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Chemical composition of tomato (*Lycopersicon esculentum*) from Tenerife, the Canary Islands

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Abstract

Chemical composition (moisture, ash, total fibre, protein, glucose and fructose), the taste index and maturity were determined in five tomato cultivars (Dorothy, Boludo, Thomas, Dominique, Dunkan) which were cultivated using intensive, organic and hydroponic methods in Tenerife. The chemical composition was similar to most of the data found in the literature. There were many significant differences in the mean values between the analysed parameters according to the cultivar, cultivation method, region of cultivation and sampling period. Glucose and fructose concentrations were strongly and positively correlated, suggesting the common origin of both sugars. The moisture correlated inversely with the rest of the analysed parameters. Applying a stepwise discriminant analysis (DA), low percentages of correct classifications were obtained according to the cultivar and cultivation methods. The correct classification of the tomato samples improved when the DA was applied to differentiate the tomatoes according to the sampling period.

Keywords: Tomato; Cultivar; Fructose; Glucose; Protein; Total fibre; Taste index; HPLC

1. Introduction

The tomato (*Lycopersicon esculentum*) is one of the most widely consumed fresh vegetables in the industrialised world. It is also widely used by the food industries as a raw material for the production of derived products such as purees or ketchup. The tomato is also the most common vegetable in the Mediterranean diet, a diet known to be beneficial for health, especially with regard to the development of chronic degenerative disease (Leonardi, Ambrosino, Esposito, & Fogliano, 2000). Tomato fruit quality has been assessed by the content of chemical compounds such as dry matter, Brix degree, acidity, single sugars, citric and other organic acids and volatile compounds (Thybo, Edelenbos, Christensen, Sørensen, & Thorup-Kristensen, 2006).

A series of quantitative and qualitative changes of the chemical composition take place during tomato fruit ripening. Organic acids, soluble sugars, amino acids, pigments and over 400 aroma compounds contribute to the taste, flavour and aroma volatile profiles of the tomatoes (Petro-Turza, 1987). The ripening of tomatoes is characterised by the softening of the fruit, the degradation of chlorophylls and an increase in the respiration rate, ethylene production, as well as the synthesis of acids, sugars and lycopene (Cano, Acosta, & Arnao, 2003). Tomatoes contain higher levels of fructose and glucose than sucrose (Garvey & Hewitt, 1991; Miron & Schaffer, 1991).

The tomato is a very important crop in the Canary Islands. It represents approximately 28% of the total agricultural production but only accounts for 7% of the agricultural soil use. The exportation of tomatoes in 2004 was 214,224 Tm (Gobierno de Canarias, 2006). We determined, in previous papers, the mineral and trace element (Hernández Suárez, Rodríguez Rodríguez, & Díaz

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Romero, 2007a) and organic acid (Hernández Suárez, Rodríguez Rodríguez, & Díaz Romero, 2007b) concentrations in several tomato cultivars which are of the highest commercial interest for the island of Tenerife, the Canary Islands.

The aims of this paper were (1) to determinate the content of several major chemical compounds which contribute to the nutritive quality of the tomato (2) to evaluate the change of the chemical composition according to the cultivation method, sampling period and region of production and (3) to apply multivariate analysis techniques for classifying the tomato samples into homogeneous groups.

2. Materials and methods

2.1. Tomato sampling

One hundred and sixty seven samples, belonging to five cultivars of tomatoes (Dorothy, Boludo, Thomas, Dominique, Dunkan), were provided by the main producer in Tenerife (ACETO) and other companies from different farms located in the southern and western regions of the island. Besides, the tomato samples were authenticated by technicians from the Excmo. Cabildo Insular de Tenerife (Insular Government).

The tomatoes were harvested between October 2004 and June 2005 and they were selected at point 7–8 of the ripening colour chart (Kleur-stadia tomaten, Holland). The preparation of the tomato samples for analysis was carried out within two weeks after harvesting. Four samples (≈1 kg of weight) of each of the five cultivars were collected during that period and they were grouped into two sampling periods: (1) October 2004–January 2005 and (2) February–June 2005. The tomatoes were grown using three cultivation methods (intensive, organic and hydroponic). Intensive tomato samples were from two regions of production, the south and west of Tenerife (Canary Islands). The hydroponic tomato samples were from the western production region and belonged to the following three cultivars: the Dorothy, Boludo and Dunkan cultivars and they were cultivated on coconut fibre. All the organic samples came from the southern region. Three tomatoes were randomly selected from each tomato sample for analysis. The main characteristics of the tomato samples analysed are described in Table 1.

2.2. Sample preparation method

The three tomatoes selected from each sample were weighed and then hand-rinsed with ultrapure water, shaken to remove any excess water and gently blotted with a paper towel. The tomatoes were then mixed and homogenised to a homogeneous puree using a model T-25 Basic Turmix (Ika-Werke, Staufen, Germany). The puree was stored in a polyethylene tube at −80 °C. Several sub-samples were taken in duplicate from this puree to measure moisture, ash, protein, total fibre, glucose and fructose. Besides, a taste index and the maturity were calculated using the equation proposed by Navez, Letard, Graselly, and Jost (1999) and Nielsen (2003) starting from the Brix degree and acidity values which were determined in a previous paper (Hernández et al., 2007b).

$$\text{Taste index} = \frac{\text{Brix degree}}{20 \times \text{acidity}} + \text{acidity}$$

$$\text{Maturity} = \frac{\text{Brix degree}}{\text{acidity}}$$

2.3. Reagents and standards

Acetonitrile of HPLC-gradient grade was purchased from Merck (Darmstadt, Germany). Standards of *D*(+)-glucose anhydrous, *D*(−)-fructose and sucrose were from Fluka (Buchs, Switzerland). Stock solutions (1 g/l) were prepared in ultrapure water (Millipore, Bedford, MA, USA) and stored in darkness at 5 °C. Deionised water was purified with a Milli-Q water system (Millipore Corporation, MA, USA).

2.4. Analytical methods

The analytical methods used were AOAC methods or similar. Moisture was determined by desiccation at 105 °C for 24 h (AOAC, 1990). Ash was determined by calcinations at 550 °C for 24 h, of the residue obtained in the moisture determination (AOAC, 1990). Nitrogen concentration was obtained applying the Kjeldahl method (AOAC, 1990) and the protein concentration was calculated using a nitrogen factor of 6.25. Total dietary fibre was determined according to the method proposed by Prosky et al. (1985).

Table 1
Distribution of the tomato samples analysed according to cultivar, cultivation method, sampling period and region of production

Cultivar	Total	Cultivation method			Sampling period		Region of production[a]	
		Intensive	Organic	Hydroponic	October 2004–January 2005	February–June 2005	West	South
Dorothy	50	25	14	11	30	20	16	9
Boludo	46	28	14	4	24	22	15	13
Dominique	19	10	9	0	12	7	0	0
Thomas	25	16	9	0	16	9	0	0
Dunkan	27	4	12	11	12	15	0	0
Overall	167	82	58	26	94	73	31	22

[a] Only in intensive cultivation.

The determination of sugars was performed by HPLC using a Waters apparatus (Milford, MA, USA) consisting of a pump (600E Multisolvent Delevery System), an autosampler (700 Wisp Model) and a differential refractive index (DRI) detector (Waters model 2414). The separation was performed by using a Waters Carbohydrate Analysis 3.9×300 mm with a particle diameter of 10 μm, using a Waters Carbohydrate Carbo^{TM} 4 μm guard column to protect the analytical column. The column was at room temperature during all the experiments. The HPLC pumps, autosampler, column oven and DRI detector were monitored and controlled using the Millennium^{32} system (version 4.0).

The analytical method used for sugar determination was the one proposed by Li, Andrews, and Pehrsson (2002), with small modifications. About 1 g of frozen homogenised tomato puree was exactly weighed in polypropylene tubes and mixed with 2 ml of 80% ethanol. Afterwards, the tubes were put into an ultrasound bath for 5 min and then centrifuged for 5 min at 3500 rpm. The supernatant was carefully recovered to prevent contamination with the homogenised tomato puree pellet. Another 2 ml of 80% ethanol were then added to the pellet and placed in an ultrasound bath and centrifuged as above. The two supernatants were pooled inside the same tube. This liquid phase was concentrated with a nitrogen stream until total ethanol elimination, the residue was adjusted to 5 ml with ultrapure water (Milli-Q water system) and stored at −80 °C in the freezer. A millilitre of this dissolution was passed through a 0.45 μm filter GHP (Waters, Millford, MA, USA) prior to HPLC analysis. Duplicate injections were performed and average peak areas were used for the quantification. The mobile phase was composed of 80% acetonitrile. The injection volumes of samples were 25 μl, at a flow rate of 2 ml/min. The HPLC sample peaks were identified by comparing the retention times.

2.5. Statistics

All the statistical analyses was performed by means of the SPSS version 14.0 software for Windows. The Kolmogorov–Smirnov test was applied to verify whether the distribution of the variables was normal ($p < 0.05$). When the statistical distribution was not normal, the variables were transformed by applying Naperias logarithms to convert them into a normal distribution. The Levene test was applied to verify the homogeneity of the variances. Mean values obtained for the variables studied in the different groups were compared by One-Way ANOVA (Duncan's multiple range), assuming there were significant differences among them when the statistical comparison gave $p < 0.05$. Simple linear correlation analysis was used to indicate a measure of the correlation and the strength of the relationship between two variables. Discriminant analysis (DA) was used to classify the tomato samples in homogeneous groups and DA is based on the extraction of linear discriminant functions of the independent variables. Two processes were applied in DA: (1) Stepwise DA that selected the quantitative variables that enhance discrimination of the groups established by the dependent variable and (2) Introduction of all independent variables. The objective of this process is to maintain all the information, although the system obtained is more complex.

3. Results and discussion

3.1. Chemical composition of the tomato cultivars

Methods for protein, ash and total fibre were validated using the Rye CRM-383. The recoveries obtained were 95.0%, 104% and 99.8% for protein, ash and total fibre respectively and the values of precision were 2.25%, 3.21% and 2.61% for those same parameters respectively.The results obtained in the chemical parameters analysed in all the samples and differentiating them according to the cultivars considered are shown in Table 2. The results of the variance analysis of the comparison among the mean values are also indicated in this Table. Significant differences were observed between the mean concentrations or values for all the analysed parameters, except for moisture and total fibre. The Dominique cultivar presented the highest values in most of the determined parameters such as weight, total fibre, protein, glucose, fructose and taste index. In contrast, the Dorothy cultivar showed the lowest mean values in weight, ash, glucose, fructose, taste index and maturity and the highest moisture content.

Leonardi et al. (2000) studied the variation of several parameters according to the typologies of tomato, including the weight of the unit. These authors found a mean weight of 107 g for the cluster tomato and of 156 g for the salad tomatoes. The mean weights observed in this paper were similar to the data found for the cluster tomato. The variance analysis statistically distinguishes two groups of cultivars according to their weight. The Dorothy and Dunkan cultivars presented a lower mean weight ($p < 0.05$) than that obtained for the other three cultivars.

The mean concentration for moisture was inside the usual range for tomatoes reported in the literature (Li et al., 2002; Moreiras, Carvajal, Cabrera, & Cuadrado, 2005; Ortega Anta, López Sobaler, Requejo Marcos, & Carvajales, 2004; Senser & Scherz, 1999). There were no statistical differences between cultivars ($p > 0.05$) for the moisture, ranging between 93.8% for the Boludo and Thomas cultivars to 94.1% for the Dorothy cultivar. The mean ash content was similar to other data reported in the literature (Oke, Ahn, Schofield, & Paliyath, 2005). Oke et al. (2005) analysed how the phosphorus fertiliser supplementation acted on the content of several parameters between the years 2000–2002. No significant differences between treatments were observed for the ash content, giving values of 0.46–1.05% for non phosphorus supplemented tomatoes and 0.51–1.24% for high phosphorus supplemented tomatoes. Our values of ash are within this range, regardless

Table 2
Means ± standard deviation; (minimum–maximum) of the chemical composition, taste index and maturity of tomato samples in all samples grouped according to cultivar[A]

Parameter	Overall	Dorothy	Boludo	Dominique	Thomas	Dunkan	p (sig)
Weight (g)	102 ± 26.3 (61.5–195)	91.1 ± 23.7^{a} (61.5–187)	107 ± 25.5^{b} (65.2–162)	119 ± 30.3^{b} (74.1–178)	111 ± 28.9^{b} (79.3–195)	91.9 ± 13.1^{a} (69.0–121)	**0.000**
Moisture (%)	93.9 ± 0.8 (91.2–95.6)	94.1 ± 0.8 (91.2–95.5)	93.8 ± 0.8 (91.7–95.3)	93.9 ± 0.9 (91.9–95.1)	93.8 ± 0.9 (91.9–95.6)	94.0 ± 0.6 (92.8–95.4)	0.383
Ash (%)	0.62 ± 0.07 (0.39–0.80)	0.59 ± 0.08^{a} (0.39–0.74)	0.65 ± 0.06^{c} (0.52–0.78)	0.63 ± 0.08^{bc} (0.47–0.75)	0.61 ± 0.06^{ab} (0.51–0.80)	0.61 ± 0.06^{ab} (0.45–0.72)	**0.001**
Total fibre (%)	1.82 ± 0.53 (0.9–3.7)	1.87 ± 0.46 (1.0–3.3)	1.84 ± 0.49 (1.0–2.9)	1.92 ± 0.65 (1.0–3.3)	1.74 ± 0.66 (1.0–3.7)	1.71 ± 0.48 (0.9–3.0)	0.447
Protein (%)	0.80 ± 0.15 (0.4–1.2)	0.79 ± 0.16^{a} (0.5–1.2)	0.78 ± 0.13^{a} (0.6–1.1)	0.87 ± 0.15^{b} (0.6–1.2)	0.82 ± 0.12^{ab} (0.6–1.1)	0.78 ± 0.16^{a} (0.4–1.0)	**0.158**
Glucose (%)	0.93 ± 0.40 (0.2–2.1)	0.85 ± 0.28^{a} (0.2–1.7)	1.00 ± 0.40^{ab} (0.2–1.7)	1.16 ± 0.49^{b} (0.3–1.9)	0.91 ± 0.51^{a} (0.3–2.1)	0.86 ± 0.37^{a} (0.2–1.7)	**0.037**
Fructose (%)	1.02 ± 0.41 (0.2–2.2)	0.96 ± 0.28^{a} (0.4–1.7)	1.04 ± 0.41^{a} (0.3–1.9)	1.24 ± 0.54^{b} (0.3–2.2)	0.97 ± 0.47^{a} (0.2–2.0)	0.98 ± 0.40^{a} (0.3–1.8)	**0.109**
Taste index	0.97 ± 0.09 (0.8–1.2)	0.94 ± 0.08^{a} (0.8–1.1)	0.98 ± 0.10^{ab} (0.8–1.2)	1.00 ± 0.07^{b} (0.9–1.1)	0.97 ± 0.10^{ab} (0.8–1.2)	1.00 ± 0.07^{b} (0.8–1.1)	**0.041**
Maturity	9.4 ± 1.9 (5.5–14.7)	9.3 ± 1.9 (6.5–13.9)	9.0 ± 1.8 (5.5–14.7)	9.5 ± 1.8 (6.9–13.1)	9.7 ± 2.0 (6.5–14.1)	9.7 ± 1.7 (5.9–13.6)	0.411

[A] Results in the same row with the same superscript were not significantly different ($p < 0.05$). Significant differences in the same group are indicated in bold letters. Results are expressed as fresh weight.

of the cultivation method. In a previous paper, we reported the concentration of the minerals (P, Na, K, Ca and Mg) and trace elements (Fe, Cu, Zn and Mn) in these samples of tomatoes (Hernández Suárez et al., 2007a). The trace elements seemed to be more influenced by the cultivar than the minerals and the cultivation method affected the mineral contents more than the trace element contents. However, significant differences were found in the mean ash content between the cultivars. The Boludo cultivar presented the highest mean ash concentration with significant differences with respect to the concentrations of the Dorothy, Dunkan and Thomas cultivars.

The mean content of total fibre in the analysed tomatoes was 1.82 ± 0.53%, which was slightly higher than other data found in the literature (Moreiras et al., 2005; Ortega Anta et al., 2004). There is no significant difference for the mean content of total fibre, with the Dunkan cultivar presenting the lowest mean value with a similar content to the Thomas cultivar. In a study about the chemical composition of five fibre sources performed by Claye, Idouraine, and Weber (1996), they observed that the tomato fibre was composed of 87% insoluble fibre and 13% soluble fibre.

The mean protein content obtained in this paper (0.80 ± 0.15%) was lower than data found in some food composition charts (Moreiras et al., 2005; Ortega Anta et al., 2004) and higher than other data described in the literature (Wheeler, Mackowiak, Stutte, Yorio, & Berry, 1997). The Dominique cultivar showed the highest mean concentration of protein with significant differences ($p < 0.05$) when compared to the Dunkan, Boludo and Dorothy cultivars.

The mean contents of glucose (0.93 ± 0.40%) and fructose (1.02 ± 0.41%) were similar and were correlated in all the cultivars. The mean concentrations of tomato carbohydrate ranged between 3% and 3.5% according to the food composition charts (Moreiras et al., 2005; Ortega Anta et al., 2004). These values are higher than ours (glucose plus fructose), which is due to the fact that other additional carbohydrates, not quantified by us, such as starch are included. Loiudice et al. (1995) observed that fructose was the most abundant sugar but with a similar value to glucose which agrees with our results. However, the concentrations of both sugars in this paper were lower than those concentrations reported by Loiudice et al. (1995): 1.2 ± 0.21% for glucose and 1.4 ± 0.24% for fructose and Osvald, Petrovič, and Demšar (2001): 1.21 ± 0.23% for glucose and 1.21 ± 0.33% for fructose. The latter authors also found minor amounts of sucrose (0.05%) and xylose (0.03%), which were not detected by us. The ratio glucose:fructose is an important data in the authenticity test of fruits (AIJN, 1999). In tomato, this ratio must be about 0.8–1 which agrees with the data obtained by us. Maul et al. (2000) studied the changes of fructose and glucose in tomatoes affected by different storage temperatures. These authors observed that at 20 °C there was a greater loss of glucose than of fructose, at room temperature. The mean glucose content was 1.24% and 0.99% after two and eight storage days respectively. As regards the fructose content, this sugar changed from 1.27% to 1.20% in the same conditions. These values are slightly higher than ours. When comparing the mean concentrations between cultivars, one can observe that, the Dominique cultivar had higher mean concentrations for both sugars than the rest of the cultivars, with significant differences in all the cases, except when the glucose content was compared with the mean concentration obtained in the Boludo cultivar.

The taste index is calculated using the values of Brix degree and acidity, applying the equation performed by Navez et al. (1999). Hernández et al. (2007b) shows the mean values of these two parameters (Brix degree and acidity) according to cultivar, cultivation method and harvest period for the same group of tomatoes. The average contents Brix degree and acidity were 4.6 ± 0.9 and 0.50 ± 0.09 g/100 g of citric acid, respectively (Hernández et al., 2007b). When using these data, the mean values of the taste index in all the tomatoes belonging to all the cultivars considered were higher than 0.85, which indicates that the tomato cultivars analysed are tasty. If the value of the taste index is lower than 0.7, the tomato is considered as having little taste (Navez et al., 1999). The Dorothy cultivar had a mean value of the taste index lower ($p < 0.05$) than those values determined for the Dominique and Dunkan cultivars. Another parameter related with the taste index is maturity which is usually a better predictor of an acid's flavour impact than Brix degree or acidity alone. Acidity tends to decrease with the maturity of the fruits while the sugar content increases (Raffo et al., 2002). The average maturity for these samples was 9.4 ± 1.9 (Hernández et al., 2007b) and therefore, it can be deduced that the maturity levels of the analysed tomatoes were adequate for consumption (Nielsen, 2003). This ratio can also be affected by climate, cultivar and horticultural practices (Nielsen, 2003). However, no significant differences were observed in the mean values of maturity between the tomato cultivars considered.

3.2. Influence of the cultivation method

The results of the variance analysis of the comparison between the mean values obtained in the weight, moisture, ash, total fibre, protein, glucose, fructose and the taste index and maturity according to the cultivar and cultivation method are shown in Table 3. The hydroponic system presented significant differences ($p < 0.05$) in the mean values between the tomato cultivars for all the parameters, except moisture, ash, protein, taste index and maturity. In contrast, the cultivars belonging to the intensive and organic methods behaved in a similar way; they only differed statistically in weight and total fibre, as well as in ash in the intensive cultivars.

The mean weight of the tomato was highly influenced by the cultivar and cultivation method, so there were many significant differences among the different groups of tomatoes analysed. The mean weight of the organic Dorothy cultivar was higher ($p < 0.05$) than the other two systems, while the weight of the intensive Thomas cultivar was higher ($p < 0.05$) than the organic Thomas cultivar. When the mean weight between the cultivars within the same cultivation method was considered, important differences were observed. Therefore, the intensively cultivated Dorothy cultivar had a lower mean weight ($p < 0.05$) than the rest of the cultivars. Organic tomatoes belonging to the Dominique cultivar had a higher mean weight than the Thomas and Dunkan cultivars. The hydroponically cultivated Boludo cultivar had a mean weight higher ($p < 0.05$) than the mean weight found for the Dorothy and Dunkan cultivars.

In general, all the intensive and organic tomato cultivars had similar mean values of moisture. Hydroponic tomatoes had a higher mean moisture content than the other two cultivation methods. No significant differences ($p > 0.05$) for the three cultivation methods were observed when considering the mean contents of moisture according to the cultivar.

There were no statistically significant differences when the ash values of each cultivar were compared according to the cultivation methods. When the ash content was compared between the tomato cultivars, the intensive Dorothy, Thomas and Dunkan cultivars showed a lower ($p < 0.05$) mean ash concentration than those mean concentrations found in the Boludo and Dominique cultivars.

The mean percentages of total fibre in the three cultivation methods were arranged in the following sequence: hydroponic tomatoes > organic tomatoes > intensive tomatoes. Comparing this parameter within each cultivation method according to their cultivar, one can observe significant differences in the three cultivation methods. The Thomas cultivar had a lower ($p < 0.05$) mean concentration than the Dorothy cultivar in the intensive tomatoes. The organic tomatoes belonging to the Dunkan, Dorothy and Boludo cultivars had a lower total fibre concentration ($p < 0.05$) than those values found in the Thomas cultivar. In the hydroponic tomatoes, the Dunkan cultivar also showed the lowest mean fibre concentration with significant differences ($p < 0.05$) in relation to the concentration found in the Boludo cultivar.

As regards the protein content, the results are opposite to those of the total fibre content. There were no significant differences when the protein content was compared according to the cultivation methods for each cultivar. Significant differences were not found when the influence of the cultivar was considered within the three types of tomatoes according to the cultivation methods.

No significant differences were found in the glucose and fructose contents for all the cultivars when the tomatoes were grouped according to the cultivation method. However, the intensive tomatoes had the highest mean contents of glucose and fructose when they were compared with the organic tomatoes, except for the Thomas cultivar. No significant differences were found either when the influence of the cultivar was considered within the intensive and organic tomatoes. However, for the hydroponic tomatoes, the Boludo cultivar presented higher ($p < 0.05$) mean concentrations of glucose and fructose than the rest of the tomato cultivars.

The hydroponic tomatoes presented a lower taste index than intensively and organically cultivated tomatoes, with significant differences for the Dorothy and Dunkan cultivars. No significant differences were observed between

Table 3
Mean values of the composition of the tomato according to cultivar and cultivation method

Parameter	Cultivar	Cultivation method			p^A
		Intensive	Organic	Hydroponic	
Weight (g)	Dorothy	82.4^{a}	106^{ab}	92.0^{a}	**0.011**
	Boludo	103^{b}	109^{ab}	130^{b}	0.134
	Dominique	115^{b}	125^{b}	–	0.488
	Thomas	121^{b}	94.4^{a}	–	**0.018**
	Dunkan	99.2^{b}	86.3^{a}	95.4^{a}	0.113
	p^B	**0.000**	**0.018**	**0.000**	
Moisture (%)	Dorothy	93.8	94.3^{b}	94.4	0.079
	Boludo	93.7	93.8^{ab}	94.2	0.547
	Dominique	93.9	93.8^{ab}	–	0.728
	Thomas	94.0	93.4^{a}	–	0.075
	Dunkan	93.4	93.9^{b}	94.3	**0.042**
	p^B	0.666	0.141	0.761	
Ash (%)	Dorothy	0.59^{a}	0.61	0.58	0.558
	Boludo	0.65^{b}	0.65	0.61	0.502
	Dominique	0.63^{b}	0.63	–	0.938
	Thomas	0.59^{a}	0.64	–	0.074
	Dunkan	0.59^{a}	0.62	0.60	0.775
	p^B	**0.008**	0.512	0.569	
Total fibre (%)	Dorothy	1.79^{b}	1.83^{a}	2.10^{ab}	0.260
	Boludo	1.72^{ab}	1.85^{a}	2.63^{b}	**0.001**
	Dominique	1.72^{ab}	2.11^{ab}	–	0.340
	Thomas	1.39^{a}	2.36^{b}	–	**0.000**
	Dunkan	1.61^{ab}	1.69^{a}	1.78^{a}	0.889
	p^B	**0.041**	**0.050**	**0.030**	
Protein (%)	Dorothy	0.83	0.79	0.70	0.071
	Boludo	0.80	0.76	0.72	0.408
	Dominique	0.84	0.90	–	0.434
	Thomas	0.81	0.84	–	0.647
	Dunkan	0.83	0.81	0.73	0.395
	p^B	0.924	0.302	0.883	
Glucose (%)	Dorothy	0.92	0.78	0.78^{a}	0.468
	Boludo	0.99	0.93	1.22^{b}	0.445
	Dominique	1.29	1.01	–	0.234
	Thomas	0.86	1.00	–	0.618
	Dunkan	1.01	0.94	0.71^{a}	0.261
	p^B	0.186	0.564	**0.001**	
Fructose (%)	Dorothy	0.99^{ab}	0.97	0.90^{a}	0.843
	Boludo	1.05^{ab}	0.94	1.26^{b}	0.425
	Dominique	1.39^{b}	1.08	–	0.183
	Thomas	0.90^{a}	1.10	–	0.283
	Dunkan	1.12^{ab}	1.01	0.88^{a}	0.561
	p^B	0.122	0.845	**0.047**	
Taste index	Dorothy	0.96	0.95	0.89	**0.047**
	Boludo	0.98	0.99	0.93	0.628
	Dominique	1.01	0.98	–	0.286
	Thomas	0.96	0.98	–	0.595
	Dunkan	1.04	1.02	0.95	**0.027**
	p^B	0.277	0.413	0.057	
Maturity	Dorothy	9.6	9.2	8.6	0.362
	Boludo	8.9	8.9	9.5	0.709
	Dominique	10.1	9.0	–	0.135
	Thomas	10.2	8.8	–	0.103
	Dunkan	10.6	9.7	9.3	0.404
	p^B	0.129	0.620	0.535	

Results in the same column with the same superscript were not significantly different ($p < 0.05$). Significant differences in the same group are indicated in bold letters. Results are expressed as fresh weight.

[A] p value of the comparison by lines.

[B] p value of the comparison by column.

intensive and organic tomatoes for all the cultivars considered. No significant differences were found between the cultivars in the mean taste index obtained for intensively and organically cultivated tomatoes.

3.3. Influence of sampling period and production region

The results regarding the analysed parameters when grouping the tomato samples according to cultivation method, cultivar and the two sampling period considered are shown in Table 4. Intensive and hydroponic tomatoes showed a higher number of significant differences between the mean values of the analysed parameters obtained in the sampling periods. This could be connected with the relatively low number of organic tomato samples analysed, which did not allow us to find significant differences between the mean values. Besides, the intensive Boludo cultivar stands out because it presented significant differences in all the parameters, except for maturity. However, the organic Boludo cultivar did not show any significant differences.

The intensive tomatoes from the October 2004–January 2005 period had higher values for mean weight in all the studied cultivars, except the Thomas cultivar, than the corresponding tomatoes sampled in the February–June 2005 period. Significant differences were for the intensive Dorothy, Boludo and Dunkan cultivars. Similar results were found in organically cultivated tomatoes, however, no significant differences were obtained for all the cultivars. In contrast, the two hydroponic tomatoes, the Dorothy and Dunkan cultivars, produced in the February–June 2005 period had a higher mean weight than those mean values found in the other period.

The parameter with the highest number of significant differences, among the intensively grown cultivars, was the moisture. In all the cultivars, except the Dominique cultivar, the mean moisture was higher ($p < 0.05$) in tomatoes sampled from the October 2004–January 2005 period than from the February–June 2005 period. A low influence of sampling period was observed on the moisture content of the organically and hydroponically produced tomatoes, with no significant differences between the mean contents.

The ash content in both sampling periods was similar in the intensive tomatoes belonging to the Dorothy, Dominique and Thomas cultivars. The results obtained in the organic tomatoes indicated that there were considerable differences for some cultivars between both sampling periods, although no significant differences were reached. So, the mean ash content in the tomatoes from the February–June 2005 period for the Dorothy, Dominique and Dunkan cultivars was higher than those mean contents obtained in the other tomatoes from the sampling period.

Table 4
Mean values of the chemical composition, weight, taste index and maturity in tomato groups according to the cultivation method, cultivar and the sampling period

	Period	Weight (g)	Moisture (%)	Ash (%)	Total fibre (%)	Protein (%)	Glucose (%)	Fructose (%)	Taste index	Maturity
(1) Intensive										
Dorothy	Oct–Jan	**88.7**	**94.2**	0.59	1.77	0.83	0.86	1.02	**0.92**	**8.9**
	Feb–Jun	**72.9**	**93.4**	0.59	1.83	0.82	1.01	0.95	**1.02**	**10.7**
Boludo	Oct–Jan	**121**	**94.1**	**0.62**	**1.43**	**0.76**	**0.80**	**0.90**	**0.91**	8.6
	Feb–Jun	**79.5**	**93.2**	**0.68**	**2.09**	**0.85**	**1.24**	**1.25**	**1.07**	9.3
Dominique	Oct–Jan	127	93.8	0.64	1.93	0.89	1.40	1.65	1.02	9.7
	Feb–Jun	102	94.1	0.63	1.59	0.79	1.18	1.13	1.01	10.4
Thomas	Oct–Jan	118	**94.5**	0.58	1.31	0.82	**0.59**	**0.63**	**0.87**	8.5
	Feb–Jun	124	**93.6**	0.59	1.47	0.80	**1.12**	**1.15**	**1.05**	11.9
Dunkan	Oct–Jan	**106**	**93.9**	**0.62**	1.68	0.87	0.63	0.84	**0.98**	9.1
	Feb–Jun	**92.3**	**93.0**	**0.57**	1.53	0.78	1.38	1.41	**1.11**	12.1
(2) Organic										
Dorothy	Oct–Jan	115	94.5	0.59	**1.63**	**0.90**	0.80	1.02	0.93	8.4
	Feb–Jun	93.7	93.9	0.63	**2.07**	**0.64**	0.76	0.90	0.98	10.4
Boludo	Oct–Jan	113	93.8	0.65	1.76	0.79	0.93	1.02	0.97	7.7
	Feb–Jun	104	93.7	0.66	1.97	0.72	0.93	0.84	1.02	10.6
Dominique	Oct–Jan	127	93.9	0.62	1.96	0.93	1.03	1.08	0.97	8.7
	Feb–Jun	120	93.5	0.68	2.64	0.77	0.96	1.08	1.02	10.0
Thomas	Oct–Jan	92.1	93.3	0.65	2.52	0.85	0.93	1.08	0.97	8.5
	Feb–Jun	113	93.8	0.58	1.13	0.77	1.53	1.31	1.07	11.7
Dunkan	Oct–Jan	90.0	94.0	0.57	1.80	0.92	0.82	0.90	0.96	8.9
	Feb–Jun	84.4	93.9	0.64	1.64	0.91	0.99	1.07	1.04	10.1
(3) Hydroponic										
Dorothy	Oct–Jan	86.9	94.7	**0.57**	1.80	**0.74**	0.82	0.97	**0.87**	8.1
	Feb–Jun	101	94.0	**0.59**	2.63	**0.63**	0.72	0.78	**0.92**	9.5
Dunkan	Oct–Jan	**90.1**	94.3	0.61	**1.50**	0.80	0.81	1.03	0.92	**8.1**
	Feb–Jun	**102**	94.2	0.60	**2.11**	0.64	0.60	0.71	0.99	**10.9**

Significant differences in the same group are indicated in bold letters. Results are expressed as fresh weight.

The hydroponic tomatoes belonging to the Dorothy cultivar from the February–June 2005 period also had a higher mean ash content than the tomatoes from the first period of sampling.

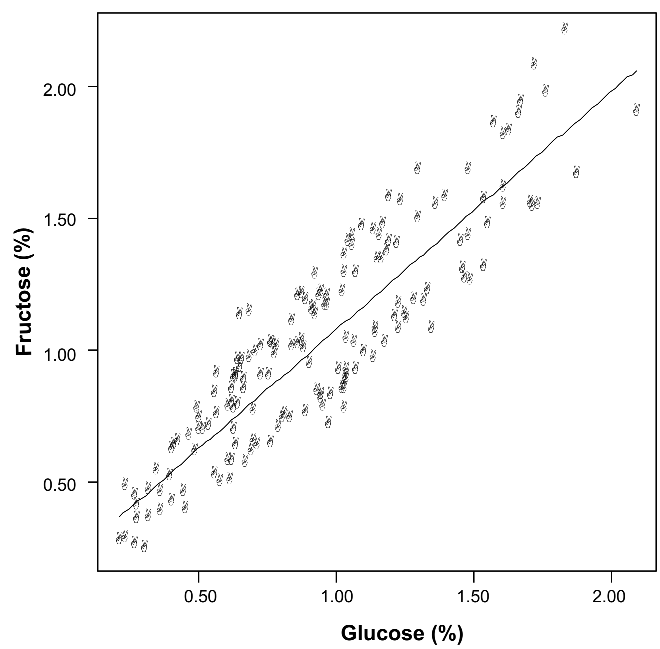
As for the total fibre and protein, there were only significant differences between the mean concentrations in the intensive Boludo cultivar, which was the cultivar with the highest total fibre and protein values in the tomatoes from the February–June 2005 period. The rest of cultivars did not show any statistical difference between both sampling periods. As regards the organic tomatoes, significant differences were only observed for the total fibre and protein of the Dorothy cultivar. There were also considerable differences between the mean contents for the other cultivars. The organic Boludo and Dominique cultivars had the highest mean contents of total fibre in tomatoes from the February–June 2005 period, while the mean protein contents of these two cultivars were higher in the other period. The hydroponic tomatoes had a higher content of total fibre in the second period while the mean values of protein were higher in the first sampling period.

The glucose and fructose concentrations were similar for most of the cultivars and cultivation methods. For all the intensive cultivars, except the Dominique cultivar, the tomatoes from the February–June 2005 period had higher mean glucose content than those collected during the October 2004–January 2005 period. Similar results were observed for the mean fructose content in all the cultivars, except the Dorothy cultivar. The mean sugar concentrations in the other two cultivation methods (organic and hydroponic cultivations) was different. There were no significant differences ($p > 0.05$) in the mean concentrations of glucose and fructose found in both considered sampling periods.

The taste index results were different to the moisture results. The tomatoes from the February–June 2005 period had the higher mean taste index and lower moisture values than these values found in the other period. Therefore, an influence of the sampling period was observed in the values of this index, related with the maturity, for the intensive tomatoes. The mean values of the taste index and maturity found in the February–June 2005 period were higher than those mean values observed in the tomatoes cultivated in the first sampling period for all the cultivation methods and cultivars, except for the intensive Dominique cultivar. Important differences, although not significant, between the mean values of maturity were also obtained in the organically produced tomato cultivars. The hydroponic Dorothy cultivar for the taste index and the hydroponic Dunkan cultivar for the maturity also presented significant differences between both sampling periods.

3.4. Multivariate analysis

A statistical study of the correlation between all the analysed parameters was previously carried out to find the associations between the measured pairs of these parameters. Many significant ($p < 0.05$) correlations were observed, although most of them had correlation coefficient factors lower than $r = 0.5$ (Table 5). The correlation between fructose and glucose had a high coefficient of correlation ($r = 0.896$) (Fig. 1). This correlation defines the following lineal regression that makes it possible to determine the content of one sugar when the concentration of



Fructose (%) = 0.90 • Glucose (%) + 0.17
r = 0.896

Fig. 1. Correlation between fructose and glucose.

Table 5
Pearson's coefficient correlation of the direct correlations obtained between all the analysed parameters

	Moisture	Ash	Total fibre	Protein	Glucose	Fructose	Taste index	Maturity
Weight	0.278[a]		−0.238				−0.244	
Moisture		−0.402	−0.402	−0.332	−0.494	−0.428	−0.715	−0.295
Ash			0.183	0.388			0.271	−0.243
Total fibre					0.293	0.283	0.246	
Protein					0.243	0.230	0.262	
Glucose						0.896	0.479	0.290
Fructose							0.391	0.223
Taste index								0.497

[a] Only the significant correlations ($p < 0.05$) are shown.

the other is known. This correlation has been observed in other fruits such as bananas (Forster, Rodríguez, & Díaz, 2002). This suggests a common origin for both sugars, probably from the sucrose obtained from starch hydrolysis (Coultate, 1998). The moisture showed positive correlation with the mean weight of tomatoes and inverse correlations with the dry weight and the rest of the parameters considered. The correlation between the moisture and taste index is particularly significant ($r = -0.715$) and is shown in Fig. 2. A decrease of the taste index can be clearly observed with the increase of moisture, or decrease of the dry extract. Besides, the taste index was related with the rest of the analysed parameters, this relationship was positive for protein, fibre, ash, glucose, fructose and maturity and inverse for the mean weight. However, the correlation coefficients were relatively low except for the sugars and taste index.

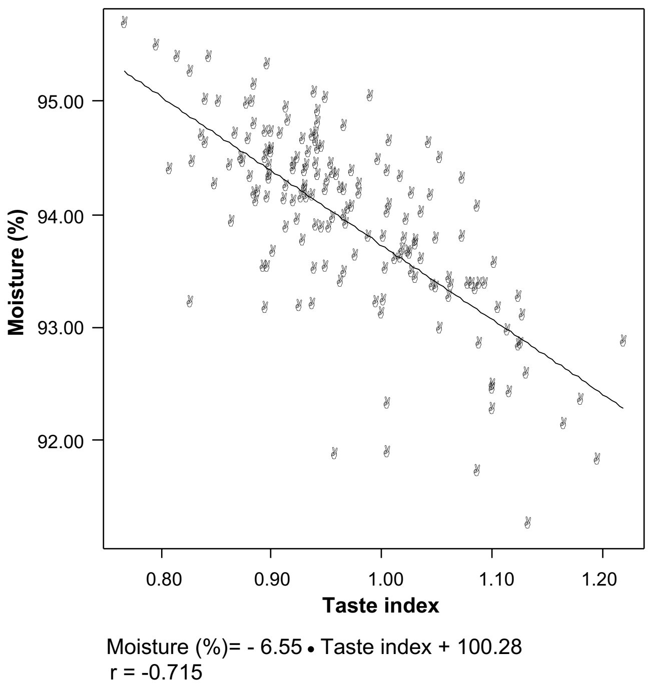


Fig. 2. Correlation between moisture content and taste index.

Discriminant analysis (DA) was performed on the studied quantitative parameters to differentiate the tomato samples according to the cultivar, cultivation method, production region and sampling period. After application of stepwise DA to all the data, low percentages of correct classification were obtained in the classifications according to the cultivar (40.7% and 38.3% after cross-validation) and cultivation method (53.3% and 50.9% after cross-validation). The stepwise DA was repeated on the samples corresponding to each tomato cultivar, in an independent manner, to differentiate the tomato samples according to the cultivation method. Low or moderate percentages of correct classification were obtained when selecting different parameters as a function of the cultivar considered. When the DA was applied by introducing all the variables, the correct classification percentage increased in all the cultivars, although the results of the cross-validation decreased: Dorothy 76.0% (52.0% after cross-validation); Boludo 76.1% (60.9% after cross-validation); Dunkan 70.4% (48.1% after cross-validation); Dominique 73.7% (47.4% after cross-validation); and Thomas 96.0% (84.0% after cross-validation).

Table 6
Results of the stepwise discriminant analysis for all the cultivars and cultivation methods to differentiate the sampling period

Cultivar	Number of samples and percentage (%) of correct classification		Selected variables
	Oct04–Jan05	Feb05–Jun05	
(1) Intensive			
Dorothy	14 (93.3%)	10 (10%)	Protein, taste index, fructose
	Global classification: 96% (88%)		
Boludo	26 (100%)	12 (100%)	Weight, ash, protein, taste index
	Global classification: 100% (92.9%)		
Thomas	8 (100%)	8 (100%)	Moisture, taste index
	Global classification: 100% (100%)		
Dunkan	2 (100%)	2 (100%)	Ash, glucose
	Global classification: 100% (100%)		
(2) Organic			
Dorothy	7 (87.5%)	6 (100%)	Protein
	Global classification 92.9% (92.9%)		
Thomas	8 (100%)	1 (100%)	Moisture, total fibre, fructose
	Global classification: 100% (88.9%)		
Dunkan	4 (400%)	8 (100%)	Moisture, protein
	100% (100%)		
(3) Hydroponic			
Dorothy	7 (100%)	4 (100%)	Total fibre, protein, fructose
	Global classification 100% (81.8%)		
Dunkan	4 (66.7%)	2 (100%)	Total fibre, protein
	Global classification: 81.8% (81.8%)		

A new DA was performed on the intensive Dorothy and Boludo cultivars to differentiate the production region. Low percentages of correct classification were obtained when stepwise DA was used. High or moderate classifications were observed: 92.0% (60.0% after cross-validation) and 71.4% (50.0% after cross-validation) for the Dorothy and the Boludo cultivars, respectively, after introducing all the variables. When the stepwise DA was applied to differentiate the tomato samples according to sampling period, the classification obtained was relatively high (84.4% and 83.2% after cross-validation), when selecting moisture and total fibre. If this same DA was applied to the groups of tomato samples in function of cultivation method and cultivar (Table 6), a high level of correct classification within their group was observed. This indicates that the sampling period is a more important factor than cultivar or cultivation methods for the differentiation of the tomato samples according to the chemical characteristics. This could be related with slight differences observed in the ripening stage, which decisively influence the chemical parameters studied in this paper.

4. Conclusions

There are many factors such as cultivar, cultivation method, region of cultivation and date of sampling that influence the chemical composition of tomatoes. The sampling period is a more influential factor than cultivar, cultivation methods or region of production in the differentiation of the tomato samples according to the chemical characteristics. Some differences in the ripening stage could decisively influence the studied chemical parameters. The glucose and fructose contents are strongly correlated. The discriminant analysis can be useful tool to differentiate the tomato samples into homogeneous groups.

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