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Assessment of 112 tomato (*Solanum lycopersicum* L.) cultivars for industrial processing in Portoviejo, Ecuador

Evaluación de 112 cultivares de tomate (*Solanum lycopersicum* L.) para procesamiento industrial en Portoviejo, Ecuador

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Abstract

Tomato (*Solanum lycopersicum* L.) processing industry requires varieties with increased production and quality, and also with resistance to pest, in order for producers to cultivate these. The aim of this study was to carry out an evaluation of 112 tomato cultivars for production and quality characteristics from the following providers: Orsetti Seed, Heiz Seed, Ohio University, United Genetic and Harrys Moran. The experiment was conducted at the Experimental Research Station Portoviejo of INIAP. Statistical analyses used were principal components analysis for a group of 112 cultivars based on production parameter: yield ($t.ha^{-1}$), average fruit weight (g), number of fruits per plant, defective fruits per plant; in addition to quality parameters as: brix degrees, pH, and acidity. Data were analyzed through an analysis of variance and a Tukey test to establish statistical differences and significance ranges among industrial tomatoes. Results showed that ca. 9 % of the total tomato varieties assessed showed superior characteristics. Five statistical significance ranges were detected, where the first three were materials developed by Ohio University. The best material evaluated was the cultivar SG 07-627, and all materials showed diverse resistance to pests, with potential for genetic breeding as part of an integral pest management strategy for tomato.

Key words: Variability; production; quality; paste; food processing; breeding program.

Resumen

La industria de procesamiento de tomate (*Solanum lycopersicum* L.) requiere cultivares con producción y calidad superiores, además de resistencia a plagas, para que los productores prefieran sembrar estos cultivares. La presente investigación se efectuó con el objetivo de evaluar 112 materiales en relación a parámetros de producción y calidad, provenientes de los siguientes proveedores: Orsetti Seed, Heiz Seed, Ohio University, United Genetic y Harrys Moran. El experimento se realizó en la Estación Experimental Portoviejo del INIAP. Para el análisis estadístico se emplearon metodología de análisis de componentes principales para la agrupación de 112 cultivares basados en parámetros de producción como: rendimiento ($t.ha^{-1}$), peso promedio de fruto (g), número de frutos por plantas, número de frutos defectuosos; y además los parámetros de calidad son: grados brix, pH y acidez. Los datos se analizaron mediante análisis de varianza y pruebas de Tukey para establecer diferencias estadísticas y rango de significancia entre tomates industriales. Los resultados mostraron que cerca del 9 % de los materiales evaluados presentaron características superiores. Cinco rangos de significancia estadística se encontraron, donde los tres primeros fueron representados por los materiales desarrollados por la Universidad de Ohio. El mejor material evaluado fue el cultivar SG 07-627, y todos los materiales presentaron distintivos de resistencias a plagas, con potencial para el mejoramiento genético como parte de la estrategia de manejo integral de plagas en tomate.

Palabras clave: Variabilidad; producción; calidad; pasta; procesamiento de alimentos; programa de mejoramiento.

Introduction

In 2013, global fresh tomato production for the processing industry was ca. 163.9 million tons, with an estimated production area of 4.7 million hectares and an average yield of 34.70 t.ha^{-1}. China is the largest tomato producer worldwide with an estimated yield of 50.60 t.ha^{-1} on an area of 984600 ha with an average production of 51.40 t.ha^{-1} (FAOSTAT, 2015). In Ecuador, tomato paste imports were 5072 t in 2010, decreasing slightly to 5010 t in 2011, then increasing for the next three years (5319 t in 2012, 5388 t in 2013, and 6278 in 2014) and decreasing again to 4629 t in 2015 (BCE, 2015); however, domestic production of industrial tomato showed a clear deficit.

High consumption of fruits and vegetable, including tomato and its derivatives, has great positive benefits on consumer health. Tomato paste is one of the most important consumption products worldwide (Xaplanteris, Vlachopoulos, Pietri, Terentes, Kardara, Alexopoulos… & Stefanadis, 2012). Moreover, weather conditions, fertilization, production systems, irrigation and the development state of the plant at harvest time are considered among the factors that affect chemical composition quality in tomato production (Casierra-Posada & Aguilar-Avendaño, 2008). Moreover, fruit quality refers to a set of physical and sensory attributes as well as their chemical composition. Flavor, texture and aroma attributes should be considered as a whole in vegetables (Moretti, Mattos, Calbo & Sargent, 2010). This information is of utmost importance to meet consumer needs as well as to enable a genetic selection of new cultivars and practices that optimizes production and postharvest handling skills for tomato (Graça, Amaral, Rodrigues, Gonçalves, Sudré, Vivas & Melo, 2015).

Many tomato components are stabilized by acidity, pH of fruit tissues and several nutrients which are conserved only for a short time and if processing is mild. During transport and storage, intact fruits and vegetables are prone to many different variables that could damage them, as harmful changes due to respiration, metabolism and enzymatic action as well as desiccation, diseases, microbial damage and temperature which stimulates wound formation. Many of these changes affect the tomato antioxidant status (Capanoglu, Beekwilder, Boyacioglu, De Vos & Hall, 2010), and thus, its quality.

Furthermore, hybrids are more productive than pure lines and open-pollinated populations, because there is a greater efficiency in genetic improvements. Thus, using tomato hybrids is reasonable considering the advantages these provide to producers and consumers, in relation to their high productivity, earliness, fruit quality and greater pest resistance (Schwarz, K., Resende, J. T. V., Preczenhak, A. P., Paula, J. T., Faria, M. V. & Dias. 2013). Tomato is a self-pollinating species and its genetic base becomes narrower along the domestication processes. Therefore, the strategy to prevent intra-population reproduction leads to genetic gain in crop improvement (Souza, Paterniani, de Melo & de Melo, 2012). In this regard, genetic variability recombination is an excellent alternative to obtain plants with superior characteristics (Maciel, Maluf, Silva, Gonçalves, Nogueira & Gomes, 2011).

In this sense, it is important to increase the genetic variability of tomato that will be used for industrial tomato paste processing in the Experimental Station of Portoviejo (EEP) of Instituto Nacional de Investigaciones Agropecuarias (INIAP) through a genetic improvement program aimed at finding tomato cultivars resistant to high temperatures and tropic humidity. Every genetic breeding program starts with massive germplasm introduction from different sources, in order to evaluate and identify cultivars to be used as possible parental material. The aim of this study was to evaluate production and quality parameters of 112 industrial tomato cultivars originating from U.S. tomato seeds distributors: Orsetti Seed, Heiz Seed, Ohio University, United Genetic and Harrys Moran. Furthermore, this study will be used to establish an Industrial Tomato Program in EEP-INIAP, located in a tropical dry forest climatic zone in the province of Manabí, Ecuador.

Materials and methods

Study area

This research was conducted between May and November 2015 in the EEP-INIAP, located at km. 13, Portoviejo-Santa Ana route, in El Cady, Columbus Parish, Canton Portoviejo, with the following geographic coordinates: latitude 0.1° S, and longitude 80° 23' W. EEP is located at 47.40 m.a.s.l., has an annual average temperature of

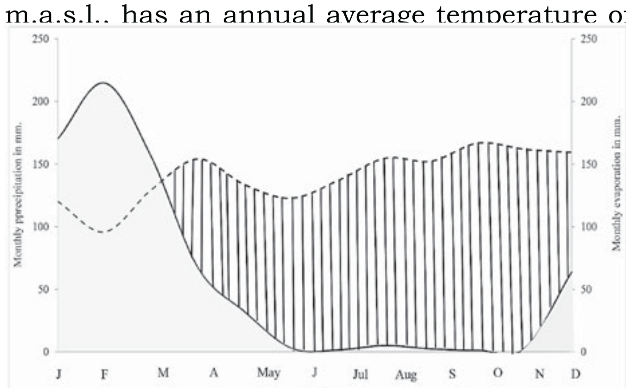

Figure 1. Water Balance - Experimental Station Portoviejo, Ecuador

Solid line represents average precipitation while the dashed line symbolizes evaporation rate; the hatched area shows the water deficit in the study area from 2008-2015.

Industrial tomato varieties

In this research, 112 tomato cultivars were assessed for paste production from different tomato seed distributors in the U.S.A. These cultivars were distributed as follows: 1.67 % Harrys Moran, 8.33 % Orsetti Seed, 13.33 % United Genetics, 16.67 % Heiz Seed, and 60 % Ohio University. The basic statistics for the parameters evaluated are summarized in Table 1.

Table 1. Productive and quality parameters, variables, and mean and standard deviation of 112 industrial tomato cultivars assessed in EEP

Parameters	Variable	Values
Production	Fruit weight in kg (25 fruits)	2.19 (± 0.44)
	Average weight per fruit (g)	87.72 (±17.73)
	Number of fruits per plant	211.65 (± 89.08)
	Number of defective fruits	106.00 (± 47.66)
	Yield (t.ha-1)	30.39 (± 14.40)
	Disease resistance	0.62 (± 0.23)
	Insect resistance	0.75(± 0.34)
Quality	°brix	3.15 (± 0.81)
	pH	4.35 (± 0.16)
	Acidity	6.51 (±1.58)

Crop management and production data collection.

In May 2015, the research started with the germination of 112 tomato cultivars, using germinating trays of 162 cavities, peat as a substrate and one (1) seed per well; transplantation was carried out 20 days after sowing with 1.5 x 0.4 m spacing, in order to obtain a population of at least 16,666 plants per hectare. Twenty g.plant^{-1} of fertilizer was applied with a mix of urea, 8-2-20 and 0-0-60, in a 2-1-1 relation five days after the first application. The second fertilization was applied with ammonium sulfate, potash muriate and calcium nitrate in a 1-1-1 relation after 35 days; finally, a third fertilization using magnesium and YaraMila® was applied after 50 days. Fertilization was supplemented with foliar fertilizers, according to the recommendations of the Department of Soil and Water Management of EEP.

Additionally, a drip irrigation system was installed applying irrigation three hours per plant three times a week. A plastic cover (mulch) was used, and the weed control requirements were minimal. Harvesting was carried out manually in a single pass, when fruits were 75% mature.

Sixteen plants from all the cultivars assessed were planted until at least six plants per net plot were obtained. Twenty-five (25) ripe fruits of each cultivar were weighed with a precision balance in order to compute average fruit weight. Total number of fruits from these plots were counted and averaged. In addition, number of affected fruits by pests, diseases, those that were green and had imperfections were also registered. During harvesting, total fruits per each net plot were weighed, and production was established in t.ha^{-1}.

Tomato quality analysis

Tomato samples were analyzed according to total soluble solids (TSS), percentage of acidity, pH, and ascorbic acid according to procedures described by AOAC (2007). TSS of tomato paste was estimated using a refractometer (ATAGO 3T) and readings were corrected to 20°C, while pH was measured using a pHmeter (Orion 420 A +) (AOAC, 2007).

Statistical Analysis

Principal components analysis

A principal component analysis (PCA) was used to reduce the number of variables (10) and to find those with greater weight. A type of varimax rotation axe was performed and correlations were identified among component variables (Bortz, 2010).

Cluster and canonical discriminant analyses

A cluster analysis was performed for the group of industrial tomato varieties with similar characteristics. Distances between each pair of observations were sized using the Gower methodology, which allows working with different kind of variables and standardizing them according to their rank (Bortz, 2010). The cluster analysis was assessed by the Wald minimum variance methodology, pseudo t^2 test and the distance matrix in order to choose the appropriate number of variables. In addition, a canonical discriminant analysis was executed to find the responsible variables of group formation. Distance between combination pairs was computed in order to observe similarities using the Wilks Lambda test, in order to address the equality hypothesis between clusters. These analyses were carried out with the SPSS program version 21.0 for Windows.

Correspondence analysis

A correspondence analysis was performed in order to associate production and quality characteristics of resulting clusters from the discriminant analysis. Its advantage lies in the generation of two-way tables, based on the Chi-square test associated with orthogonal components (Bortz, 2010); moreover, these analyses were also carried out with the SPSS Statistics 21 software (analytical software, New York, USA).

Results

Classification of 112 tomato cultivars

According to Bortz (2010), the variables with coincidences greater than 0.70, are acceptable to the PCA interpretation. From 10 variables proposed in the methodology, 30% were deleted, including pest resistance variables. Table 2 shows the commonalities of selected variables.

Table 2. Selected variable commonalities prior to PCA for industrial tomato characteristics in EEP

Variables	Extraction
Fruit weight (kg per 25 fruits)	0.998
Fruit weight average (g)	0.998
Number of defected fruits	0.978
Yields (t.ha^{-1})	0.978
°brix	0.800
pH	0.886
Acidity	0.747

Two clusters from the PCA explains 93.98 % of the total variance. The distance matrix for the cluster analysis was generated with seven (7) selected variables. The t^2 pseudo test suggested creating three clusters (Table 3). The first one grouped 24.11 % of tomato cultivars, the second one 51.78 % and the third one 24.10 %.

Table 3. Generalized distance matrix to the squared D2 (ij) between pairs of clusters

Clusters	1	2	3
1	0		
2	245.82	0	
3	91.12	59.33	0

The discriminant analysis based on the combined covariance matrix of the 10 variables evaluated, according to the Lambda Wilks multivariate test, showed highly significant differences between clusters (P = 0.0001), rejecting the null hypothesis of no difference between clusters. Two canonical variables were obtained from the discriminant analysis; the first function (going from left to right) had a greater weight in characteristics which allow identifying production attributes such as number of fruits per plant, number of defective fruit, disease resistance and yield. The second function was related to quality parameters as ° brix, pH and acidity, from bottom to top of Figure 2.

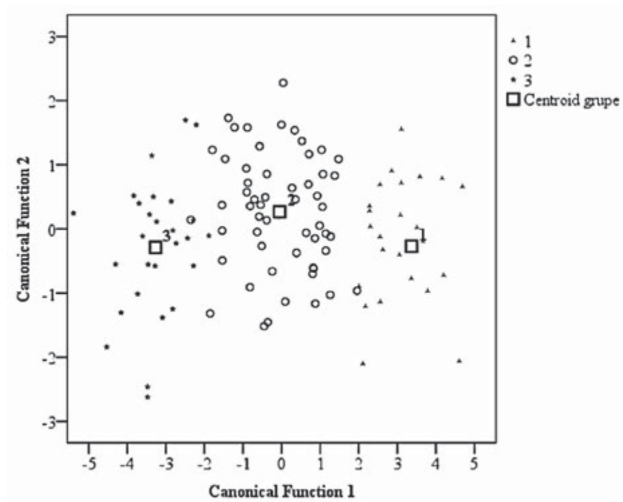

Figure 2. Relationship between clusters (industrial tomato cultivar groups) in relation to the canonical function1 and 2 in EEP.

Three groups of industrial tomato cultivars were classified. Cluster 1 is characterized by high yield and low quality fruit. The second cluster showed average yield and quality. In addition, the third cluster was classified by low production and better quality properties for industrial tomato (Figure 2).

Industrial tomato characterization

Tomato production

Figure 3 shows the asymmetric map of highest production tomatoes (24.11 %) obtained from the discriminant analysis. The first inertia dimension shifted the 56.70 % of the total variance, separating the number of defective fruits to the left, from yield, average fruit weight, average weight in kg, associating higher production with the seed supplier company (Ohio University).

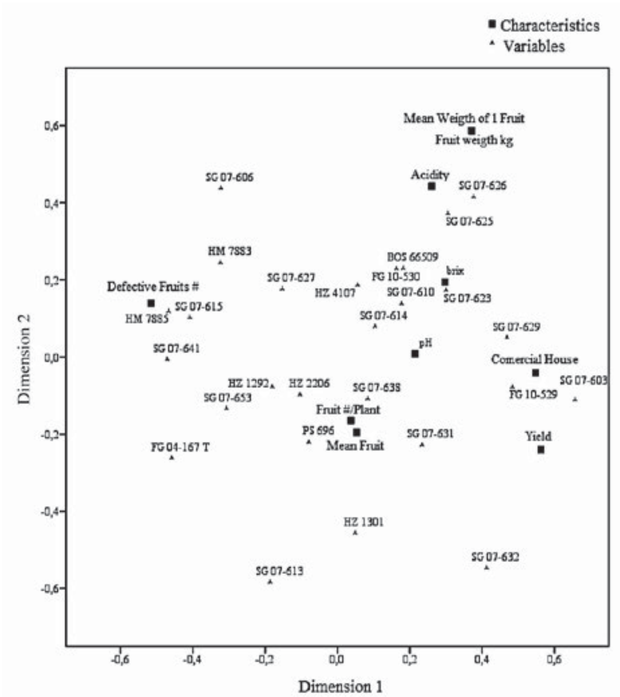

Figure 3. Asymmetric map for higher-yielding tomato cultivars and their characteristics in EEP.

The second dimension of the asymmetric map clarified the inertia to 26.9 % and contrasts yield, fruits per plant, number of fruits per plant with defective fruit number and quality variables, such as pH, ° brix and acidity. Cultivar SG 07-632 stood out with an average yield of 68.58 t.ha^{-1}, 72.73 g of average fruit weight, and a production of 72.20 (± 8.39) fruits per plant, followed by cultivar SG 07-627 with an average yield of 64.40 t.ha^{-1}, 98.18 g (± 8.39) average fruit weight and a production of 50.20 (± 10.45) fruits per plant. Moreover, cultivar SG 07-603 was placed third, showing an average yield of 61.60 t.ha^{-1}, an average fruit weight of 94.55 g, and a production of 61.78 (± 7.13) fruits per plant.

Tomato Quality

The asymmetric map of the group with quality features obtained from the discriminant analysis (24.10 %) is shown in Figure 4. The first dimension explains 69% of inertia, where features from average defective fruits oppose with tomato quality properties. The second dimension contributes with 14.70 % of total inertia, contrasting yield with tomato quality characteristics for tomato paste.

The cultivar UG 10109 stood out with a production of 13.00 t.ha^{-1}, 5 °brix, pH of 4.22, and an acidity value of 10.70. Moreover, cultivar UG 16609 was located in second place with a production of 10.20 t.ha^{-1}, 5 °brix, a pH of 4.12 and an acidity of 9.80. Finally, cultivar UG 1103913F has a production of 5.10 t.ha^{-1}, 4 °brix, a pH of 3.97, and an acidity of 10.10. All these materials came from United Genetics.

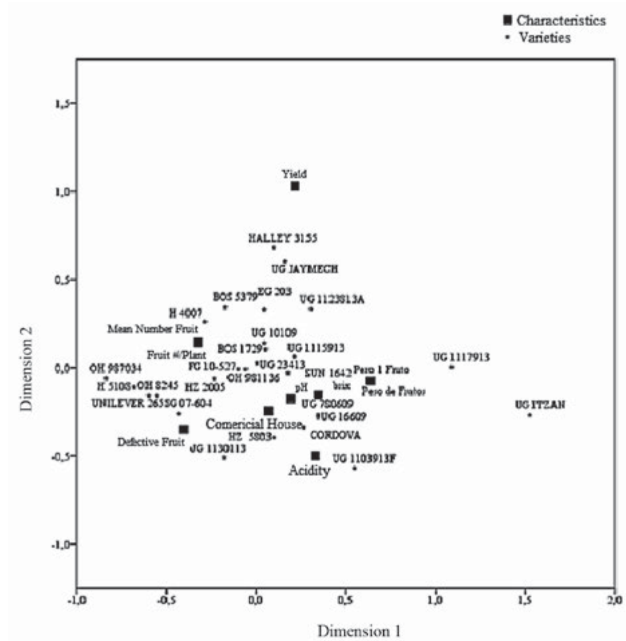

Figure 4. Asymmetrical map for tomato cultivars of better quality and their characteristics in EEP.

Discussion

Production characterization

Fertilization and irrigation is especially important for tomatoes that will be used for paste production, as imbalances from water stress and moisture can lead to reduced production. These conditions were not observed during the experiment carried out in EEP. Industrial tomatoes originated in Ohio University were those that showed highest productions. Cultivar SG 07-632 had a production of 68.58 t.ha^{-1} and was ranked in the first place, followed by cultivar SG 07-627 with an average production of 64.40 t.ha^{-1} and cultivar SG 07-603 with 61.60 t.ha^{-1}. Figueiredo, Resende, Faria, Paula, Rizzardi & Meert (2016), when carrying out an agronomic evaluation of industrial tomatoes found that the best yields were obtained from hybrids RVT-07 x RVT-10 (77.05 t.ha^{-1}) and RVT-02 x RVT-03 (70.65 t.ha^{-1}). These results contrast with production values reported by Giordano, Fonseca, Silva, Inoue-Nagata & Boiteux (2005), who recorded 107 t.ha^{-1} of tomato for industrial purposes. On the other hand, tomato paste yield values assessed in this research were even above the industrial tomato production values reported in India, with an average of 14.16 $t.ha^{-1}$ and also compared to a world average of 34.70 $t.ha^{-1}$ (FAOSTAT, 2015)

Likewise, Figueiredo *et al.* (2016), on a genetic improvement study carried out for industrial tomatoes in Brazil found that no hybrid exceeds the hybrid test called Tinto, which showed fruit weight of 104.40 $g.fruit^{-1}$. However, plant materials used in this study were lower to those shown by cultivar SG 07-632 from Ohio University, with an average of 73.73 g, and lower to cultivar SG 07-627 with 98.18 g (Ohio University).

In relation to production parameter as fruits per plant, according to the study conducted by Santos, Melo, Santos, Carvalho Filho & Menezes, (2014), in general, high fruit production per plant should not be considered as the best production parameter, because most of these fruits become small on the same plant, reducing fruit quality and production. Under this consideration, in this study variation in fruit production per plant for the higher production group was 72.20 fruits per plant. However, studies published by Santos *et al.* (2014), reported a production of 96.15 fruits per plant under greenhouse conditions, and 57.89 fruits per plant under field conditions. These values are higher than those registered for tomatoes in Brazil used for industrial purposes (Giordano *et al.*, 2005). However, cultivar SG 07-627 showed values of 50.20 fruits per plant and cultivar SG 07-603 displayed 61.78 fruits per plant, which showed to be below the data registered in Brazil (Giordano *et al.*, 2005). This could be due to stress caused by high temperature in different tomato crop environments as this reduces the production of pollen grains in susceptible tomato genotypes (Santos *et al.*, 2014).

Evaluation of fruit quality

We must state that industrial tomato cultivars assessed in this research have been exposed to tropical dry forest conditions, with high temperatures and increased levels of carbon dioxide (CO_2) in the atmosphere. Changes in CO_2 concentration related to environmental temperature can alter plant tissues in terms of growth and physiological behavior. Many of these effects have been studied in detail for tomatoes under cultivation (Moretti *et al.*, 2010). Exposure of tomato fruits to temperatures above 30°C inhibits many normal fruit ripening parameters, including color development, sagging, respiration radios and ethylene production (Santos *et al.*, 2014).

Production of the cultivars with the highest fruit qualities were those that showed lowest production. Thus, the cultivar UG 10109 produced 13.00 $t.ha^{-1}$, cultivar UG 16609 showed a yield of 10.20 $t.ha^{-1}$ and cultivar UG 1103913F was the lowest yield producing cultivar with only 5.1 $t.ha^{-1}$. These production values can be compared with hybrids studied by Figueiredo *et al.* (2016), who found the following production values: RVT-01 showed 35.17 $t.ha^{-1}$, RVT-02 showed 40.13 $t.ha^{-1}$ and RVT-09 showed 40.35 $t.ha^{-1}$, which are all placed in the same statistical significance range.

Likewise, pH is an extremely important factor for product acceptance level analysis by consumers, given that excessively acidic fruits are rejected by them (Casierra & Aguilar, 2008). According to Hernández Suárez, Rodríguez & Romero (2008), tomato is considered acid if it has a pH of less than 4.5. However, all assessed materials in this study with better quality characteristics obtained from the United Genetics home provider, were classified as acid. On the other hand, high temperature in tomato crops leads to low amount of citric, malic and oxalic acid, in contrast to high amounts of ascorbic acid, fructose, glucose and sucrose synthesis.

On the other hand, high increases in temperature allow fruit growth and coloration during their development (Moretti *et al.*, 2010). These conditions were observed during this research.

Tomato flavor is generally determined by soluble solids content, acidity (measured as entitled acidity) and the presence of several volatile flavors. Moreover, some ethereal flavors are generated through enzymatic catalytic reactions (Wang, Sun, Feng, Cao & Jiang, 2008). However, the volatile flavors were not analyzed in this study. Average of cultivars with highest fruit quality was 3.62°brix (± 0.96). The best industrial tomato cultivars were as follows: UG 10109 with 5°brix, UG 16.609 with 5°brix, and UG 1103913F with 4°brix. These values were however, above the values found for the RVT-08 line studied by Figueiredo *et al.* (2016), who registered the highest value of 4.90°brix in their experiment with industrial tomatoes.

Furthermore, tomato juice with ca. 4 to 6°brix is a requirement for long-term tomato paste storage, which influences taste, pulp production and finally the price paid for this raw material (Barrett, Weakley, Diaz & Watnik, 2007). Hannan, Ahmed, Roy, Razvy, Haydar, Rahman,... & Islam (2007), during their study about heterosis, combined ability and genetic over °brix, number of days of first fruiting and production, and observed additive and non-additive effects for total soluble solids and °brix. Likewise, they found a high statistical significance between tomato cultivars characterized by good tomato paste features, which were associated with a high level of °brix that contribute favorably to tomato flavor. Total soluble solids are one of the main components in tomato flavor and influences consumer preferences and industrial performance (Graça *et al.*, 2015). On the other hand, soluble solids are important not only for their contribution to flavor, but also in terms of processing requirements. In this sense, it is desirable to produce tomatoes with high soluble content because they require less energy to evaporate the water in industrial processes (Graça *et al.*, 2015).

Collecting tomato fruits in their very early developmental stage would reduce the organoleptic quality of these materials. In this research, titratable acidity ranges between 10.70 and 3.50 were found. This acidity variation among 27 industrial tomato cultivars, suggests that the harvest point of 75% was not suitable for the tomato material assessed. Consequently, Santos *et al.* (2014), observed that, titratable acidity and soluble solids content were 20 % higher and 10% lower respectively, in those tomatoes directly exposed to sunlight when mature.

Conclusion

Six relevant cultivars were identified from this research; three cultivars with particular fruit production quantities were SG 07-632 (68.58 $t.h^{-1}$), followed by SG 07-627 and SG 07-603, all obtained from seeds originating from Ohio University. On the other hand, high levels of total soluble solids, acidity, consistency and production levels are desirable characteristics for tomato that will be used for paste production, and these features were found in three tomato cultivars: UG 10109, UG 16609 and UG 1103913F from seeds stemming from United Genetics. These showed good quantitative and qualitative properties, which will be used to start a genetic breeding program for tomato paste production in EEP-INIAP, Manabí, Ecuador.

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