.

Table 1. Estimation of genetic parameters and residuals of morphological, phenological and productive response variables in "chonto" type tomato lines (*Solanum lycopersicum* L.), in Palmira, Valle del Cauca, Colombia, 2016

Variable	Genetic variance	Environmental variance	Phenotypic variance	Heritability	Linear mean heritability	Selection efficiency	Coefficient of genetic variation	Coefficient of environmental variation
FPH	730.22	83.87	814.08	0.92 ± 0.47	0.97	0.99	20.64	6.99
PHH	597.36	83.76	681.12	0.88 ± 0.46	0.97	0.98	21.16	7.92
LE	1.79	0.58	2.37	0.76 ± 0.43	0.93	0.96	13.72	7.78
SD	0.008	3.69	3.7	0.002 ± 0.02	0.009	0.09	0.55	11.3
DTF	5.68	1.13	6.81	0.83 ± 0.45	0.95	0.98	11.54	5.14
DTH	17.48	3.91	21.39	0.82 ± 0.45	0.95	0.97	5.58	2.64
HDU	4.67	7.33	12	0.39 ± 0.31	0.72	0.85	13.42	16.82
BD	0.05	0.06	0.11	0.42 ± 0.32	0.74	0.86	5.06	5.97
DM	0.53	0.87	1.4	0.38 ± 0.3	0.71	0.84	14.71	18.79
FD	0.0005	0.0007	0.001	0.42 ± 0.32	0.74	0.86	2.12	2.51
NB	2.22	1.93	4.14	0.53 ± 0.36	0.82	0.91	11.16	10.41
NFP	42.48	10.65	53.13	0.82 ± 0.44	0.94	0.97	18.18	%1
PW	4.18	5.36	9.54	0.44 ± 0.33	0.76	0.87	2.02	2.29
PP	511648.6	104691.8	616340.5	0.83 ± 0.45	0.95	0.98	19.56	8.85

Final height plant (FPH), height plant to harvest (PHH), stalk diameter (SD), internode length (LE), days to flowering (DTF), days to harvest (DTH), harvest duration (HDU) soluble solids content in Brix degrees (BD), fruit dry matter (DM), fruit diameter (FD), fruit weight (FW), number of bunches per plant (NB), number of fruits per plant (NFP) and production per plant (PP).

The h^2 g values found were highly contrasted, between 0.002 and 0.92, for the SD and FPH variables, respectively. With the values of h^2 g obtained, the variables were separated into three groups, the first with values of h^2 g greater than 0.76, in which were the parameters FPH, PHH, PP, FD, NFP, DTH and LE, in decreasing order. The second group, with values between 0.53 and 0.38, for NB, FW, FD, BD, HDU and DM; and the third, with values lower than 0.38, in which only the parameter SD was present (**Table 1**). Regarding the selection efficiency for the parameters measured, it was found that the values ranged between 0.09 and 0.99, being the values greater than 0.95 those estimated by the response variables FPH, PHH, LE, DTF, DTH, NFP, PP; while the lowest value corresponded to SD.

Regarding the percentage of genetic gain (GG) (**Table 2**), it was found that the commercial control presented the highest values in all the response variables, with respect to the average of the evaluated population, with the exception of the results estimated in the parameters FD and NB, in which the GG was higher for the lines with determinate growth. One of the parameters of greatest interest in the selection of materials with low plant size is the FPH, in which the highest GG was found in the control with 47%, while lines D5, D2, D6 and D3 had -16%, -13%, -12%, -12%, respectively, indicating that these lines presented lower height with respect to the population average. In the focus of this research, this is favorable, since selection is directed towards genotypes with lower height, in order to reduce production costs. In the GG of PHH, the same behavior was found as in FPH.

Table 2. Genetic gain of genetic parameters and residuals of morphological, phenological and productive response variables in "chonto" tomato lines (*Solanum lycopersicum* L.), in Palmira, Valle del Cauca, Colombia, 2016

Line	FPH	PHH	SD	LE	DTF	DTH	HDU	BD	DM	FD	NB	NFP	FW	PP
D2	-12.73	-15.32	-0.051	-8.15	-8.79	-2.80	1.81	1.10	15.56	0.10	15.29	1.57	-2.59	-2.46
D3	-12.08	-11.79	-0.008	-4.59	-1.87	-5.01	5.16	-1.10	-6.26	-1.35	-0.40	10.11	-1.69	7.25
D5	-16.02	-15.03	-0.032	-5.30	-19.17	-5.54	7.39	-1.10	11.99	-1.10	8.37	12.94	-0.20	12.12
D6	-12.21	-13.65	-0.001	-4.12	-1.87	-5.01	5.16	-1.54	-0.89	-0.77	10.22	12.39	-1.32	9.04
D7	1.29	3.63	0.051	-2.46	7.35	4.46	-17.15	-2.42	-10.91	2.69	-10.41	-23.25	0.31	-23.80
D8	1.90	4.76	-0.024	-4.83	0.43	2.57	-9.34	-2.86	-19.86	1.39	-9.02	-20.07	1.62	-19.48
D9	3.27	0.41	0.006	-2.93	5.04	2.25	-10.46	-2.42	-l.25	1.78	-10.10	-16.68	1.75	-15.46
T	46.59	46.98	0.058	32.39	18.88	9.20	17.43	10.35	11.63	-2.73	-3.94	23.00	2.12	32.80

Final plant height (FHP), plant height to harvest (HPH), stalk diameter (SD), internode length (LE), days to flowering (DTF), days to harvest (DTH), duration of harvest (HDU), content of soluble solids in degrees Brix (BD), fruit dry matter (DM), fruit diameter (FD) fruit weight (FW), and number of bunches per plant (NB), number of fruits per plant (NFP), and production per plant (PP).

The SD parameter presented the lowest genetic gain (GG), probably because it is a variable affected by environmental conditions and because the variation between genotypes of different growth habit was not contrasted. While for LE, the control presented the highest GG with 32%, compared to the mean of the entire population evaluated.

When analyzing the phonological variables, the period necessary to reach flowering is of great interest, because it is a characteristic that conditions the precocity of the species to reproduce, in this case to advance in the fruiting process. In this research it was found that the control presented the highest GG with 19%, being the latest genetic material to flower, while lines D5, D2, D3 and D6, had negative values, indicating their greater earliness with respect to the population with -19%, -9%, -2% and -2%, respectively. For DTH, in which genetic gain values were low, the control presented the highest value with 9%, being the latest genotype, while the lowest percentage of GG was obtained by the same determined growth lines mentioned above. In this phenological parameter, a higher earliness is of great interest. In HDU, a low GG was found in the lines evaluated, with respect to the control, which presented the highest value with 17%. This parameter is of interest because it allows to concentrate harvesting work, increasing efficiency and avoiding possible losses due to biotic and abiotic conditions.

For the parameters of fruit quality and shape it was found that, in BD, the control had the highest value of GG (10%), surpassing the lines of determined growth habit; while for fruit dry matter (DM) the highest value was obtained by line D2 (16%), followed by line D5 (12%), which had the same result as the control. Fruit diameter did not present contrasting values, because all the genetic materials used were lines with "chonto" type fruit format. For FFB, it was found that the lines of determined growth D8, D9 and the control presented a low GG of 2%.

Regarding yield components, the number of clusters (NB) showed a behavior of interest for GG, because D2 (15%), D6 (10%) and D5 (8%) outperformed the control (-4%), possibly due to the fact that the low bearing plants presented a concentrated harvest and were able to express their productive potential in a single period, while the indeterminate habit continues its cluster production process in a prolonged manner. In NFP, the highest GG was found for the control with 23%, followed by lines D2, D6 and D5, with 15%, 10% and 8%, respectively. Finally, in terms of production per plant, it was found that the plants with the greatest height, represented by the control, achieved the greatest genetic gain, followed by lines D5 and D6, with 33%, 12% and 7%, respectively.

4. Discussion

Results of interest were found regarding h^2 g, since it is suggested that values higher than 20% are important as selection criteria[22] and within this range were all response variables with the only exception of SD, which corresponded to the lowest value. In addition, high values of h^2 g and GG were also related to high selection efficiency[23,24]. Thus, the selection of these lines, with determined growth habit, can be supported by the use of other morphological, phenological, fruit quality and format and productive criteria[3,21].

The determination of genetic parameters is of great interest for the selection of genotypes in breeding programs[9]. Regarding the morphological component parameters, such as SD, the lowest h^2 g was found with 0.002, probably due to the fact that it is a characteristic influenced by the environment[25,26], a similar response for this character was reported by Peralta, *et al.*[27] in advanced tomato lines. Another morphological parameter quantified was LE, a characteristic that evidenced a high CVg%, probably due to the existing differences between plants with contrasting growth habits, in addition, this characteristic is a differential attribute, from the genetic point of view, being the internodes shorter in plants of low bearing or determined growth habit[2].

Plant height (FPH and PHH) is considered a parameter of great interest in tomato breeding programs[24], and can be affected by genetic and environmental factors[3]. If growth habit is taken into account as a determinant of plant height, it is reported that this condition is mainly governed by a recessive gene in homozygous state (self-pruning, spsp) for the given growth habit[3,28–30]. In this study the highest values of h^2 g were determined for FPH 0.92 and for PHH 0.88, which, in turn, allowed determining high GG that could relate these parameters to additive type genes[24], therefore, it could be considered that selection by growth habit is feasible considering plant height as an indicator. In tomato hybrids, values of 0.90 of h^2 g have been determined[31], meanwhile, Kumar, *et al.*[24] reported a GG value of 63.36% for plant height in tomato genotypes. The CVg%, obtained in these parameters, was among the highest when compared with the result of the other response variables this may be due to the fact that within the evaluated population were genotypes with determinate and indeterminate growth habit. On the other hand, it is also worth mentioning that plant height, without considering the type of growth habit, has been reported as a parameter or quantitative descriptor, which can have a h^2 g greater than 0.50[15].

The period required to initiate flowering (DTF) presented a low CVg% (11.54), and a high value for h^2 g (0.83), related to a high estimated selection efficiency, suggesting that it could be considered as a promising selection criterion. The h^2 g obtained was lower but comparable with what was found in an evaluation of tomato hybrids, where values of 0.96 were found[31,32], however, Nuez[2] mentioned that earliness in the flowering period is higher in cultivars with determinate growth habit, which has also been supported by Burbano and Vallejo[21]. For DTF, GG values of 19.8%[32] and 19.9%[10] have been reported in evaluation of tomato hybrids and in genetic materials from a germplasm collection, respectively, values similar to that recorded by the control in this study.

The parameter days to harvest (DTH) presented a CVg% of 5.58, being a low value, which allows inferring that the lines did not vary much in terms of this trait and that the environmental effect was reduced in this trait, which allowed a reliable estimate of h^2 g (0.82) suggesting that it is a trait associated to the genetic component. In general, reports of h^2 g are high for this parameter, on the order of 0.98[32] and 0.96[31], estimated from the duration (HDU), a parameter considered of interest, depending on the approach and type of crop, in the case of industrial type crops, a short harvest duration increases labor efficiency and possibly reduces production costs by reducing expenses in materials, inputs and labor. In this way it could be considered a selection criterion, however, in this research the value was low for h^2 g, which does not agree with other evaluations in which a value of 0.76 was obtained, indicating a good participation of the genetic component in this parameter[24], however, the h^2 g given by the particular selection of lines does register at 0.72, which is high. Neuze[2] mentioned that short duration may be a trait of genetic materials of particular growth habit. HDU is a characteristic that is related to the type of plant, because cultivars with determinate growth habit are characterized by a short harvest period[33], therefore, selection would focus on lines with lower GG[3]. Some authors reported GG of 5.20% for the fruit formation period[32], which indicates that this parameter has also presented low values in other investigations.

In general, the selection of the control marks a higher GG in most of the estimated parameters, while for the lines, for the most part, they presented negative GG values, which is consistent when taking into account the contrasting differences between cultivars with indeterminate and determinate growth habit[2,3,21]. Similar GG was found in another investigation where the value was 25.29 for DTH and 17.79% for HDU[24]. A preliminary inference allows cataloging these phenological variables as traits of interest in the selection of improved genetic materials.

The soluble solids content BD, presented an intermediate value of h^2 g with 0.42, which indicates an interesting genetic influence in this research, despite the fact that this characteristic may be affected by multiple physiological and environmental conditions[34], as well as growth characteristics, given that cultivars with indeterminate growth may present higher BD values than low bearing plants[35]. For this parameter, values of h^2 g from 0.55[36] to 76.29% have been determined, with low GG[24]. On the other hand, DM presented evaluation of tomato hybrids. Meanwhile, harvest low h^2 g and high CVe%, suggesting influence of environmental factors, however, in terms of GG the lines D2 (16%) and D5 (12%) were higher and equal to the control (12%), which is favorable in the selection of lines with determined growth habit.

The FD and FW parameters are important characters to differentiate the type of tomato, the latter in a weight range for “chonto” type tomato fruits between 80 and 180 g[21] and both represent variables of interest within the yield components. For the FD parameter there is a marked environmental influence, determining an intermediate h^2 g (0.42), which is between values reported by other authors for this genetic parameter from 0.23 to 0.66[27,36]. Meanwhile, the FW presented a CVg% of 2.02, probably due to the fact that the genetic materials evaluated share genetic information[21] and their fruit format is within the range established for the “chonto” type fruit. The h^2 g was intermediate, indicating that this character may be influenced by the genetic and environmental component or other gene-gene interaction effects. The environmental effect on this parameter was also reported in the research of Ahmad *et al.*[37], who found a value of 0.24 for the h^2 g of this character, indicating a low influence of the genetic component on this trait. Falconer and Mackay[23] suggested that traits with such levels of h^2 g may be related to polygenic effects.

Production per plant (PP) corresponded to one of the parameters of greatest interest for improvement. In this analysis it was found that the CVg% was one of the highest (8.85%) when compared with the value of the other traits measured in this research, this is probably due to the fact that this is a polygenic trait, in addition to the fact that lines of different growth habit were evaluated. The h^2 g was high (0.83%), indicating a high genetic influence on this parameter, according to what was reported in tomato hybrids with h^2 g values of 0.87[16,31], however, the same authors mentioned the difficulty to improve in terms of this parameter, due to the influence of other factors, such as the inverse association between number and weight of fruits. Regarding the GG of the lines with determinate growth, lower values were found than the control, as has been reported when comparing cultivars with different growth habits[2,3]; however, it is necessary to analyze the production costs in the two types of plant, in order to know the cost-benefit relationship.

The NFP presented a high h^2 g (0.82), which is considered highly heritable according to the evaluation; however, it is lower than that reported by Vallejo and Lobo[16] and Ramzan *et al.*[13] in tomato hybrids, with values of 0.93 and 1.00, respectively. This productive parameter presented an intermediate GG for the control, followed by lines D5, D6 and D3, which highlights the participation of plants with lower height. This result differs from the 92.11% found in another research[24], however, this depends on the type of population evaluated.

Finally, for the number of bunches per plant (NB) an intermediate h^2 g was found, whose value was lower than that reported for tomato hybrids (0.94)[13], however, it should be considered that in the present work the estimates were based on line evaluation. An intermediate value of CVg% (11.6%) was estimated, showing that variation was present within the "chonto" tomato lines with determinate growth and the indeterminate control. Some authors reported a GG of 3.17% for the number of fruits per bunch[32], while another report mentions a high value of 80% GG, which could be due to the fact that the productive behavior was very contrasting when coming from a germplasm collection[10], unlike this research in which the lines were advanced and homogeneous. This allowed evidencing the important productive potential of these lines, since, despite their lower production, they can present benefits in terms of lower labor requirements, tutoring, materials and agricultural inputs, which are grouped within production costs, as mentioned in other researches[3,21].

5. Conclusion

Selection criteria based on morphological, phenological and productive parameters, such as plant height, internode length, days to flowering, days to harvest, number of fruits per plant and plant production, may be of interest for the selection of tomato genotypes with determinate growth habit, due to their high h^2 g. In addition, in the tomato lines used in this research, the negative genetic gain for plant height was a favorable indicator for obtaining low-growing plants, as evidenced in lines D2, D3, D5 and D6, despite the lower genetic gain in yield per plant.

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Conflict of interest

The authors declare that they have no conflict of interest.

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