CHARACTERIZATION AND PHENOTYPIC EVALUATION OF FRUIT QUALITY TRAITS RELATED TO FUNCTIONAL AND ORGANOLEPTIC QUALITY OF SPANISH TOMATO LANDRACES

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Abstract

Among the different vegetable crops, tomato is one of the most popular and widely cultivated in the world due to its socio-economic and nutritional importance. There are more than 25,000 tomato varieties, although only 20% are marketed, which is causing a loss of valuable genetic diversity through the loss of cultivars and the disappearance of traditional and local varieties. In this sense, landraces cover a wide genetic diversity that can help mitigate the current genetic erosion within agricultural diversity, improving nutritional and organoleptic traits compared to commercial F1. The objective of this study was to determine the diversity of fruit quality parameters related to nutritional and bioactive compounds such as glucose and fructose, organic acids as glutamic, malic and citric acid, vitamin C and carotenoids of forty-eight tomato landraces belonging to nine different cultivar groups: 'Flor de Baladre', 'Corazón', 'de la Sierra', 'Muchamiel', 'de la Pera', 'Pimiento', 'Kumato', 'Mesa Murciano' and 'Cherry'. Fruits with different shapes (squared, slightly flattened, rounded, heart-shaped, long oblong and pyriform), colours (yellow, P and R) and sizes (from very small to very large) were included in this study. The highest values in compounds related to the organoleptic quality of the fruits were found in the orange and yellow 'Cherry' varieties. While the varieties belonging to the 'Cherry' and 'Pimiento' types showed a high content of compounds related to the functional quality (vitamin C and carotenoids). The results obtained show an important intravarietal and intervarietal variability, which would allow the selection of varieties to be used in breeding lines focused on obtaining fruits of high organoleptic and nutritional quality.

Keywords: *traditional genotypes, germplasm, fruit variability, bioactive composition*

1. INTRODUCTION

In addition to its economic importance, the agricultural sector has a direct impact on the preservation of the rural way of life and the environment, and therefore plays a key role in land management and has a great responsibility in the preservation of natural resources. In the European area, almost 50% of the territory is covered by agricultural land, so monitoring the conditions for sustainable agriculture is very important in order to achieve the desired balance between agriculture and the environment. While the agricultural sector continues to grow, global agrobiodiversity is decreasing due to the loss of genetic diversity in food crop varieties (Messmer, 2015). This has led to a notable loss in the nutritional quality, flavour and taste of vegetables (Figàs et al., 2015, Ribes-Moya et al., 2018).

Unfortunately, modern agriculture does not make the right choices, as it focuses its efforts on the development of economically important plant varieties, prioritizing traits such as high yield, longevity and visual impact, but neglecting organoleptic and nutritional quality, leading to consumer dissatisfaction (Casals et al., 2011, Oltman, 2014). In this context, traditional varieties play a fundamental social, environmental and agronomic role in ecosystems. These local varieties (or landraces) represent a genetic heritage and a source of biodiversity, and are the result of a selection process carried out by farmers over generations. The main selection criterion has been organoleptic properties, of which flavour is one of the most important. In this sense, several studies show the superiority of traditional vegetable varieties over commercial ones, taking into account aspects of flavour (Klee and Tieman, 2018), aroma (Cheng et al., 2020), content of compounds beneficial to health (Martínez-Ispizua, et al., 2021) and consumer appreciation (Sinesio et al., 2021). Another interesting aspect of traditional varieties is that their selection/breeding process has been based on their ability to adapt to local environmental conditions with specific edaphic-climatic characteristics, mainly in the context of traditional low-input farming systems, so that in many cases they are expected to show satisfactory performance under stress conditions (Fita et al., 2015). In particular, the cultivation of horticultural products in areas of eastern Spain is conditioned by various factors that limit production and affect crop quality, such as scarcity of water resources, high temperatures and poor soil quality (erosion and salinisation) (Alrteimei et al., 2022, Bonachela et al., 2022, Polade et al., 2017). In this scenario, traditional varieties are usually excellent starting materials for breeding programmes, since farmers have selected these landraces or heirlooms for their great behaviour in low input systems and under stress conditions (Cebrino, et al., 2011, Ribes-Moya, et al., 2018, Fullana-Pericàs et al., 2022). In addition, promoting their cultivation contributes to the enhancement of agrobiodiversity in the agrifood sector, thus stabilising food production (Renard and Tilman, 2019).

Tomato (*Solanum lycopersicum*) crops are of great economic, social and cultural importance, as they are consumed all over the world. This crop occupies a large area in the eastern part of Spain (about 30,000 ha) and is the most important vegetable produced in Spain, with a total production of 200,000 T. From a nutritional point of view, tomato is considered a high quality food in terms of its content of vitamins, phenolics, carotenoids and antioxidant capacity (Morales-Soto et al., 2014, Kavitha et al., 2014, Flores et al., 2016, Flores et al., 2017, Flores et al., 2018, Ribes-Moya et al., 2020, Guijarro-Real et al., 2023) and traditional genotypes have been found to have very high levels of these compounds and 'taste-of-the-past' flavours, making them more attractive and healthier for consumers (Figàs et al., 2015, Ribes-Moya et al., 2018, Moreno-Peris et al., 2020).

The aim of this study was to determine the diversity of fruit quality parameters related to nutritional and bioactive compounds such as glucose and fructose, organic acids such as glutamic, malic and citric acids, vitamin C and carotenoids of forty-eight tomato landraces belonging to nine different cultivar groups: 'Flor de Baladre', 'Corazón', 'de la Sierra', 'Muchamiel', 'de la Pera', 'Pimiento', 'Kumato', 'Mesa Murciano' and 'Cherry'. Fruits of different shapes (square, slightly flattened, rounded, heart-shaped, oblong and pyriform), colours (yellow, pink, red and orange) and sizes (from very small to very large) were included in this study.

2. MATERIALS AND METHODS

2.1. Materials

Forty-eight traditional genotypes of tomato (Solanum lycopersicum L., Fig. 1) were provided by the genebank of the Instituto Murciano de Investigación y Desarrollo Agrario y Medioambiental (BAGERIM_IMIDA) and grown in a greenhouse at an experimental farm (La Pilica) located in Águilas (Murcia, SE Spain, -1.483, 37.433). This area has a desert-arid climate with mild temperatures and was irrigated with a mixture of desalinated water and well water (1.8-2 dS m^{-1}). The crop design was the same for all varieties, in single rows with 40 cm plant spacing within the row and 1 m row spacing. The plots were managed according to a low-input tomato production management system, using integrated pest management with the support of flower margins to promote the presence of auxiliary fauna, mainly *Macrolophus sp*. to control fruit worms as *Tuta absoluta* and whiteflies. The plants were maintained until the end of the production phase (150-240 days after transplanting, depending on the genotype). Throughout production, fruits were collected and weighed individually to determine total number and average weight. For the analysis of quality parameters, fully red and ripe fruits were selected from trusses 2-4, discarding those that were not homogeneous in colour or had any defect. The ripeness of the fruit was measured daily to avoid over-ripening.

2.2. Methods

To determine the mean weight, colour and equatorial and longitudinal diameter of the fruits, four sub-samples of at least ten ripe fruits were randomly collected and processed individually. The weight of each fruit was determined using a Mettler Toledo PG 6002-S (Uznach, Switzerland) balance, colour was measured with a MinoltaCR-200 colourimeter (Ramsey, NJ, USA) and the diameter was determined using a Mitutoyo Digimatic caliper (Japan). Tomatoes belonging to the same tank were cut into small pieces, mixed, frozen in liquid N_2, and homogenized in a food processor (Thermomix, Vorwerk, Switzerland). The homogenate of each sample was frozen at -80 ºC for further analysis.

Total soluble solids (TSS) content was determined with a calibrated hand-held refractometer (Atago, USA) and expressed as ºBrix, and titratable acidity (TA) were determined by titration with 0.1 N NaOH with an endpoint titrator (Mettlet Toledo, USA) and expressed as grams of citric acid per liter of juice.

Fig. 1. Pictures of the accessions studied according to the key in table 1. From one to forty-eight, from right to left and from top to bottom.

Soluble sugars and organic acids were extracted with water and subsequently purified using C18 Sep-Pak cartridges (Flores et al., 2016). Soluble sugars were analysed in a liquid chromatograph (Agilent 1100 Waldbronn, Germany) equipped with a refraction index detector and a CARBOSep CHO-682 LEAD column using ultrapure water as mobile phase at a flow rate of 0.4 mL min^{-1}, and organic acids were determined by liquid chromatography using a G6410A triple quadrupole mass spectrometer detector (Agilent Technologies, Santa Clara, CA, USA) according to Flores et al. (2012).

Vitamin C (ascorbic and dehydroascorbic acids) was determined according to the method developed by Fenoll et al. (2011), briefly, tomato samples were homogenised with EDTA, 0.05% (w/v) and dithiothreitol and analysed by LC-MS-MS (Agilent Technologies, Santa Clara, CA, USA).

Total carotenoids and chlorophyll were extracted with ethyl acetate and determined by measuring the optical density at 450, 663 and 645 nm in a Shimadzu UV-2401PC spectrophotometer (Kyoto, Japan) according to Nagata and Yamashita (1992), carotenoids were quantified by comparison with a standard curve of lycopene and β carotene (Merck KGaA, Damstadt, Germany).

The results were statistically analysed using IBM SPSS Statistic 25 with analysis of variance (ANOVA) and Duncan's multiple range test for differences between means.

3. RESULTS

Based on previous results (Flores et al., 2016), a selection of 48 *Solanum lycopersicum* accessions (Fig. 1) from the IMIDA germplasm bank was made to be evaluated as sources of variability for the valorisation and breeding of high quality horticultural cultivars.

The selected landraces belong to nine cultivars such as 'Flor de Baladre', 'Corazón', 'de la Sierra', 'Muchamiel', 'de la Pera', 'Pimiento', 'Kumato', 'Mesa Murciano' and 'Cherry'. Within each variety there are fruits of different colour, size and shape (Table 1). In terms of colour, the selection includes four yellow (Y), one orange (O), nine pink (P) and thirty-four red (34) varieties. They include carriers (7) and non-carriers (41) of the STAY-GREEN (SGR) protein mutation.

Table 1. Fruit morphological characteristics in fully ripened fruits of the 48 tomato genotypes studied.

Type	Local Name (Number Identification)	Colour*	Size**	Shape
Corazón Toro	Tomate Corazón (1)	P	XL	Heart-shaped
	Corazón de Toro (2)	R	XL	Heart-shaped
de la Sierra	Amarillo Chaparral (3)	Y	L	Flattened
	Tomate Amarillo (4)	Y	XL	Flattened
	Tomate de Agramón (5)	P	XL	Flattened
	Tomate de la Sierra (6)	P-B	XL	Squared
	Negro de Nerpio (7)	R-B	XL	Flattened
Flor de Baladre	Tomate Rosa (8)	P	XL	Flattened
	Flor de Baladre 1 (9)	P	XL	Flattened
	Flor de Baladre 2 (10)	P	XL	Squared
	Flor de Baladre 3 (11)	P	XL	Flattened
Kumato	Bola Negra (12)	R-B	M	Rounded
	Tomate Redondo (13)	R-B	M	Rounded
	Tomate Pera Negro (14)	R-B	M	Pruned
Mesa Murciano	Rosa de Barranda (15)	P	XL	Flattened
	Rosa de la Arboleja (16)	P	XL	Flattened
	Tomate Acorazonado (17)	R	XL	Heart-shaped
	Tomate Cuarenteno (18)	R	L	Flattened
	Tomate Murciano (19)	R	L	Rounded
	Tomate del País 1 (20)	R	L	Rounded
	Tomate del País 2 (21)	R	XL	Flattened
	Tomate Mesa 1 (22)	R	XL	Squared
	Tomate Mesa 2 (23)	R	L	Rounded
	Tomate Gordo (24)	R	L	Globose
Muchamiel	Muchamiel (25)	R	XL	Pruned
	Pera Muchamiel (26)	R	L	Flattened
	Tomate Aplastado (27)	R	L	Flattened
	Tomate de Molina (28)	R	XL	Squared
	Tomate Muchamiel 1 (29)	R	XL	Squared
	Tomate Rizado (30)	R	XL	Flattened
	Muchamiel Corazón (31)	R	XL	Pyriform

	Muchamiel Gordo (32)	R	XL	Squared
	Tomate Muchamiel 2 (33)	R	XL	Flattened
Pera	Pera Pinatar (34)	R	L	Pyriform
	Tomate Alargado (35)	R	M	Squared
	Tomate Aperado (36)	R	M	Pyriform
	Tomate de Mesa (37)	R	L	Squared
	Tomate Pera (38)	R	L	Pyriform
Pimiento	Tomate Pimiento 1 (39)	R	L	Pepper
	Tomate Pimiento 2 (40)	R	L	Pepper
Cherry	Bombilla Amarillo (41)	Y	S	Pyriform
	Cherry Amarillo (42)	Y	S	Rounded
	Bolica Naranja (43)	O	S	Rounded l
	Bolica Roja (44	R	XS	Rounded
	Cherry (45)	R	XS	Rounded
	Tomate Bombilla (46)	R	S	Pyriform
	Tomate Negro (47)	R-B	S	Rounded
	Tomate Redondico (48)	R-B	S	Rounded

*P: Pink, R: Red, Y: Yellow, R-B: Red-Black, P-B: Pink-Black, O: Orange. **XL: Very Large, L: Large, M: Medium, S: Small, XS: Very Small.

This mutation causes the inhibition of chlorophyll degradation during the ripening process and therefore the presence of chlorophyll in the ripe fruit. As a result of this mutation, the fruits are pink-black (P-B), as in 'de la Sierra', or reddish-black (R-B), as in 'Negro de Nerpio', 'Bola Negra', 'Tomate Redondo', 'Pera Negro', 'Tomate Negro' and 'Tomate Redondico', which have a dark colour of varying intensity.

A high variability in size and weight was also observed, including varieties with flattened (15), squared (8), rounded (11), heart-shaped (3), pepper-shaped (2), pyriform (6), spherical (1) and truncated (2) fruits, and with different sizes and weights, from very small to very large. Thus, fruits were classified as very small (<15 g), small (≥15 and <70 g), medium (≥70 and <150 g), large (≥150 and <300 g) and very large (≥300 g).

This variability was observed both between types and between varieties. As expected, the smallest varieties were of the 'cherry' type (41-48), with weights ranging from about 8 to 50 grams (Table 2), the smallest being the so-called 'cherry' variety with an average weight of 8 grams. On the other hand, the largest varieties were 'Corazon' and 'Flor de Baladre', with fruits weighing over 400 grams. For the 'Pera' and 'Pimiento' varieties, the average weight and size of the fruit was between 130 and 190 grams per fruit.

With regard to titratable acidity (TA) and total soluble solids (TSS), the values obtained showed a high variability within types and varieties (Table 2), ranging from 2 to 7.8 g citric acid L^{-1} and 3.3 to 8.7 ºBrix. In general, the highest values of both parameters corresponded to the 'Cherry' type, among which the varieties 'Bolica Roja (44)' and 'Cherry (45)' stood out. On the other hand, the lowest values, between 2 and 3 for total acidity and 3 and 4 for TSS, were found in the varieties 'Pimiento', 'Muchamiel' and 'Mesa Murciano' and in 'de la Sierra', 'Flor de Baladre', 'Mesa Murciano' and 'Muchamiel'. Within these varieties, 'Tomate Gordo (24)' and 'Tomate Rosa (8)' stood out for their low TSS values, 3.3 and 3.6

ºBrix, respectively, and 'Tomate Gordo 2 (32)' and 'Tomate Pimiento 2 (40)' for their low acidity values, 2 and 2.4 g L^{-1}, respectively.

As with the previous parameters, a large variability was observed between both types and varieties in the equatorial and longitudinal diameters and in the colour parameters determined, which were consistently related to the shape and colour defined by the IPGRI (International Plant Genetic Resources Institute) descriptors and were in line with what was expected within the characteristics of each variety. The variability observed in the size, colour and shape of the selected varieties was also observed in the nutritional and organoleptic composition of the fruits (Figures 2, 3 and 4). In general, the cherry genotypes were superior in terms of organoleptic and nutritional compounds, with high concentrations of sugars, organic acids, vitamin C and carotenoids.

With regard to sugars, the main compounds found were glucose and fructose (Fig. 2), whose values ranged between 6-25 mg g^{-1} and 6-30 mg g^{-1}, respectively. For both sugars, the highest values were found in genotypes 42, 43 and 45 (cherry type). Among the remaining genotypes, 6, 13 and 18 showed the highest values for both sugars.

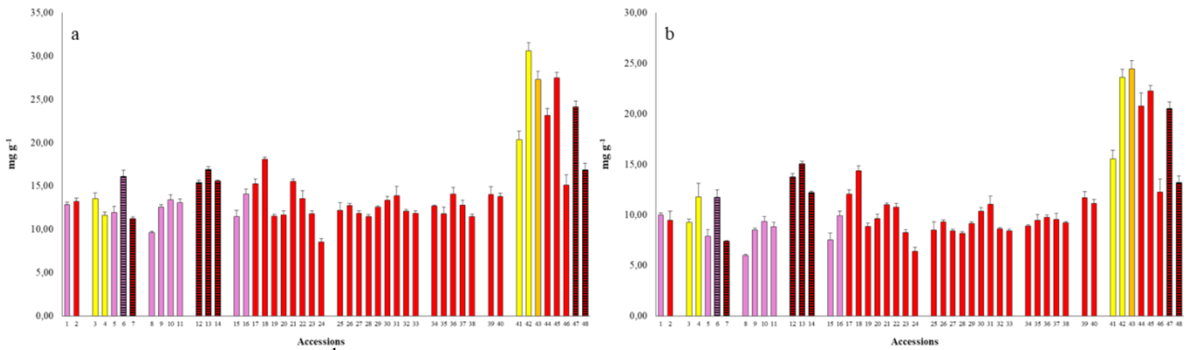

Fig. 2. Concentration (mg g^{-1} FW) of fructose (a) and glucose (b) in tomato accessions classified from 1 to 48 (according to the key in Table 1) and coloured according to the external colour of the fruit. Bars represent mean ± SE (n=4).

Table 2. Fruit weight (g), equatorial diameter (Eq. Diameter, mm), longitudinal diameter (Lg. Diameter, mm), colour parameters (L, a*, b*), total soluble solids (SST, ºBrix) and acidity (AT, g L^{-1}) of landrace tomatoes at harvest.

Landrace	Fruit Weight	Eq. Diameter	Lg. Diameter	L	a*	b*	SST	AT
1	406.8	92.4	94.3	35.0	19.4	11.1	4.7	3.1
2	441.4	96.8	89.7	35.5	18.1	10.5	4.4	3.1
3	207.0	86.3	50.7	48.9	-4.5	21.6	5.0	3.5
4	507.4	112.5	77.0	51.9	-5.2	23.0	4.0	3.7
5	524.1	111.6	68.4	33.9	11.4	12.3	4.4	3.2
6	387.0	100.0	70.0	34.7	11.0	10.0	5.3	4.7
7	535.7	113.8	70.6	32.6	10.3	11.9	4.0	3.1
8	586.2	116.0	64.9	36.2	15.8	10.4	3.6	2.9
9	474.9	172.5	132.9	38.0	17.4	12.1	4.7	3.4
10	529.0	120.6	70.4	37.3	18.7	11.6	4.7	3.0
11	535.9	119.6	72.7	39.8	18.1	12.5	4.6	3.1
12	120.0	62.8	54.8	31.3	10.4	11.0	5.8	3.3
13	123.1	61.5	55.7	30.8	7.9	10.0	5.6	3.1

14	54.2	42.3	52.3	31.9	10.0	11.0	5.7	5.0
15	494.9	111.2	70.6	42.9	14.5	12.3	5.7	2.6
16	451.8	105.9	70.2	41.4	19.2	13.8	5.5	4.2
17	325.8	91.2	71.1	48.7	10.0	24.5	5.0	3.6
18	235.7	83.6	62.0	35.3	19.4	14.7	5.8	3.0
19	259.0	81.8	67.6	37.0	20.8	15.9	4.5	4.0
20	288.1	90.4	69.6	36.0	18.5	14.9	4.7	4.5
21	462.3	110.8	70.7	31.5	15.2	12.1	5.7	3.8
22	313.7	88.6	62.9	35.2	16.1	12.8	4.8	3.5
23	237.1	79.7	75.2	37.7	16.4	15.1	4.3	3.5
24	269.9	84.7	65.8	37.0	18.8	16.0	3.3	2.9
25	477.7	113.6	68.7	38.3	15.3	15.2	3.9	2.6
26	274.7	94.3	65.8	36.6	22.3	14.5	4.5	3.6
27	417.2	108.8	65.6	36.6	17.9	13.5	4.4	3.2
28	371.9	98.2	66.1	37.5	19.2	14.6	4.3	3.1
29	378.3	106.1	70.9	35.2	20.5	13.7	4.4	2.7
30	284.5	91.5	74.9	38.2	21.5	15.8	5.0	2.6
31	284.2	92.4	77.8	36.5	20.2	15.0	4.9	2.7
32	420.7	113.2	69.8	35.2	22.9	14.9	4.1	2.0
33	391.1	99.9	68.3	38.6	17.7	11.7	3.9	2.6
34	159.2	72.5	73.4	37.6	19.1	13.9	4.9	3.2
35	135.6	68.4	58.3	35.5	19.0	13.8	5.3	3.8
36	135.5	63.9	64.7	36.0	19.0	14.1	4.8	4.0
37	171.6	72.2	72.1	36.2	22.0	15.1	5.0	2.7
38	140.9	62.2	66.9	37.5	21.1	16.2	5.0	3.6
39	195.5	57.8	117.3	33.9	20.2	14.6	5.2	3.1
40	190.9	62.8	103.2	35.8	21.2	15.3	5.0	2.4
41	15.3	28.1	43.7	48.2	-3.7	23.3	6.3	4.6
42	16.1	29.5	30.8	40.6	-0.9	18.9	8.7	5.2
43	19.6	28.0	39.8	39.5	11.4	19.4	8.2	5.5
44	11.9	26.9	26.4	30.7	14.9	11.1	8.3	7.8
45	7.9	23.6	22.1	33.4	17.9	13.3	8.7	5.0
46	46.9	46.3	43.4	34.2	18.1	13.1	5.6	4.8
47	41.5	41.7	40.7	29.2	3.3	9.3	7.7	4.6
48	51.8	42.1	52.4	30.7	10.8	10.3	5.6	3.4

With regard to the organic acids (Fig. 3), thirteen compounds were determined, three major acids, citric, malic and glutamic, which ranged between 4.5-13.6, 0.6-1.7 and 4.4-10.4 mg g^{-1} respectively, and ten minor acids (quinic, tartaric, pyruvic, isocitric, shikimic, malonic, ketoglutaric, succinic, fumaric and glutaric), which were present in all the genotypes studied. In general, the citric acid content (Fig. 3a) of the cherry-type fruits was higher than that of the other varieties, with the 'Bolica Roja' genotype standing out (13.6 mg g^{-1}). On the other hand, genotype 3 (de la Sierra type, Amarillo Chaparral) stood out for its malic acid content (1.7 mg g^{-1}). Cherry tomatoes also stood out for their minority acid content (Fig. 3d). The pepper genotypes also showed the lowest values of organic acids. The glutamic acid content ranged from 4.4 (44, Bolica Roja) to 10.4 mg g^{-1} (26, Pera Muchamiel).

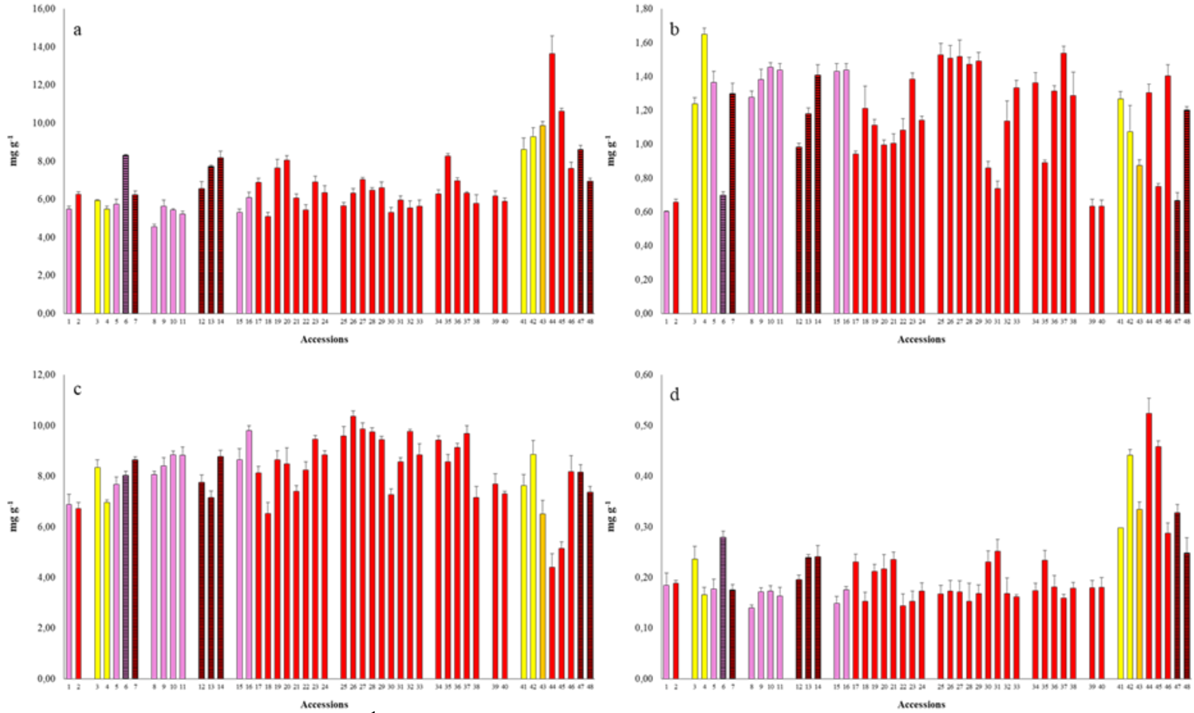

Fig. 3. Concentration (mg g^{-1} FW) of citric acid (a), malic acid (b), glutamic acid (c) and sum of minority acids (d), in tomato accessions classified from 1 to 48 (according to the key in Table 1) and coloured according to the external colour of the fruit. Bars represent mean ± SE (n=4).

Similarly to the previous results, the vitamin C content (Fig. 4) was related to the type and size of the fruit, with the highest concentrations being obtained in the small or very small cherry genotypes. The minimum value (9 mg 100 g^{-1}) was found in 23 and 24 (Mesa Murciano type) and the maximum value (40 mg 100 g^{-1}) in 45 (Cherry).

Finally, the content of total carotenoids (Fig. 4), which ranged from 18 to 165 µg g^{-1}, was directly related to the colour of the fruit, being absent or present in low concentrations in yellow and pink fruits. Red, orange and red-black coloured fruits showed the best results. Again, the highest levels were found in cherry fruits, especially in genotype 47 (Black Tomato), which had a very intense red-black colour.

4. DISCUSSION

The development and valorisation of new varieties must take into account many factors, from yield to resistance to environmental changes, from taste to storage or transport characteristics, and of course consumer preferences and/or market requirements (Ribes-Moya et al., 2018, Sinesio et al., 2021). In this respect, landraces can represent a portfolio of desirable crop characteristics, as they are best adapted to local growing conditions, require less agrochemical resources compared to modern varieties, and maintain a high diversity of yields, flavours, colours and shapes (Ribes-Moya et al., 2018, Moreno-Peris et al., 2020). The latter makes them very attractive to consumers and markets.

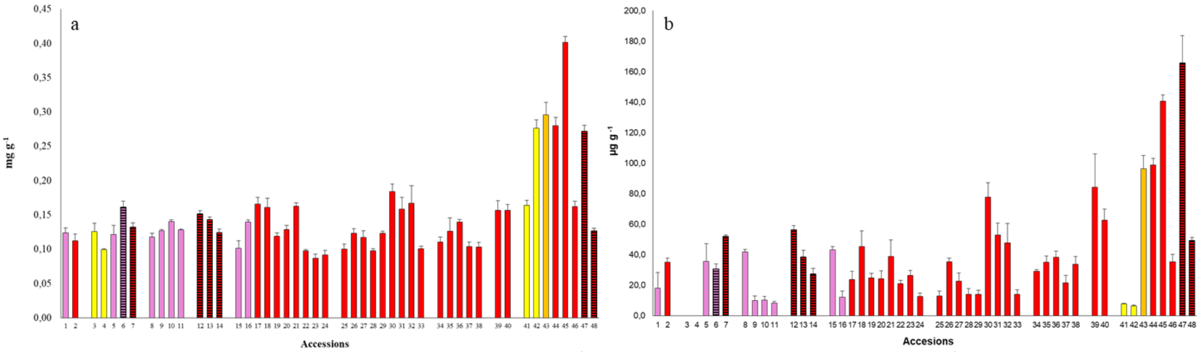

Fig. 4. Concentration of vitamin C (a, mg g^{-1} FW) and carotenoids (b, µg g^{-1} FW), in tomato accessions classified from 1 to 48 (according to the key in Table 1) and coloured according to the external colour of the fruit. Bars represent mean ± SE (n=4).

This study analysed the diversity present in a number of local tomato varieties, taking into account different physical (weight, colour, size, shape), organoleptic (total soluble solids, acidity, sugars and organic acids) and nutritional (vitamin C and carotenoids) characteristics. The analysis of fruit weight and colour gave an idea of the variability present both between and within varieties. This variability was also observed in the nutritional and organoleptic composition of the fruits. It is well known that consumers often select tomatoes based on their appearance, and colour and size are two of the most important quality factors that influence the appearance of tomatoes and therefore their acceptability (Yahia and Brecht, 2012).

In our study, tomato fruits have different external colours, such as pink, yellow, orange and red, as a result of the colour of the flesh and skin. Thus, a pink tomato is due to a colourless skin and red flesh, while an orange tomato is due to the presence of a yellow skin and red flesh (Figás et al., 2015). Genotypes with reddish-black and pinkish-black colouring are also included in our study because they carry the STAY-GREEN (SGR) mutation. These genotypes are currently widely accepted by consumers and growers, partly due to their distinctive colour and characteristic flavour (Manoharan et al., 2017). In addition to their organoleptic quality, these varieties have a high nutraceutical value due to their proven properties against cancer and other diseases (Fahey et al., 2005). In this sense, and considering the role of nutrition in health, it is interesting to include in the diet products rich in antioxidants such as vitamins, carotenoids and chlorophylls (Cruz et al., 2013). For example, the vitamin C content of commercial tomatoes is around 0.13 mg g^{-1} (George et al., 2017, Bonachela et al., 2022) and the carotenoid content is 40-60 µg g^{-1} (Cebrino et al., 2011, Figàs et al., 2015, Flores et al., 2017), while in our study 50% of the varieties studied reached or exceeded these concentrations, so they can be considered good sources of healthy compounds and can be defined as varieties with "high added value".

5. CONCLUSIONS

An integrated description of traditional tomato varieties from south-eastern Spain was carried out, including morphological, organoleptic and nutritional parameters. The aim of this study was to characterise and subsequently exploit local tomato varieties particularly adapted to low-input cultivation. The results showed a high variability and the presence of varieties with high nutritional quality. The red-black and pink-black varieties, regardless of their size, stood out for their organoleptic composition and flavour, mainly due to their fructose and citric acid content. Muchamiel tomatoes also stood out for their glutamic acid content, one of the components of the "umami" flavour. In terms of bioactive compounds, the cherry tomatoes were once again outstanding, but the 'tomate cuarenteno' and 'tomate pimiento' also showed very interesting values for vitamin C and carotenoids. After this study, we hope that these varieties can be used either for direct exploitation ("per se") or for the improvement and development of new hybrid varieties of high quality and taste, supporting the interest of farmers and consumers.

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REFERENCES

1. Messmer, MM 2015, "Plant breeding techniques-an assessment for organic farming", *Research Institute of Organic Agriculture*, vol. 37.
2. Figàs, M.R.; Prohens, J.; Raigón, M.D.; Fita, A.; García-Martínez, M.D.; Casanova, C.; Borràs, D.; Plazas, M.; Andújar, I.; Soler, S. Characterization of composition traits related to organoleptic and functional quality for the differentiation, selection and enhancement of local varieties of tomato from different cultivar groups. Food Chem. 2015, 187, 517–524.
3. Ribes-Moya, AM, Raigón, MD, Moreno-Peris, E, Fita, A, Rodríguez-Burruezo, A 2018, "Response to organic cultivation of heirloom Capsicum peppers: Variation in the level of bioactive compounds and effect of ripening", *PLoS ONE*, vol. 13, pp. 0207888.
4. Casals, J, Pascual, L, Cañizares, J, Cebolla-Cornejo, J, Casañas, F, Nuez, F 2011, "The risks of success in quality vegetable markets: Possible genetic erosion in Marmande tomatoes (*Solanum lycopersicum* L.) and consumer dissatisfaction", *Scientia Horticulturae*, vol. 130, pp. 78–84
5. Oltman, SM 2014, "Consumer attitudes and preferences for fresh market tomatoes", *Journal of Food Science*, vol. 79, pp. 2091-2097.
6. Klee, HJ, Tieman, DM. 2018, "The genetics of fruit flavour preferences", *Nature Reviews Genetics*, vol. 19, pp. 347–356 (2018).
7. Cheng, G, Chang, P, Shen, Y 2020, "Comparing the Flavor Characteristics of 71 Tomato (Solanum lycopersicum) Accessions in Central Shaanxi", *Frontier Plant Science*, vol. 11, pp. 586834.
8. Martínez-Ispizua, E, Martínez-Cuenca, MR, Marsal, JI, Díez, MJ, Soler, S, Valcárcel, JV, Calatayud, Á 2021, "Bioactive compounds and antioxidant capacity of valencian pepper landraces", *Molecules*, vol. 26, pp. 1031.
9. Sinesio, F, Cammareri, M, Cottet, V, Fontanet, L, Jost, M, Moneta, E, Palombieri, S, Peparaio, M, Romero del Castillo, R, Saggia-Civitelli, E 2021, "Sensory traits and consumer's perceived quality of traditional and modern fresh market tomato varieties: a study in three European countries", *Foods*, vol. 10, pp. 2521.
10. Fita, A, Rodríguez-Burruezo, A, Boscaiu, M, Prohens, J, Vicente, O 2015, "Breeding and domesticating crops adapted to drought and salinity: a new paradigm for increasing food production". *Frontiers in Plant Science,* vol. 6, pp. 978.
11. Alrteimei, HA, Ash'aari, ZH, Muharram, FM 2022, "Last decade assessment of the impacts of regional climate change on crop yield variations in the Mediterranean region", *Agriculture*, vol. 12, nº11, pp. 1787-1799.
12. Bonachela, S, Fernández, MD, Cabrera-Corral, FJ, Granados, MR 2022, "Salt and irrigation management of soil-grown Mediterranean greenhouse tomato crops drip-irrigated with moderately saline water", *Agricultural Water Management*, vol. 262, pp. 107433-107450.
13. Polade, SD, Gershunov, A, Cayan, DR, Dettinger, M, Pierce, D 2017, "Precipitation in a warming world: Assessing projected hydro-climate changes in California and other Mediterranean climate regions", *Scientific Reports*, vol. 7, pp. 10783.
14. Cebrino, F, Ruiz, M. Yuste, M. García, M. Gómez, D 2011, "Characterization of traditional tomato varieties grown in organic conditions", *Spanish Journal Agricultural Research,* vol. 2, pp. 444–452.

15. Fullana-Pericàs, M, Conesa, MÀ, Gago, J, Ribas-Carbó, M, Galmés, J 2022, "High-throughput phenotyping of a large tomato collection under water deficit: Combining UAVs' remote sensing with conventional leaf-level physiologic and agronomic measurements". *Agricultural Water Management*, vol. 260, pp. 107283.
16. Renard, D, Tilman, D 2019, "National food production stabilized by crop diversity". *Nature*, vol. 571, pp. 257-260.
17. Morales-Soto, A, Garcia-Salas, P, Rodriguez-Perez, C, Jimenez, C 2014, "Antioxidant capacity of 44 cultivars of fruits and vegetables grown in Andalusia (Spain)", *Food Reseach International*, vol. 58, pp. 35-46.
18. Kavitha, P, Shivashankara, KS, Rao, VK, Sadashiva, AT, Ravishankar, KV, Sathish, GJ 2014, "Genotypic variability for antioxidant and quality parameters among tomato cultivars, hybrids, cherry tomatoes and wild species", *Journal of the Science of Food and Agriculture*, vol. 94, pp. 993-999.
19. Flores, P, Hernandez, V, Hellin, P, Fenoll, J, Cava, J, Mestre, T, Martinez, V 2016, "Metabolite profile of the tomato dwarf cultivar Micro-Tom and comparative response to saline and nutritional stresses with regard to a commercial cultivar". *Journal of the Science of Food and Agriculture*, vol. 96, pp. 1562-1571.
20. Flores, P, Sánchez, E, Fenoll, J, Hellín, P 2017, "Genotypic variability of carotenoids in traditional tomato cultivars", *Food Research International*, vol. 100, pp. 510-516.
21. Flores, A, Pérez, A, Abadía, E, Sánchez, J, Garrido, I, Molina, MV, Rodríguez-Burruezo, A, Raigón, MD, Ribes-Moya, AM, Fenoll, J, Hellín, P 2018, "Evaluación de la productividad de variedades tradicionales de tomate de alta calidad sensorial y nutricional", *Actas de Horticultura*, vol. 80, pp. 18-21.
22. Ribes-Moya, AM, Adalid, AM, Raigón, MD, Hellín, P, Fita, A, Rodríguez-Burruezo, A 2020, "Variation in flavonoids in a collection of peppers (Capsicum sp.) under organic and conventional cultivation: effect of the genotype, ripening stage, and growing system", *Journal Science Food and Agricultural*, vol. 30, pp. 2208-2223.
23. Guijarro-Real, C, Adalid-Martínez, AM, Pires, CK, Ribes-Moya, AM, Fita, A, Rodríguez-Burruezo, A 2023, "The effect of the varietal type, ripening stage, and growing conditions on the content and profile of sugars and capsaicinoids in capsicum peppers", *Plants*, vol. 12, pp. 231.
24. Flores, P, Hellín, P, Fenoll, J 2012, "Determination of organic acids in fruits and vegetables by liquid chromatography with tandem-mass spectrometry". *Food Chemistry*, vol. 132, pp. 1049-1054.
25. Fenoll, J, Martínez, A, Hellín, P, Flores, P 2011, "Simultaneous determination of ascorbic and dehydroascorbic acids in vegetables and fruits by liquid chromatography with tandem-mass spectrometry", *Food Chemistry*, vol. 127, pp. 340-344.
26. Nagata, M, Yamashita, I 1992, "Simple method for simultaneous determinations of chlorophyll and carotenoids in tomato fruit", *Nippon Shokuhin Kogyo Gakkaish*, vol. 39, pp. 925-928
27. Moreno-Peris, E, Cortés-Olmos, C, Díez-Díaz, M, González-Mas, MC, de Luis-Margarit, A, Fita, A, Rodríguez-Burruezo, A 2020, "A hybridization in peppers (*capsicum* spp.) to improve the volatile composition in fully ripe fruits: the effects of parent combinations and fruit tissues", *Agronomy*, vol. 10, pp. 751.
28. Yahia, EM, Brecht, J 2012, "Tomatoes". In *Crop Post-Harvest*, Rees, D., Farrell, G.O.J., (Eds.; Wiley-Blackwell, Oxford, UK), pp. 5–23. ISBN 0632057254.
29. Manoharan, RK, Jung, HJ, Hwang, I 2017, "Molecular breeding of a novel orange-brown tomato fruit with enhanced beta-carotene and chlorophyll accumulation", *Hereditas*, vol. 154, pp. 1-8.

30. Fahey JW, Stephenson KK, Dinkova-Kostova AT, Egner PA, Kensler TW, Talalay P. 2005, "Chlorophyll, chlorophyllin and related tetrapyrroles are significant inducers of mammalian phase 2 cytoprotective genes", *Carcinogenesis*, vol. 26, pp. 1247–55.
31. Cruz, RM, González, JM, Sánchez, P 2013, "Propiedades funcionales y beneficios para la salud del licopeno". *Nutrición Hospitalaria*, vol. *28*, pp: 6-15.
32. George, GM, Ruckle, ME, Abt, MR, Bull, SE 2017, "Ascorbic acid biofortification in crops", In *Ascorbic Acid in Plant Growth, Development and Stress Tolerance*, Springer: Cham, Switzerland, pp: 375-415.