Evaluating the Fruit Production and Quality of Cherry Tomato (*Solanum lycopersicum* var. *cerasiforme*)

Evaluación de la Producción y Calidad del Fruto del Tomate Cereza *Solanum lycopersicum* var. *cerasiforme*

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***Abstract**. The greatest genetic diversity of tomato (**Solanum lycopersicum** L.) in terms of fruit quality characteristics such as flavor, aroma, color, and lycopene and β-carotene contents is found in wild species. This study evaluated the agronomic characteristics and fruit quality of 30 cherry tomato introductions of the germplasm bank of the Universidad Nacional de Colombia - Sede Palmira in trials conducted at the Montelindo experimental farm of the Universidad de Caldas (1010 m absl average temperature 22.8 °C, average annual rainfall 2200 mm, 76% relative humidity). A 5 x 6 rectangular lattice experimental design was used with 30 treatments (introductions) and a commercial control (Sweet Million), 4 replicates/treatment, and 5 plants/replicate as experimental unit. The descriptors used were those suggested by the former International Plant Genetic Resources Institute, now Bioversity International. Data were statistically analyzed by ANOVA and Duncan's means test using the SAS program. In addition, principal component and cluster dendrogram analyses using the SAS Princom and Cluster procedure (SAS Institute, Cary, NC) were performed. Six principal components accounted for 80.39% of the morphological variability of the introductions evaluated. The most promising materials in terms of average fruit weight, yield per plant and per hectare, and soluble solids, vitamin C and lycopene contents were IAC1624, IAC391, IAC3652, LA2131, IAC424, IAC1621, IAC426, LA1480 and IAC1688. The broad phenotypic variability observed in the evaluated introductions favors the potential selection and breeding of tomato for traits associated with fruit production and quality.*

Key words: Plant breeding, lycopene, phenotypic variability, Colombia.

***Resumen**. La mayor diversidad genética del tomate (**Solanum lycopersicum** L.) en términos de características de calidad del fruto como sabor, aroma, coloración y contenidos de licopeno y β-caroteno se encuentra en especies silvestres. Este estudio evaluó las características agronómicas y de calidad del fruto de 30 introducciones de tomate cereza provenientes del banco de germoplasma de la Universidad Nacional de Colombia –Sede Palmira en ensayos realizados en la granja Montelindo de la Universidad de Caldas (1010 m sobre el nivel del mar; temperatura media, 22,8°C; precipitación promedio anual, 2200 mm; humedad relativa, 76%). Se usó un diseño experimental de látice rectangular 5 x 6, con 30 tratamientos (introducciones) y un testigo comercial (Sweet Million), 4 repeticiones/tratamiento y 5 plantas/repetición como unidad experimental. Se utilizaron descriptores sugeridos por el antiguo Instituto Internacional de Recursos Fitogenéticos, ahora Bioversity International. Los datos fueron analizados estadísticamente utilizando ANAVA y la prueba de promedios de Duncan a través del programa SAS. Adicionalmente se realizaron análisis de componentes principales y agrupamiento por dendrograma por medio del procedimiento Princom y Cluster de SAS (SAS Institute, Cary, NC). Seis componentes principales explicaron el 80,39% de la variabilidad morfológica de las introducciones evaluadas. Los materiales más promisorios en términos de peso promedio de fruto, producción por planta, rendimiento y contenidos de sólidos solubles, vitamina C y licopeno fueron IAC1624, IAC391, IAC3652, LA2131, IAC424, IAC1621, IAC426, LA1480 y IAC1688. La amplia variabilidad fenotípica de las introducciones evaluadas favorece la posibilidad de selección y mejoramiento genético en tomate por caracteres asociados a la producción y calidad del fruto.*

Palabras clave: Fitomejoramiento, licopeno, variabilidad fenotípica, Colombia.

Tomato (*Solanum lycopersicum* L.) is the most important vegetable in Colombia and worldwide, accounting for 30% of global vegetable production, with about 4.4 million hectares planted and 145,751,507 t of fruit harvested in 2010 (FAOSTAT, 2010). This vegetable is a major source of vitamins, minerals and fiber, important for nutrition and human health (Razdan and Mattoo, 2007); also, contains various nutrients, ascorbic acid, vitamin E, flavonoids, phenolic acids and carotenoids (Kuti and Konuru, 2005), and is the main source of lycopene for humans (Candelas *et al*., 2008). In 2010, production of tomato in Colombia was 546,322 t, with a planted area of 16,227 ha and an average yield of 33.66 t/ha (FAOSTAT, 2010).

According to Miller and Tanksley (1990), most genetic diversity is found in the wild relatives of tomato, which show variability for fruit quality characteristics such as flavor, aroma, color, and texture as well as a

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high vitamin C content (> 57 mg/100 g fresh weight). Several authors have also been reported as having market potential because of their high content of antioxidants such as lycopene (>10 mg/100 g fresh weight) (Nuez, 1999). Current breeding efforts in tomato focus on incorporating qualities such as color, firmness, flavor, and high carotenoid content into new commercial cultivars. It is more common to find these fruit quality traits in traditional cultivars than in modern cultivars, whose improvement efforts have focused more on productivity and agronomic characteristics of the plant (Valcárcel, 2009). For example, including cherry tomatoes (*S. lycopersicum* var. *cerasiforme*), one of two promising wild types of *Solanum* in breeding programs, offers great potential because of their valuable characteristics in terms of genetic diversity for selection of parental material and their broad geographic range (Medina and Lobo, 2001). Desirable traits found in cherry tomatoes include disease resistance, fruit abscission, soluble solids content, fruit size, flavor, texture, pigmentation, and post-harvest quality (Kwon *et al*., 2009).

The characterization of the biodiversity of plant genetic resources -a global strategic research line- lies the groundwork for solving problems currently affecting crops such as the adaptation to climate change as well as for the development of new alternatives that improve crop productivity and quality (Virk *et al*., 1995). According to Abadie and Berretta (2001), the value of collections of plant genetic resources lies in its use. Collections should provide plant breeders with genetic variants, genes, or genotypes, allowing them to tackle the new challenges posed by production systems. To do so, it is essential to know the characteristics of the conserved germplasm.

Wild tomato species originate from the Andes of Chile, Bolivia, Peru, Ecuador and Colombia (Nuez, 1999). According to Vallejo (1999), the most promising wild types of *Solanum* are *S. lycopersicum* var. *cerasiforme* and *S. pimpinellifolium*. Several studies have shown that some tomatoes, known as 'cerasiforms', are not ancestors of modern cultivars, but have resulted from the hybridization of wild and cultivated tomatoes (Peralta *et al*., 2006).

Some commercial cherry tomato varieties such as Brillantino, Marasca, Ovalino, Tamburino, To1251, and Sweet Million are more representative of the market, reporting yields between 54.27 and 87.73 t/ha (Macua *et al*., 2008). Results of a study conducted by Nuez (1999) indicate that cherry tomatoes are generally of determinate, semi-determinate, or indeterminate growth habit; present long racemes with many fruits of intense color and flavor, generally round in shape and weighing between 10 and 30 g; are resistant to diseases and tolerant to high relative humidity (> 80%); have a high nutritional value because of their high vitamin C content (> 57 mg/100 gfw); and present a highly variable number of fruits per cluster (15–50). Cherry tomato lycopene content exceeds 10 mg/100 g fresh weight (Medina and Lobo, 2001), which is considered as high. *S. lycopersicum* var. *cerasiforme* and *S. pimpinellifolium* may be used as a source of genes to increase the lycopene content of species with low content (Nuez, 1999).

Medina and Lobo (2001) studied the morphological variability of 39 qualitative and 11 quantitative traits in 82 cherry tomato introductions in the department of Antioquia, Colombia. Results indicated a broad qualitative and quantitative variability, indicating great potential for improving this type of tomato or for introgressing genes for materials with large fruits. Restrepo and Vallejo (2003) evaluated 25 tomato introductions from the departments of Cauca, Valle del Cauca, Antioquia, Santander, and Huila as well as the country's coffee-growing region, and formed three groups: (1) those of var. *cerasiforme*; (2) all types of tomato introductions and (3) 'chonto'-type tomato var. Rio Grande. Garzon (2011) evaluated 36 cherry tomato introductions of the germplasm bank of the Universidad Nacional de Colombia, Sede Palmira (UNAPAL), finding that introductions IAC426, LA1314, LA1480, LA1307, and LA1311-1 formed a group that was high yielding with optimal average fruit weight for use in breeding programs for this type of tomato. The introductions that presented low average fruit weight showed the highest lycopene and vitamin C contents, particularly LA2841, LA4133, LA1461, LA3842, and Roldanillo.

The search for internal quality (nutritional and organoleptic) is one of the main objectives of improved fresh tomato market (Rosello *et al*., 2000). The fruits of wild tomato species such as *S. pimpinellifolium* have an excellent balance of flavor, 7.0 to 8.0 °Brix, an attractive red color (Cestoni *et al*., 2001), and high vitamin C content, all key components for the internal quality of tomato (Rosello *et al*., 2000).

In Colombia, there are cherry tomato introductions and collections that can be used in breeding programs. The use of this resource, however, is subject to characterization and agronomic evaluation. This research aims to evaluate the agronomic performance and fruit quality of 30 cherry tomato introductions from the UNAPAL germplasm bank to select promising genotypes that could serve to improve cultivated tomato and commercial cherry tomato.

MATERIALS AND METHODOS

Introductions were evaluated at the Montelindo experimental farm of the Universidad de Caldas, located in the tropical rainforest region of Santágueda on the eastern bank of the Cauca river, in the municipality of Palestina, department of Caldas, Colombia (1.030 masl; average temperature, 23 °C; 75% relative humidity; annual precipitation, 2,000–2,225 mm; annual solar radiation, 2,049 h). Plant material consisted of 30 introductions of the UNAPAL germplasm bank with no previous characterization report that could be included in breeding programs of cultivated tomato. Sweet Million was selected as commercial check from among the commercial materials of cherry tomato best positioned in the market and capable of adapting to the study area (Table 1). Soils were sandy loam, pH 5.4, rich in organic matter (7.91%), deep (60 cm), and well-drained (Boada *et al*., 2010).

Introductions were sown on 1 July 2010 in trays of 72 grids with grade 3 peat substrate and seedlings were transplanted to the field on 28 July 2010 when they reached the fourth true leaf stage (Jaramillo *et al*., 2007). A 5 x 6 rectangular lattice experimental design was used with 30 introductions and two replicates/main block. The experimental unit consisted of five plants per introduction, planted at 1.5 m between rows, 0.8 m between plants, and 2 m between blocks. Agronomic management was that defined by Jaramillo *et al*. (2007) for commercial tomato crops but modified to leave 3 axis/plant when defining plant architecture to allow these wild tomato introductions to express their potential regarding the production variables being evaluated. A black-and-white padded plastic 0.8 m wide, 1.2 caliber, was used to control weeds. After reaching full maturity at 65 days after transplanting, fruits were harvested according to the performance of each introduction until plants completed 10 harvests on 10 December 2010 (1 harvest/week).

Table 1. Cherry tomato introductions evaluated for fruit production and quality in the department of Caldas, Colombia.

No.	Introduction	Description	No.	Introduction	Description
1	IAC391*	Red cherry tomato	16	LA1546	Cherry tomato
2	IAC420	Cherry tomato	17	LA1705	Cherry tomato
3	IAC421	Cherry tomato ‘Alemão Vermelho’	18	LA2076	Cherry tomato
4	IAC424	Cherry tomato	19	LA1334	Cherry tomato
5	IAC426	Cherry tomato ‘Juliet’	20	LA2131	Cherry tomato
6	IAC445	Cherry tomato ‘Jundiai’	21	LA168	Cherry tomato
7	IAC1621	Cherry tomato ‘Aleman 12’	22	LA2640	Cherry tomato
8	IAC1624	Cherry tomato	23	LA2692	Cherry tomato
9	IAC1685	Cherry tomato ‘11B’	24	LA2710	Cherry tomato
10	IAC1688	Cherry tomato ‘Lili’	25	LA2845	Cherry tomato
11	IAC1622	Cherry tomato	26	LA3139	Cherry tomato
12	IAC1686	Cherry tomato	27	LA3652	Cherry tomato
13	IAC412	Cherry tomato	28	LA1455	Cherry tomato
14	IAC416	Cherry tomato	29	LA1428	*Solanum pimpinelifollium*
15	LA1480**	Cherry tomato	30	LA3158	*Solanum pimpinelifollium*
31	Check	Commercial cherry tomato Sweet Million			

* IAC: Introductions proceeding from the Instituto Agronómico de Campinas, Campinas, Brazil.

** LA: Introductions proceeding from the Tomato Genetics Resources Center (TGRC), University of California–Davis.

Characters were measured using the methodology suggested by the former International Plant Genetics Resources Institute (1996), now Bioversity International. All observations about the fruit were made in the second raceme per introduction per replicate in the stage of full maturity. Characters evaluated were the number of flowers/raceme (NFLR), number of fruits/raceme (NFR), number of racemes/plant (NRP), total number of fruits (TNF), average fruit weight (AFW), production/plant (g/pL) (PDN), lycopene content (mg/mL) (LYC), vitamin C content (g/100 gfw) (VITC), fruit acidity (FA) and soluble solids content (°Brix) (SSC); additionally to the principal component analysis were measured the number of good fruit (NGF), weight of damaged fruit (WDF), good fruit weight (GFW), external color of fruit (ECF), fruit shape (FS), number seeds per fruit (NSF), fruit firmness (FF) and number of locules/fruit (NLF).

Lycopene was extracted in a mixture of acetone:n-hexane (4:6) and centrifuged at 5,000 rpm for 5 min at 4 °C. Subsequently, the optical density of the supernatant was measured spectrophotometrically at wavelengths of 663, 645, 505 and 453 nm, using the acetone/n-hexane mixture as blank (Rosales, 2008). The lycopene concentration was quantified using the equation proposed by Nagata and Yamashita (1992) cited by Rosales (2008), as follows:

$$[\text{lycopene}]\ (\text{mg/mL}) = -\ 0.0458\ A_{663} + 0.204\ A_{645} + 0.372\ A_{505} -\ 0.0806\ A_{453}$$

Fruit acidity and vitamin C content were measured from juice samples, obtained from 10 fruits of the second raceme per introduction per replicate. Juice samples (10 mL) were diluted in 100 mL distilled water and the total acidity was determined by means of a potenciometric titration with a solution of 0.1 M NaOH up to pH 8.2, the results were expressed as citric acid (%). The vitamin C content was determined by a redox titration with a standardized solution of 0.1 N iodine (IPGRI, 1996). Finally, the soluble solids content was measured using a Hanna® Instruments refractometer at a scale of 0.2 °Brix.

Analysis of variance was performed using the SAS GLM procedure (SAS Institute, Cary, NC) to determine the occurrence of significant differences between introductions for all the quantitative variables evaluated. Means were compared by Duncan's means test (P<0.05), principal component analysis was performed, and qualitative and quantitative descriptors assigned based on the matrix of 30 introductions with the averages of previously obtained variables. The SAS Princom and Cluster procedure was used (SAS Institute, Cary, NC). Ward's criterion was used to prepare the dendrogram.

RESULTS AND DISCUSSION

Number of flowers per raceme (NFLR) and number of fruits per raceme (NFR). Significant differences (P<0.05) were found between introductions for the variables NFLR and NFR. In 80% of the introductions, a direct relationship was observed between these two variables—the higher the number of flowers, the higher the number of fruits. However, fruit set percentage was higher (70–85%) in introductions presenting the lowest number of flowers and fruits such as LA2710, LA2845, LA168 and LA3139 (Table 2). Average values yielded by introductions IAC421, IAC1688, IAC424, and IAC1621 surpassed 20 flowers and 10 fruits/raceme (P<0.05). Eight introductions yielded values above the overall average of 7.40 fruits/raceme, while introductions LA2710, IAC1686, IAC1622 and IAC2640 presented values below 4.50 fruits/raceme (Table 2).

Lobo and Medina (1994), evaluated the morphological variability of cherry tomato *Solanum lycopersicon* var. *cerasiforme* and found that the NFLR ranged from 4 to 20. Estimated raceme weight (g) per introduction indicated that the highest values depended primarily on average fruit weight and secondly on the NFR (Ceballos and Vallejo, unpublished data). Therefore, a plant offering a balance between these two variables can be competitive in terms of production as compared with commercial materials.

Number of racemes per plant (NRP). In a five month period, from transplanting to harvest, the NRP with three axis presented significant differences (P<0.05). Introduction LA1428 presented the highest value (40.90 racemes/plant) with a confidence level of 95%, followed by LA3139, LA2710, LA2692, IAC420, LA3158 and IAC445 with values ranging between 32 and 34 racemes with no statistical difference among them. Lowest average values were found in IAC416 (13.10 racemes/plant), LA2131 (12.80), IAC1686 (8.70) and IAC1622 (5.60), with no statistical difference among them. Rodríguez *et al*. (2005), found 11 racemes/plant in materials of wild tomato var. *cerasiforme*, which is significantly lower than the average found in this study (23.25 racemes/plant). Rodríguez (2007) evaluated cherry tomato (*S.l.* var. *cerasiforme*) and found 5.47 racemes in treatment TI (bran and straw), followed by 5.14 racemes in T3 (plastic) and 4.89 in T2 (straw), with no significant differences.

Total number of fruits (TNF) and average fruit weight (AFW). Significant differences were found between TNF and AFW (P<0.05) (Table 2). Fourteen introductions presented values above the overall average (96.1 fruits/plant), even though the commercial check presented one of the highest values of TNF per plant (119.8) while reporting the highest percentage of losses (77%) (P<0.05). Introductions LA1428, IAC1480, IAC424, LA1546, LA1455, IAC420 and IAC426 showed a direct relationship between large amount of good fruit and total number of fruit harvested per plant, while the percentage of losses or discarded fruit were below 30% (P<0.05).

Table 2. Partitioning of means according to Duncan's means test for production variables in 30 cherry tomato introductions.

Introduction	NFLR*	NFR*	NRP*	TNF*	AFW* (g)	PPR* (g/pl)	Yield (t/ha)
Check	54.10 a**	34.00 a	21.30 e	119.80 ei	17.00 eg	2054.60 a	17.12 a
IAC426	21.30 d	7.50 ef	27.70 d	141.60 cf	16.00 eh	2039.90 a	17.00 a
IAC1624	8.20 e	5.50 fh	30.80 c	80.00 kj	24.10 bc	1937.30 a	16.14 a
LA1480	10.90 e	8.30 de	17.50 fg	157.90 bc	10.80 ik	1704.90 b	14.21 b
IAC391	8.10 e	5.90 eh	27.40 d	62.10 kl	26.50 b	1643.70 bc	13.70 bc
IAC1688	32.60 b	12.50 c	21.80 e	133.40 cg	12.90 gj	1642.00 bc	13.68 bc
LA3652	8.70 e	5.30 fh	31.00 c	83.80 kj	18.80 df	1574.00 bd	13.12 bd
IAC1621	23.70 c	9.80 d	26.50 d	108.20 gj	13.60 gi	1432.90 cd	11.94 cd
IAC424	35.00 b	9.90 d	26.30 d	175.60 b	9.80 il	1421.00 cd	11.84 cd
LA2692	7.90 e	5.20 fh	33.40 bc	94.00 ij	16.30 eh	1420.60 cd	11.84 cd
LA2131	8.70 e	5.80 eh	12.80 i	82.50 kj	22.40 cd	1369.20 d	11.41 d
IAC421	35.40 b	16.40 b	26.30 d	145.30 ce	10.50 ik	1348.70 d	11.24 d
LA2076	7.20 e	5.40 fh	17.30 fg	103.90 hj	12.70 hj	1314.70 d	10.96 d
LA2845	6.40 e	4.70 gh	25.90 d	42.00 ln	23.90 bc	1032.30 e	8.60 e
LA1705	9.60 e	5.90 eh	16.20 gh	81.40 kj	12.60 hj	1013.90 e	8.45 e
LA1428	7.50 e	6.40 eg	40.90 a	201.70 a	4.80 mo	979.60 ef	8.16 ef
IAC445	7.60 e	5.30 fh	31.90 bc	84.70 kj	12.20 hj	958.70 ef	7.99 ef
IAC420	10.90 e	7.50 ef	33.10 bc	161.30 bc	5.90 lo	887.30 eg	7.39 eg
IAC1686	27.30 c	3.70 h	8.70 j	80.50 kj	12.70 hj	878.00 eh	7.32 eh
LA2640	6.50 e	3.60 h	19.70 ef	22.20 mn	37.20 a	817.80 eh	6.81 eh
LA168	6.40 e	5.10 fh	16.80 g	99.00 hj	8.70 jm	814.20 eh	6.78 eh
IAC412	8.20 e	6.00 eh	25.80 d	34.70 ln	21.60 cd	739.60 fi	6.16 fi
IAC1685	9.80 e	7.00 eg	17.60 fg	49.10 lm	15.30 fh	629.20 gj	5.24 gj
LA2710	5.60 e	4.50 gh	33.50 bc	59.60 kl	10.60 ik	619.30 hj	5.16 hj
LA3139	6.40 e	5.20 fh	34.40 b	114.70 fi	7.50 kn	551.90 ij	4.60 ij
IAC1622	8.90 e	0.70 i	5.60 k	26.00 mn	19.60 de	517.90 ik	4.32 ik
LA1546	7.30 e	6.20 eh	13.70 hi	148.00 cd	3.70 on	512.20 ik	4.27 ik
LA1455	8.10 e	7.00 eg	16.20 gh	123.20 dh	4.10 on	475.40 ik	3.96 ik
LA1334	11.00 e	6.50 eg	15.40 gi	61.30 kl	7.10 kn	418.50 jk	3.49 jk
IAC416	8.80 e	5.70 fh	13.10 i	20.00 n	22.30 cd	388.00 jk	3.23 jk
LA3158	9.10 e	6.70 eg	33.00 bc	83.20 kj	3.00 o	277.40 k	2.31 k
Means	13.80	7.40	23.20	96.10	14.30	1077.90	8.98

* NFLR, number of flowers per raceme; NFR, number of fruits per raceme; NRP, number of racemes per plant; TNF, total number of fruits per plant;AFW, average number of fruits; PRP, production per plant.
** Different letters in a column indicate significant differences (P<0.05) by Duncan's means test.

The AFW was 14.3 g/fruit with a confidence level of 95%. Macua *et al*. (2009) reported AFW values of 17 g for cherry tomato variety Pizzaiolo, while the other commercial varieties evaluated presented values ranging between 6.5 and 13 g/fruit. Under greenhouse conditions, Márquez and Cano (2005), found AFW of 16.3 g/fruit; Trani *et al*. (2003), found AFW values of 13.3 g/fruit in commercial tomato cherry. The commercial check treatment (Sweet Million) obtained similar values and ranked 10th with an AFW of 17 g/fruit (P<0.05). Of the introductions, 42% presented values between 15.3 and 37.2 g/fruit (P<0.05), with the remaining 58% presenting below-average values between 3 and 13.6 g/fruit (P<0.05). Cestoni *et al*. (2001), described fruits of wild tomato species weighing 12–18 g/fruit, while Macua *et al*. (2009), on the other hand, reported the following AFW values for cultivated cherry varieties: Pizzaiolo, 17 g; ISI-447655, 15 g; Tamburino, 6.5 g; and Ovalino, 13 g. Introductions evaluated in this study reporting the highest values were LA2640 (37.2 g), IAC391 (26.5 g), IAC1624 (24.1 g), LA2845 (23.9 g), LA2131 (22.4 g), IAC416 (22.3 g) and IAC412 (21.6 g) (P<0.05) as compared with introductions LA1428, LA1455, LA1546 and LA3158 that presented values below 5 g/fruit, with no statistical differences (Table 2).

Production per plant (PDN). Regarding the PDN variable, highest yields were obtained by introductions LA426 (2039.90 g/plant, 17 t/ha) and IAC1624 (1937.30 g/plant, 16.14 t/ha), with no statistical difference. The commercial check yielded 2,054.60 g/plant (17.12 t/ha), but also presented the highest amount of damaged fruit (1,570 g, 13 t/ha (Ceballos and Vallejo, unpublished data). Introduction LA3158 presented the lowest yield at 277.40 g/plant (2.31 t/ha; P<0.05) (Table 2). Macua *et al*. (2006), evaluated nine cherry tomato varieties in greenhouse conditions and found average yields of 85.78 t/ha, whereas other cherry tomato varieties yielded between 66 and 103.68 t/ha (Macua *et al*., 2008). In studies conducted by Uresti *et al*. (2007), in hydroponic tomato, yields of 30.1 t/ha were obtained at a population density of 25,650 plants/ha. In experiments conducted by Márquez and Cano (2005), involving the organic production of cherry tomato under greenhouse conditions, yields of 95 t/ha were obtained in the check treatment (sand-fertigation), whereas Márquez *et al*. (2006), reported yields of 78 t/ha in the check treatment with inorganic fertilizer when using different organic substrates in cherry tomato. In studies conducted by Padua *et al*. (2002), in cherry tomato planted at a low density of 16,000 plants/ha, PDN values of 2,060 g/plant were obtained, whereas Azevedo and Melo (2001), reported yields of 1,500 g/plant. Similar values were achieved in the control treatment and introductions IAC1624 and IAC426, with no statistical difference (Table 2).

In this study, highest yields were obtained by the commercial check Sweet Million (17.12 t/ha), followed by IAC1624 (17 t/ha) and IAC426 (16.14 t/ha), at a population density of 8.333 plants/ha in field conditions (Table 2). These results suggest that the use of controlled systems (greenhouse and fertigation) and commercial densities (between 16,000 and 26,650 plants/ha) could increase PDN (g) and yield (t/ha), enabling more sustainable production.

Soluble solids contents (SSC). The SSC presented statistical differences (P<0.05) (Table 3). The commercial check Sweet Million presented a value of 4.91 °Brix, close to the overall average of 4.92 °Brix. Twelve introductions, which corresponded to 39% of the introductions evaluated, presented above-average values ranging from 4.99 to 6.7 °Brix, with statistical differences (P<0.05). Highest SSC values were found in materials LA3158 (6.7 °Brix), IAC424 (6.18 °Brix) and IAC420 (5.49 °Brix), differing statistically (P<0.05). Macua *et al*. (2009), reported values between 5.47 and 8.71 °Brix in industrial cherry tomato varieties and Marquez and Cano (2005), reported values between 7.23 and 7.93 °Brix in cherry tomato produced organically under greenhouse conditions. Raffo *et al*. (2003), on the other hand, reported fluctuating but high SSC (6.1 °Brix) and sugar content (3.6 g/100 g) in cherry tomato grown in greenhouse conditions. Although most of the previously reported values exceed those reached by the introduction evaluated in this study, 39% reported values higher than the commercial check (Table 3) in field conditions. For 20 *S. pimpinellifolium* introductions collected in Ecuador and Peru, Rosello *et al*. (2000), reported a maximum SSC value of 13.6 °Brix. *S. pimpinellifolium* introductions LA3158 and LA1428 presented above-average values, also surpassing the commercial check (Table 3). LA3158 reported the highest SSC value (6.7 °Brix) of all the introductions evaluated, presenting statistical differences (P<0.05).

Fruit acidity (FA). Significant differences were found for FA (P<0.05), expressed as % citric acid (g/100 g fresh weight). With a confidence level of 95%, introductions IAC412, LA3652, IAC1686, LA2076, LA1428 and LA2710 presented values greater than 2 g/100 g fresh weight.

Twenty-four of the 30 introductions presented values above that of the commercial check (1.39 g/100 g fresh weight). Introductions IAC445, LA1480, LA1705, IAC426 and IAC424 presented the lowest values of citric acid, ranging from 1.04 to 1.28 g/100 g fresh weight, with statistical differences (P<0.05) (Table 3). In studies conducted by Rosales (2008), cherry tomato harvested three times during the crop production cycle and at the same stage of maturity yielded values between 3.57 and 3.70 mg/g fresh weight (citric acid). Urrestarazu (2004), reported titratable acidity values for cherry tomato between 520 and 807 mg citric acid/mL, whereas values for common tomato were between 370 and 550 mg citric acid/mL. Murray *et al*. (2000), assessed fruits of cherry tomato cultivar Super Sweet grown in greenhouse conditions and found values between 1.01 and 0.81% citric acid. Higher values were obtained in this study, which ranged between 1.04% citric acid for IAC412 and 2.44% citric acid for IAC445, when harvested at stage 3 when 90% of the crop has ripened fruit.

Vitamin C (VITC) content. Statistically significant differences were found in VITC (P<0.05). The commercial check presented the highest value (84.5 mg/100 g fresh weight) followed by introductions IAC445 with 72.5 mg/100 g fresh weight) and LA2710 with 58.8 mg/100 g fresh weight, differing statistically (P<0.05) (Table 3). At a confidence level of 95%, 14 introductions had above-average values (47.6 mg/100 g fresh weight) (Table 3). Raffo *et al*. (2003), found that ascorbic acid varies significantly in greenhouse-grown cherry tomato, but is within desirable range of vitamin C (50–120% of the daily recommended allowance of 60 mg), which makes it very appealing for the market. Four of the evaluated materials (LA2710, IAC445, IAC1624 and LA2076), together with the commercial check, presented values equal to or above the recommended daily intake of vitamin C (60 mg), showing potential to be produced sustainably.

All the evaluated introductions presented VITC higher than those reported by Lenucci *et al*. (2006) in introductions LA2933, LA2656 and BGV009560 of var. cerasiforme and *S. pimpinellifolium* from the germplasm bank of the Center for Conservation and Improvement of Agro-Biodiversity of the Universidad Politécnica de Valencia (COMAV), which reported values of 37, 25 and 21 mg/100 g fresh weight. According to Galiana *et al*. (2000), vitamin C levels vary considerably depending on the species —from 80 mg/kg fresh weight in cultivated varieties to 1.113 mg/kg fresh weight in *S. pimpinellifolium* L. The 30 introductions from the UNAPAL germplasm bank yielded values that significantly exceed those reported by COMAV, with LA2710 presenting 73 mg/100 g fresh weight; IAC445, 61 mg/100 g fresh weight; and IAC416, 29 mg/100 g fresh weight (the lowest of the study).

Lycopene (LYC) content. Duncan's means test revealed significant differences (P<0.05) in LYC among the different introductions evaluated. Introductions with highest content were LA1455 and LA2845, both with 0.32 mg/mL, followed by IAC426 with 0.30 mg/mL, with no statistical difference between them but differing statistically with the other materials (P<0.05) (Table 3). Materials with lowest LYC were IAC412 (0.04 g/mL) and LA2640 (0.02 mg/mL), which differed statistically (P<0.05). Hernandez *et al*. (2007), found LYC values ranging from 1.89 to 2.56 mg/100 g fresh weight in commercial cultivars Dunkan and Thomas. Stamova *et al*. (1998), reported LYC concentrations of 2.10 to 6.95 mg/100 g fresh weight in 35 cherry tomato lines.

Zambrano *et al*. (1995), concluded that LYC synthesis in tomato var. Rio Grande and pear- type tomato gradually increases with maturation, ranging from 0.233 mg/g for the stage of physiological maturity (PM) to 28.72 mg/g in mature fruits on the plant (M) in the case of the former and from 0.21 µg/g at PM to 29.72 mg/g in detached mature fruit in the case of the latter. In this study, fruits were harvested at full maturity, reaching maximum LYC values of 0.32 mg/mL in LA1455 and minimum of 0.02 µg/mL in LA2640. Lenucci *et al*. (2006) observed large variations between different tomato cultivars, with eight introductions of *S. lycopersicum* var. *cerasiforme* presenting LYC values ranging from 0.2 to 17.4 mg/100 g fresh weight, while the highest values were found in the species *S. pimpinellifolium* with 18 and 25 mg/100 g fresh weight. Average LYC content for introductions evaluated in this study was 0.18 µg/mL, with a confidence level of 95%; 55% of the introductions evaluated scored above this level, including the check (Sweet Million). One of the introductions of the species *S. pimpinellifolium* (LA1428) presented a LYC content of 0.21 µg/mL, at a confidence level of 95%.

Principal component analysis. The results of principal component analysis indicated six components

Table 3. Partitioning of means according to Duncan's means test for fruit quality variables in 30 cherry tomato introductions.

Introduction	Lycopene (mg/mL)	Vitamin C (mg/100 gfw)	Titratable acidity (% citric acid)	Soluble solids (°Brix)
LA3158	0.09 mn	40 im	1.9 cd	6.7 a
IAC424	0.22 df	52 ci	1.28 gi	6.18 b
IAC420	0.12 km	46.75 ek	1.87 cd	5.49 c
IAC1621	0.24 ce	43.75 fl	1.57 ef	5.36 cd
IAC1688	0.13 jl	47.75 ej	1.9 cd	5.31 cd
IAC445	0.16 hk	58.75 ce	1.04 j	5.29 ce
LA1455	0.32 a	54.75 cg	1.89 cd	5.24 cf
IAC426	0.3 ab	35 km	1.21 hj	5.17 cg
LA1546	0.25 ce	54 cg	1.79 de	5.16 cg
IAC391	0.17 gj	41.25 hl	1.35 fi	5.07 dh
LA2076	0.09 mn	55.75 cf	2.07 bc	5.04 dh
LA1428	0.21 eg	35 lm	2.05 bd	4.99 di
Testigo	0.18 fi	84.5 a	1.39 fh	4.91 ej
IAC421	0.15 il	41 hl	1.54 f	4.89 fj
IAC412	0.04 op	38 jm	2.44 a	4.84 fk
IAC1624	0.27 bc	60.25 cd	1.57 ef	4.84 fk
LA168	0.23 ce	52.25 ci	1.47 fg	4.83 fk
IAC1685	0.18 fi	34.25 lm	1.83 cd	4.81 gl
LA2692	0.12 km	33.25 lm	1.94 cd	4.77 gl
LA2710	0.2 eh	72.5 b	2.01 bd	4.7 hm
LA1705	0.08 no	46.5 fk	1.2 hj	4.7 hm
IAC1686	0.12 lm	41 hl	2.2 b	4.63 im
LA3139	0.15 il	49 dj	1.84 cd	4.59 im
IAC1622	0.18 fi	51 ci	1.92 cd	4.57 jm
LA2640	0.02 p	28.9 m	1.47 fg	4.54 jm
LA1480	0.26 cd	44.5 fl	1.14 ij	4.51 jm
LA2131	0.24 ce	43 gl	1.46 fg	4.47 km
LA2845	0.32 a	61.25 c	1.55 f	4.43 km
LA1334	0.24 ce	43.5 fl	1.91 cd	4.41 lm
IAC416	0.05 op	32.75 lm	1.55 f	4.33 mn
LA3652	0.23 ce	52.75 ch	2.21 b	4.04 n
Mean	0.18	47.6	1.7	4.93

* Different letters indicate significant differences (P<0.05) by Duncan's means test.

with eigenvalues > 1, accounting for 80.39% of the variability of the introductions evaluated (Table 4). The variables contributing most to the first component were NFLR (0.31), NFR (0.28), TNF (0.28) and NGF (0.17). This component is referred to as number of fruits. The second component, referred to as yield, gathers the following variables: PDN, WDF, AFW and GFW with eigenvalues between 0.35 and 0.23 (Table 5). The third component was called external quality and the fourth, internal quality, gathering variables such as ECF, FS, NSF, NLF and internal aspects such as FF, VITC, FA and LYC. The highest eigenvalues

Table 4. Eigenvalues of the principal components of the correlation matrix for 30 cherry tomato introductions.

Principal component	Eigenvalue	Difference between Eigenvalue	Variation explained (%)	Cumulated value
1	6.57	1.71	0.27	0.27
2	4.86	1.66	0.20	0.48
3	3.20	0.79	0.13	0.61
4	2.41	1.18	0.10	0.71
5	1.23	0.19	0.05	0.76
6	1.03	0.05	0.04	0.80
7	0.98	0.21	0.04	0.84

corresponded to ECF, scoring 0.41 in terms of external quality and FF scoring 0.27 in terms of internal quality (Table 5).

The variability of the introductions is attributed to principal components 1 and 2, with component 1 accounting for 27% and component 2, 20%. Component 3 accounted for 13% and component 4, 10%. Together these four components account for 71% of the variability of the introductions evaluated. Components 5 accounted for 5% and component 6 for 4% of the variability, together accounting for only 9% of the variability of these introductions.

Lobo and Medina (1994), assessed the phenotypic variation of American tomato cultivars based on a multivariate canonical discriminant procedure for 12 quantitative traits including number of petals/flower, fruit size, number of locules/fruit, pericarp width, number of flowers/inflorescence and SSC in fruit. These variables accounted for 66% of the variability of the cultivars evaluated.

Table 5. Variables with the highest weight in the principal component (PC) analysis for 30 cherry tomato introductions: fruit number, yield, external quality, and internal quality.

Fruit number	PC 1	Yield	PC 2	External quality	PC 3	Internal quality	PC 4
Flowers/raceme	0.31	g/plant	0.35	Fruit color	0.41	Firmness of fruit	0.27
Fruits/raceme	0.28	Fruit weight loss	0.32	Fruit shape	-0.32	Vitamin C	-0.24
Fruits/plant	0.28	g/fruit	0.32	Number of locules	0.24	Titratable acidity	-0.21
Good fruit	0.17	Fruit weight	0.23	Number of seeds/fruit	0.22	Lycopene	0.17

Cluster dendrogram analysis. Cherry tomato germplasm presented 81% phenotypic similarity, generating two main groups: cluster 1 (with subclusters 1, 2 and 3) with materials from the IAC germplasm bank of the Agronomic Institute of Campinas (IAC) and coded accordingly and cluster 2 (subclusters 4 and 5) with materials from Tomato Genetics Resource Center (TGRC) coded LA, indicating the genetic variation in the evaluated germplasm consisting of 30 introductions and the commercial check Sweet Million (Figure 1). The cluster that disappears at a genetic distance of 14.78% corresponds to the commercial check (cluster 6), which merges with cluster 1 formed by three materials and cluster 2 formed by four materials; 86% of these materials are materials from the IAC germplasm bank. These two clusters are the first to merge when they reach 94% similarity, while the other four remain separate until 86% similarity. Clusters 3 and 4 are formed by seven introductions each, which begin to form between 97% and 99% similarity. In cluster 3, compound clustering is mostly evidenced by IAC materials, whereas cluster 4 tends to group materials from the coded LA. Finally, the most distant cluster (cluster 5) groups the rest of the LA materials (Figure 1), representing the largest of the clusters with nine introductions in total. Cluster 5 merges with clusters 3 and 4 when it reaches 85% genetic similarity, showing the highest variability as compared with the aforementioned four clusters.

Restrepo and Vallejo (2003), classified 25 introductions of tomato, locally known as 'chonto', from the departments of Cauca, Valle del Cauca, Antioquia, Santander and Huila as well as the coffee-growing region of Colombia. Three groups were formed: the first consisted of two introductions of var. cerasiforme; the second of all tomato 'chonto' introductions from the departments of Cauca, Valle del Cauca, Antioquia, and Huila as well as the coffee-growing region of Colombia; and the third exclusively of tomato 'chonto' variety Rio Grande from the department of Santander. Garzón (2011), evaluated 36 cherry tomato introductions using principal component analysis and found that the variables yield, AFW, predominant shape of fruit and pericarp thickness contributed most to the expression of variability in introductions.

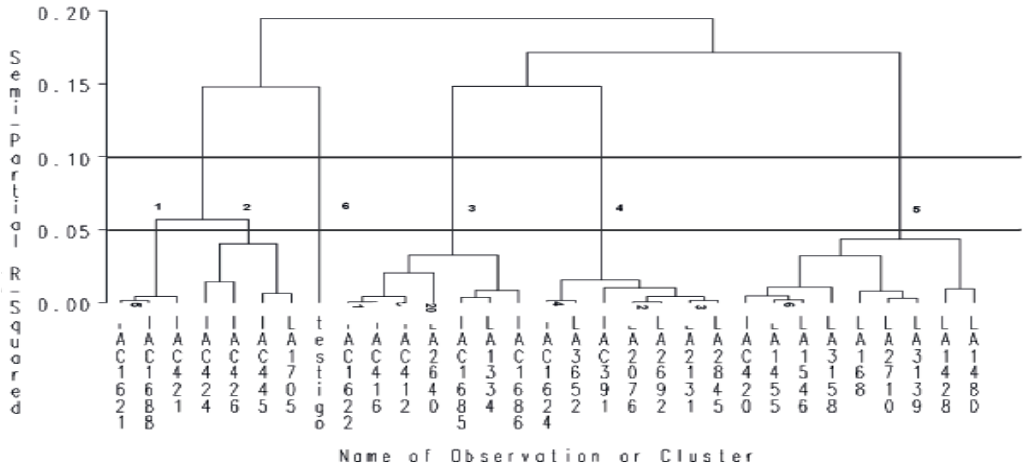

Figure 1. Cluster dendrogram of fruit production and quality of 30 cherry tomato introductions.

Rodríguez *et al*. (2003) evaluated 59 introductions from North America that had been planted in Valencia, Spain, under greenhouse conditions and discovered four attributes of the fruit (AFW, predominant color of ripe fruit, fruit size, predominant fruit shape) that could be used to characterize and differentiate the germplasm evaluated, which showed a high degree of variability for the traits under study.

CONCLUSIONS

Variables with the highest weight in the principal component analysis indicate that the traits associated with production and number of fruits, followed by production/plant, account for 47.6% of the phenotypic variability expressed in the introductions. Joining these traits are the components of external and internal quality, which account for 23.3% of the variability and all together for 70.9% of germplasm variability.

Cherry tomato germplasm presented 81% phenotypic similarity, generating two main groups: cluster 1 (with subclusters 1, 2, and 3) with materials from the IAC germplasm bank coded IAC and cluster 2 (subclusters 4 and 5) with materials from TGRC coded LA, which favors the selection of contrasting materials and genetic improvement of tomato for traits such as yield components and fruit quality.

Of the introductions evaluated in this study, the most promising for selection for production and quality were IAC1624, IAC391, IAC3652, LA2131, IAC424, IAC1621, IAC426, LA1480 and IAC1688 in at least three of the five main variables, such as AFW, yield per plant (g/plant), SSC (°Brix), VITC (mg/100 g), and LYC (µg/mL).

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