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ScienceDirect
Food Chemistry 104 (2007) 489–499
Food Chemistry
www.elsevier.com/locate/foodchem

Mineral and trace element concentrations in cultivars of tomatoes

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Received 5 April 2006; received in revised form 23 October 2006; accepted 28 November 2006

Abstract

The concentrations of minerals (P, Na, K, Ca and Mg) and trace elements (Fe, Cu, Zn and Mn) were determined in 167 tomato samples belonging to five cultivars (Dorothy, Boludo, Dunkan, Dominique and Thomas) produced on the island of Tenerife. The contribution to the intake of minerals and trace elements was in general low, with special emphasis on the contributions of K and Mg. The cultivar, cultivation method, period of sampling and region of production in the island influenced the concentrations of minerals and trace elements of the tomatoes. Trace elements seemed more influenced by the cultivar than the minerals, and the cultivation method affected mineral contents more than trace element contents. The period of sampling had an important influence on the mineral and trace elements. Many correlations were observed between the minerals and trace elements studied. Applying discriminant analysis, the tomato samples tended to be classified according to the cultivation method, period of sampling and region of cultivation.

Keywords: Tomatoes; Tenerife island; Mineral; Trace element; Multivariate analysis; Method of cultivation; Region of cultivation; Sampling period

1. Introduction

The consumption of tomatoes is currently considered as a nutritional indicator of good dietary habit and healthy life style. This fruit has undoubtedly assumed the status of a food with functional properties, considering the overwhelming epidemiological evidence for its capacity to reduce the risk of certain types of cancers (Nguyen & Schwartz, 1999). Thus, its consumption contributes to the intakes of fibre, antioxidant compounds and certain minerals.

The tomato (*Lycopersicum esculentum*) crop represents approximately 28% of total production in the Canary Islands, with only 7% of the agricultural soil (Gobierno de Canarias, 2005). The exportation of tomatoes in the year 2004 was 214,224 Tm. In accordance with the ENCA (Serra-Majem, Armas Navarro, & Ribas Barba, 1999), the consumption of tomatoes in the Canary Islands is approximately 24 g of crude tomato per day and person, and it is the most consumed vegetable.

On the other hand, the mineral and trace element composition in tomato fruits has scarcely been investigated. Therefore, it is important to establish the composition of mineral and trace elements in tomatoes, and to elucidate the main factors influencing this composition. Yields are generally higher in the hydroponic system than in soil, partly because of its effective prevention of the propagation of soil-borne diseases. The hydroponic cultivation of tomatoes has recently increased in the Canary Islands, representing 24% of the total production (Gobierno de Canarias, 2005). The main substrate used for hydroponic cultivation in the Canary Islands was coconut fiber (Gobierno de Canarias, 2005), and therefore, this was the method of hydroponic cultivation studied in this paper.

The majority of consumers are convinced that vegetables, including tomatoes, grown in soil, are of superior quality to those grown in hydroponic systems and other systems using defined substrates (Dudan, 1987). Thus, it is important that both hydroponic tomato growers and producers know which factors are most important for

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doi:10.1016/j.foodchem.2006.11.072

improving tomato quality. If the type of substrate has no influence, it is important to provide definitive data showing this; if there is an effect, the hydroponic product should be adjusted to ensure the best quality possible. Obviously, the mineral and trace element contents can be altered in hydroponic cultivations.

The objectives of this paper were (1) to determine the concentrations of mineral and trace elements of nutritional interest in tomato fruits, (2) to evaluate the influence of the cultivar, growth medium and sampling period on the mineral contents and (3) to apply techniques of multivariate analysis for classifying the tomato samples into homogeneous groups.

2. Materials and methods

2.1. Tomato sampling and sample preparation

One hundred and sixty seven samples belonging to five cultivars of tomatoes were provided by the main producer of Tenerife (ACETO) and other companies from different farms located in the South and West regions of the island. They were harvested between October 2004 and June 2005 and the analyses were carried out within two weeks of harvesting. The tomato samples, corresponding to all the cultivars analysed, were grouped into two sampling periods: (1) the October 2004–January 2005 period and (2) February–June 2005 period. The tomato cultivars were authenticated by technicians from the Excmo. Cabildo Insular de Tenerife. The main characteristics of the five tomato cultivars are described in Table 1. The Dominique cultivar presented the highest mean weight, with significant differences when compared with the Dorothy and Dunkan cultivars. Each tomato sample was composed of approximately 1 kg of tomatoes selected at point 7–8 of the ripening colour chart (Kleur-stadia tomaten, Holland). The tomatoes were hand-rinsed with ultra-pure water, shaken to remove any excess water and gently blotted with a paper towel. The tomatoes were then mixed and homogenized to a homogeneous puree. A part of the puree was desiccated, homogenized again and stored in a polyethylene tube at room temperature until acid-digested for the determination of metals.

2.2. Analytical methods

Mineral and trace elements were determined using a Varian Spectra AA-10 Plus atomic absorption spectrometer equipped with a D2 lamp background correction system, using an air–acetylene flame. Determinations were carried out in duplicate. Between 0.9 and 1.1 g of dried tomato sample was weighed into digestion tubes and 6 ml of HNO_3 Suprapure (Merck) were added. The mixture was heated in a digestion block according to the following sequence: 100 °C/15 min, 115 °C/15 min, 130 °C/15 min and 160 °C/90 min. After cooling to room temperature, 1 ml of Suprapure HCl (Merck) was added and the mixture heated to 160°C/5 min. Then, this solution was quantitatively transferred and adjusted to 10 ml with ultra-pure water. One milliliter of the concentrated solution was mixed with 1 ml of LiCl (122 g/l) solution, adjusting to 10 ml with ultra-pure water for the determination of Na and K. One milliliter of the concentrated solution was mixed with 2 ml of a solution of $LaCl_3 \cdot 7H_2O$ (134 g/l), adjusting to 10 ml with ultra-pure water for the determination of Ca and Mg. Both diluted solutions were also stored in polyethylene tubes prior to the instrumental measurement. The minerals and trace elements were determined by atomic absorption spectrometry with air/acetylene flame, except K, which was determined by atomic emission spectrometry using the instrumental conditions recommended for each mineral.

Phosphorus was measured by a colorimetric method, which uses vanadate–molybdate reagent (B.O.E., 1995). In short, 0.1 ml of the concentrated acid solution obtained for the determination of mineral and trace elements was warmed in a precipitated glass until it was almost totally dry. The residue obtained was quantitatively transferred and adjusted to 2.5 ml, and 2.5 ml of vanadate–molybdate (diluted 1:2 in water) reagent (Panreac) were added. Then, the tubes were shaken and the absorbance at 400 nm was measured after 10 min.

2.3. Quality control

Wheat Flour Reference Material (ARC/CL3, LGC Deselaers) was used to evaluate the analytical methods for all the studied elements, except for Na. Quality control for

Table 1
Description of the tomato cultivars according to weight, method of cultivation and sampling period

Cultivar	Total	Weight (g)[a]	Method of cultivation			Sampling period	
			Intensive	Organic	Hydroponic	October 2004–January 2005	February–June 2005
Dorothy	50	91.1 ± 23.7[a]	25	14	11	30	20
Boludo	46	107.3 ± 25.5[b]	28	14	4	24	22
Dominique	19	119.2 ± 30.3[b]	10	9	0	12	7
Thomas	25	111.3 ± 28.9[b]	16	9	0	16	9
Dunkan	27	91.9 ± 13.1[a]	4	12	11	12	15
Overall	167	101.8 ± 26.3	82	58	26	94	73

[a] Mean ± standard deviation. Results in the same vertical column with the same superscript were not significantly ($p < 0.05$) different.

Na was checked using tomato samples spiked or not spiked with known amounts of Na standards. The recovery percentages were acceptable: P $97.5 \pm 4.8\%$; Na $98.7 \pm 3.5\%$; K $102 \pm 4.6\%$; Ca $105 \pm 2.6\%$; Mg $101 \pm 2.7\%$; Fe $99.5 \pm 4.2\%$; Cu $96.8 \pm 3.6\%$; Zn $97.3 \pm 3.3\%$; Mn $96.0 \pm 2.6\%$. Therefore, the variation coefficients were always below 5%, ranging between 2.5% and 4.9% for Ca and P respectively. The detection limits were the following: P 100 μg/100 g; Na 1 μg/100 g; K 5 μg/100 g; Ca 40 μg/100 g; Mg 14 μg/100 g; Fe 2 μg/100 g; Cu 1 μg/100 g; Zn 5 μg/100 g; Mn 1 μg/100 g. The contents of the minerals in the tomato samples were clearly above the detection and the determination limits observed. So, the determinations were of sufficient accuracy, precision and safety.

2.4. Statistics

All the statistics were performed by means of the SPSS version 13.0 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 Naperian logarithms to convert it 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 that there were significant differences among them when the statistical comparison gave $p < 0.05$. When the numbers of data were too low to verify the normality of statistical distribution, the Kruskal–Wallis non-parametric test was used to compare the mean values. Simple linear and logarithmic correlation analysis was used to indicate a measure of the correlation and the strength of the relationship between two variables. Factor analysis, using principal components as the factor extraction method, was used to summarize the information in a reduced number of factors. Discriminant analysis (DA) is based on the extraction of linear discriminant functions of the independent variables by means of a qualitative dependent variable and several quantitative 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 not to lose information, although the system obtained is more complex.

3. Results and discussion

3.1. Comparative statistical tests

3.1.1. Influence of cultivar and cultivation method

Table 2 shows the results (mean ± standard deviation) for the concentrations of the minerals studied, differentiating the cultivar and the method of cultivation. From a nutritional point of view, the consumption of one serving (≈200 g) of the tomato represents 11% of the adequate intake for K in individuals older than 14 years (Food & Nutrition Board, 2004). The contribution to the P and Mg intakes for a serving of tomato accounts for 5–10% of the recommended dietary allowances (RDA) of these elements for adults (Food & Nutrition Board, 1997), while the contributions to the Na and Ca intake were low, representing only 1–2% of the adequate intake and RDA for adults (Food & Nutrition Board, 1997, 2004).

The data obtained in this paper on Na were higher than most data published in the literature (Belitz & Grosch, 1997; Gundersen, McCall, & Bechmann, 2001; Loiudice et al., 1995; Moreiras, Carvajal, Cabrera, & Cuadrado, 2001; Senser & Scherz, 1999). Only the data reported by Künsch et al. (1994) were similar to the concentrations found in this paper. The high Na concentration in soil is due mainly to the influence of the marine aerosol (Larcher, 2003). Also, the high salinity of the water used in the irrigation (Vargas Chavez & Rodríguez Rodríguez, 2000) could explain the relatively high concentration of Na in the tomatoes from Tenerife. The concentrations of K were similar to the data indicated by Künsch et al. (1994) and Holland et al. (1991), and a little below the concentrations reported by most authors (Belitz & Grosch, 1997; Gundersen et al., 2001; Loiudice et al., 1995; Moreiras et al., 2001). Our results for Ca were near to those reported by certain investigators (Gundersen et al., 2001; Loiudice et al., 1995), although lower than most data found in the literature (Belitz & Grosch, 1997; Holland et al., 1991; Künsch et al., 1994; Loiudice et al., 1995; Moreiras et al., 2001; Senser & Scherz, 1999). With respect to Mg, the concentrations obtained by us were similar to the concentrations published by some researchers (Holland et al., 1991; Künsch et al., 1994; Moreiras et al., 2001), lower than the data reported by others (Belitz & Grosch, 1997; Senser & Scherz, 1999), and a little higher than other data found in the literature (Gundersen et al., 2001; Künsch et al., 1994).

Significant differences were observed between the mean values observed when the method of cultivation was considered (Table 2). The mean P concentration in hydroponic tomatoes was higher than its mean concentrations in the other two methods of cultivation, with significant differences in relation to the intensive tomatoes for the three cultivars studied. This could be due to the use of phosphoric acid to adjust the pH of the nutritive solution. Besides, the acid pHs, usually used for nutritive solutions, increase the bioavailability of P (Urrestarazu, 2000). The organic and intensive cultivations did not present significant differences between the mean concentrations of P. The behaviour of Na depends on the cultivar considered. Therefore, the Dorothy and Boludo cultivars, cultivated in an intensive form, showed much higher mean values than did the other two cultivation methods, while no significant differences were observed between intensive and organic cultivations for the Dominique, Thomas and Dunkan cultivars. The low concentrations of Na in the hydroponic cultivations of the Boludo and Dunkan cultivars are notable.

Table 2
Concentrations (mg/kg of wet weight) of the minerals analyzed in tomato groups according to the cultivar and the cultivation method

Element	Cultivar	Cultivation method			Overall	p[1]
		Intensive	Organic	Hydroponic		
P	Dorothy	217 ± 52^{a}	250 ± 38^{ab}	269 ± 47^{b}	238 ± 51	0.017
	Boludo	240 ± 54^{a}	254 ± 44^{a}	336 ± 24^{b}	253 ± 56	0.009
	Dominique	233 ± 47^{a}	209 ± 47^{a}	–	222 ± 47	0.271
	Thomas	270 ± 49^{a}	271 ± 22^{a}	–	271 ± 41	0.840
	Dunkan	225 ± 46^{a}	250 ± 57^{ab}	291 ± 52^{b}	263 ± 57	0.096
	p^2	0.069	0.038	0.085	–	–
Na	Dorothy	119 ± 69^{b}	57 ± 29^{a}	77 ± 64^{a}	92 ± 64	0.003
	Boludo	106 ± 70^{c}	52 ± 22^{b}	19 ± 4^{a}	82 ± 64	0.000
	Dominique	84 ± 25^{a}	104 ± 39^{a}	–	94 ± 33	0.276
	Thomas	84 ± 31^{a}	71 ± 46^{a}	–	79 ± 37	0.223
	Dunkan	138 ± 68^{b}	168 ± 67^{b}	48 ± 20^{a}	115 ± 77	0.000
	p^2	0.419	0.000	0.010	–	–
K	Dorothy	2342 ± 444^{a}	2523 ± 552^{a}	2631 ± 440^{a}	2456 ± 481	0.223
	Boludo	2583 ± 448^{a}	2545 ± 546^{a}	2159 ± 81^{a}	2535 ± 470	0.250
	Dominique	2798 ± 564^{a}	2873 ± 340^{a}	–	2834 ± 461	0.629
	Thomas	2329 ± 456^{a}	2606 ± 520^{a}	–	2429 ± 488	0.186
	Dunkan	2399 ± 118^{a}	2472 ± 477^{a}	2517 ± 449^{a}	2479 ± 421	0.933
	p^2	0.041	0.418	0.174	–	–
Ca	Dorothy	$67.6 \pm. 16.1^{a}$	70.4 ± 19.3^{a}	75.0 ± 14.0^{a}	70.0 ± 16.6	0.422
	Boludo	60.8 ± 14.2^{a}	69.1 ± 22.8^{a}	119 ± 10.5^{b}	68.4 ± 23.2	0.000
	Dominique	60.5 ± 12.1^{a}	58.7 ± 11.9^{a}	–	59.7 ± 11.7	0.744
	Thomas	69.4 ± 12.7^{a}	61.2 ± 10.2^{a}	–	66.4 ± 12.3	0.124
	Dunkan	75.4 ± 1.1^{a}	65.9 ± 11.1^{a}	68.1 ± 16.5^{a}	68.1 ± 12.9	0.466
	p^2	0.102	0.546	0.000	–	–
Mg	Dorothy	110 ± 21^{a}	112 ± 24^{a}	109 ± 14^{a}	110 ± 20	0.967
	Boludo	119 ± 19^{b}	115 ± 18^{b}	67 ± 4^{a}	113 ± 23	0.000
	Dominique	125 ± 21^{a}	131 ± 14^{a}	–	128 ± 18	0.417
	Thomas	100 ± 12^{a}	131 ± 27^{b}	–	111 ± 24	0.001
	Dunkan	127 ± 20^{b}	124 ± 12^{b}	106 ± 19^{a}	117 ± 19	0.019
	p^2	0.008	0.105	0.000	–	–

[1] p-Value of the comparison by lines. Results in the same horizontal row with the same superscript were not significantly ($p < 0.05$) different.
[2] p-Value of the comparison for columns.

The mean concentrations of K were similar in all methods of cultivation and cultivars, with no significant differences between the mean values. The mean Ca concentration in hydroponic tomatoes of the Boludo cultivar was higher ($p < 0.05$) than its mean values found in intensive and organic cultivations. The Boludo and Dunkan cultivars in the hydroponic cultivation showed lower mean Mg concentrations than they did in the other two methods of cultivation. Besides, the Thomas cultivar, organically cultivated, presented higher mean Mg concentration than it did in intensive cultivations.

The influence of the mineral concentrations among cultivars within the same method of cultivation was studied (Table 2). Considering the hydroponic tomatoes, it can be observed that the Boludo tomatoes showed lower mean Na and Mg concentrations and higher mean Ca concentration than did the Dunkan and Dorothy cultivars. Besides, the Boludo tomatoes had the highest mean P concentration, with significant differences in relation to the Dorothy cultivar. With respect to the intensive cultivations, the Dunkan cultivar showed the highest mean Na, Ca and Mg concentrations, and significant differences with the Boludo and Dominique cultivars for Ca, and with the Thomas cultivar for Mg. On the other hand, the Dominique cultivar showed the highest mean K with significant differences from the Dorothy and Thomas cultivars. However, the Dominique cultivar had a high mean Mg concentration, similar to the Dunkan, with significant differences in relation to the Thomas cultivar. When the organic tomatoes were considered, no significant differences between cultivars were observed for K and Ca. The organic tomatoes belonging to the Dunkan cultivar had a higher mean Na concentration than had those tomatoes from the Dominique cultivar, and these had a higher mean Na concentration than the rest of cultivars. The Dominique cultivar presented a mean concentration of P significantly lower than the rest of the cultivars, and the highest mean Mg concentration, with significant differences from the Dorothy cultivar.

The results (mean ± standard deviation) for the trace elements studied are shown in Table 3. In general, the contribution to the trace element intake for the consumption of one serving (≈200 g) of the tomato is very low. Thus, a serving of tomato accounts for only 5–7% of the recom-

Table 3
Concentrations (mg/kg of wet weight) of the trace elements analyzed in tomato groups according to the cultivar and the cultivation method

Element	Cultivar	Cultivation method			Overall	p^1
		Intensive	Organic	Hydroponic		
Fe	Dorothy	1.83 ± 0.54^a	1.86 ± 0.41^a	1.67 ± 0.21^a	1.80 ± 0.45	0.570
	Boludo	1.94 ± 0.44^a	1.74 ± 0.34^a	2.43 ± 0.34^b	1.92 ± 0.44	0.017
	Dominique	1.89 ± 0.45^a	1.86 ± 0.39^a	–	1.87 ± 0.41	0.900
	Thomas	2.07 ± 0.69^a	2.00 ± 0.30^a	–	2.04 ± 0.57	0.979
	Dunkan	2.62 ± 0.10^b	2.52 ± 0.43^b	1.67 ± 0.33^a	2.19 ± 0.56	0.000
	p^2	0.057	0.000	0.001	–	–
Cu	Dorothy	0.30 ± 0.11^a	0.38 ± 0.12^b	0.29 ± 0.07^a	0.32 ± 0.11	0.059
	Boludo	0.27 ± 0.13^a	0.30 ± 0.09^a	0.34 ± 0.04^a	0.28 ± 0.12	0.147
	Dominique	0.26 ± 0.14^a	0.22 ± 0.06^a	–	0.24 ± 0.11	0.739
	Thomas	0.30 ± 0.10^a	0.34 ± 0.13^a	–	0.31 ± 0.11	0.435
	Dunkan	0.18 ± 0.09^a	0.28 ± 0.06^b	0.32 ± 0.10^b	0.28 ± 0.10	0.008
	p^2	0.144	0.003	0.440	–	–
Zn	Dorothy	0.74 ± 0.24^a	0.85 ± 0.09^a	0.72 ± 0.17^a	0.77 ± 0.20	0.087
	Boludo	0.69 ± 0.15^a	0.83 ± 0.15^a	1.06 ± 0.10^b	0.76 ± 0.18	0.000
	Dominique	0.60 ± 0.14^a	0.79 ± 0.19^b	–	0.69 ± 0.19	0.025
	Thomas	0.82 ± 0.18^a	0.94 ± 0.17^a	–	0.86 ± 0.18	0.112
	Dunkan	0.75 ± 0.21^{ab}	0.66 ± 0.13^a	0.86 ± 0.16^b	0.75 ± 0.18	0.018
	p^2	0.042	0.001	0.009	–	–
Mn	Dorothy	0.59 ± 0.14^a	0.64 ± 0.14^a	0.59 ± 0.08^a	0.61 ± 0.13	0.520
	Boludo	0.53 ± 0.10^a	0.57 ± 0.13^a	1.53 ± 0.15^b	0.63 ± 0.30	0.000
	Dominique	0.59 ± 0.14^a	0.55 ± 0.10^a	–	0.57 ± 0.12	0.553
	Thomas	0.67 ± 0.19^a	0.64 ± 0.09^a	–	0.66 ± 0.16	0.780
	Dunkan	0.69 ± 0.15^b	0.44 ± 0.05^a	0.61 ± 0.13^b	0.54 ± 0.15	0.000
	p^2	0.022	0.000	0.000	–	–

[1] p-Value of the comparison by lines. Results in the same horizontal row with the same superscript were not significantly ($p < 0.05$) different.
[2] p-Value of the comparison for columns.

mended dietary allowances (Food & Nutrition Board, 2001) of Cu and Mn for adults. The contributions of the rest of the trace elements to the daily intake are lower. Investigation into the contents of trace elements in tomatoes has not only been scarce, but also out of date. Our results for Fe, Cu, Zn and Mn were similar to the data found in the literature (Gundersen et al., 2001). This could be related to the improvement of the methods for the determination of these trace elements, which suggests that it is necessary to bring the mineral values indicated in certain Food Composition Charts up to date.

There were significant differences between the mean values obtained when the method of cultivation was considered. The Dorothy cultivar, organically cultivated, had higher mean concentrations for all the trace elements studied than had those tomatoes cultivated using hydroponic and intensive systems, with significant differences for Cu. Hydroponic tomatoes belonging to the Boludo cultivar had significantly higher mean concentrations of Fe, Zn and Mn than those from the other two methods of cultivation. The Dominique and Thomas cultivars, cultivated in intensive and organic form, did not present significant differences in the mean concentrations of any of the trace elements, except that the organic Dominique cultivar showed a higher concentration of Zn than that in the intensive cultivar. Besides, the Dunkan cultivar presented lower mean Fe, Cu and Mn concentrations in the hydroponically, intensively and organically grown tomatoes, respectively, than did the other two cultivation methods.

Comparing the mean values of the trace elements among the cultivars and considering the method of cultivation in an independent manner (Table 3), it is notable that, for hydroponic cultivations, the tomatoes belonging to Boludo cultivar showed the highest mean concentrations of all the trace elements, with significant differences for Fe, Zn and Mn. In the tomato samples cultivated under intensive and organic conditions, the Dunkan cultivar showed a mean Fe concentration significantly higher than the rest of the cultivars. The Thomas cultivar showed the highest mean Cu and Zn concentrations in intensive cultivation. Besides, the Dunkan and Thomas cultivars, in intensive cultivation, had the highest mean Mn concentrations, with significant differences for the Boludo cultivar. On the other hand, the organically cultivated Dunkan cultivar presented mean Mn and Zn concentrations significantly lower than the rest of cultivars, with the Thomas cultivar having the highest mean Zn concentration. The Dorothy cultivar and Dominique had the highest and lowest mean Cu concentrations, respectively, with significant differences between them.

3.1.2. Influence of sampling period and region of production

The results for minerals (P, Na, K, Ca and Mg), corresponding to the intensive, organic and hydroponic toma-

Table 4
Concentrations (mg/kg of wet weight) of the minerals analyzed in tomato groups according to the cultivation method, the cultivar and the sampling period

	Period	P	Na	K	Ca	Mg
(1) Intensive						
Dorothy	Oct04–Jan05	210 ± 58	**84.1 ± 39.6**	2239 ± 251	**61.8 ± 14.9**	109 ± 24
	Feb05–Jun05	228 ± 42	**171 ± 71**	2496 ± 620	**76.2 ± 14.5**	110 ± 17
Boludo	Oct04–Jan05	**223 ± 44**	**69.3 ± 41.3**	**2411 ± 352**	64.2 ± 14.3	**110 ± 18**
	Feb05–Jun05	**265 ± 59**	**157 ± 71**	**2814 ± 472**	56.2 ± 13.2	**130 ± 15**
Dominique	Oct04–Jan05	215 ± 41	91.5 ± 18.0	2674 ± 409	57.8 ± 5.6	128 ± 16
	Feb05–Jun05	252 ± 51	78.5 ± 32.1	2923 ± 715	63.3 ± 16.7	122 ± 26
Thomas	Oct04–Jan05	264 ± 55	**68.6 ± 25.6**	2227 ± 464	65.2 ± 13.6	100 ± 15
	Feb05–Jun05	278 ± 46	**100 ± 31**	2467 ± 553	73.6 ± 10.9	101 ± 10
Dunkan	Oct04–Jan05	**264 ± 19**	93.9 ± 4.0	2475 ± 104	75.7 ± 1.7	**144 ± 5**
	Feb05–Jun05	**186 ± 9**	183 ± 78	2323 ± 89	75.0 ± 0.5	**110 ± 1**
(2) Organic						
Dorothy	Oct04–Jan05	239 ± 38	50.7 ± 22.2	**2280 ± 441**	64.1 ± 18.6	108 ± 30
	Feb05–Jun05	265 ± 37	65.7 ± 37.3	**2846 ± 548**	78.7 ± 18.4	118 ± 10
Boludo	Oct04–Jan05	239 ± 45	44.7 ± 17.8	2343 ± 481	62.3 ± 16.5	118 ± 23
	Feb05–Jun05	275 ± 37	60.7 ± 26.1	2814 ± 547	78.2 ± 28.2	112 ± 11
Dominique	Oct04–Jan05	202 ± 45	109 ± 43	2770 ± 283	**53.1 ± 4.32**	132 ± 15
	Feb05–Jun05	234 ± 59	88.8 ± 7.2	3233 ± 338	**78.4 ± 5.4**	127 ± 10
Thomas	Oct04–Jan05	270 ± 23	69.6 ± 48.7	2633 ± 549	62. 0 ± 10.6	134 ± 27
	Feb05–Jun05	278	82	2390	54.6	107
Dunkan	Oct04–Jan05	**186 ± 43**	147 ± 53	2124 ± 134	70.1 ± 11.6	**112 ± 8**
	Feb05–Jun05	**282 ± 27**	179 ± 74	2646 ± 496	63.8 ± 11.0	**130 ± 9**
(3) Hydroponic						
Dorothy	Oct04–Jan05	254 ± 48	87.7 ± 75.5	2481 ± 261	70.7 ± 9.2	113 ± 7
	Feb05–Jun05	294 ± 39	58.2 ± 36.7	2894 ± 604	82.5 ± 18.9	103 ± 21
Dunkan	Oct04–Jan05	303 ± 59	52.0 ± 23.5	2481 ± 439	64.9 ± 19.7	113 ± 21
	Feb05–Jun05	277 ± 45	42.0 ± 16.0	2560 ± 508	71.9 ± 12.8	96.9 ± 13.8

Significant differences ($p < 0.05$) between mean values are indicated in bold.

toes, grouped by cultivar and sampling period, are shown in Table 4. Considering the intensive cultivation, the Dorothy, Boludo and Thomas cultivars produced in the October 2004–January 2005 period had lower mineral mean concentrations than had those tomato samples of February–June 2005, except for Ca in the Boludo cultivar. The differences between the mean Na concentrations reached significance for these three cultivars. Also notable are the significant differences for P, K and Mg in the Boludo cultivar and for Ca in the Dorothy cultivar. The Dominique tomatoes did not present significant differences when they were grouped according to the sampling period. However, the tomatoes produced in the October 2004–January 2005 period had lower mean contents of P, K and Ca than had those of February–June 2005. The results for the Dunkan cultivar were different. Thus, the tomatoes sampled in the February–June 2005 period showed lower mean P, K and Mg concentrations than did those produced in the October 2004–January 2005 period, with significant differences for P and Mg.

With respect to organic tomatoes, the results for the corresponding intensive tomatoes observed for the Dorothy and Boludo cultivars were similar. Therefore, the tomatoes sampled in the October 2004–January 2005 period presented lower mineral mean concentrations than did those of February–June 2005, except for Mg in the Boludo cultivar. However, the difference was only significant for K in the Dorothy cultivar. The tomatoes belonging to the Thomas cultivar and produced in the October 2004–January 2005 period had lower mean concentrations of P and Na than had those of February–June 2005. Organic tomatoes of the Dominique cultivar showed similar results to those obtained in an intensive form. Thus, the samples collected in the October 2004–January 2005 period had lower mean P, K and Ca concentrations than had those of February–June 2005, with significant differences for Ca. In the case of Dunkan, it can be seen that, in contrast with the results obtained in the tomatoes intensively cultivated, organic tomatoes of the February–June 2005 period showed higher mean concentrations of P, Na, K and Mg than did those from the other period, with significant differences for P and Mg. Within the hydroponic cultivation, only the Dorothy and Dunkan cultivars were produced in both sampling periods. No significant differences were observed between the mean values obtained in these periods for all the minerals.

Table 5 shows the results for the trace elements (Fe, Cu, Zn and Mn), grouping the tomatoes according to cultivation method, cultivar and sampling period. In intensively cultivated tomatoes, the mean Fe concentrations in the Dorothy and Boludo tomatoes collected in the February–June 2005 period were higher ($p < 0.05$) than were those of the October 2004–January 2005 period. In contrast, Thomas and Dominique tomatoes had lower mean Fe concentrations in this sampling period. In the Dunkan and

Table 5
Concentrations (mg/kg of wet weight) of the trace elements analyzed in tomato groups according to the cultivation method, the cultivar and the sampling period

	Period	Fe	Cu	Zn	Mn
(1) Intensive					
Dorothy	Oct04–Jan05	**1.58 ± 0.25**	0.303 ± 0.105	0.673 ± 0.164	0.625 ± 0.133
	Feb05–Jun05	**2.18 ± 0.68**	0.291 ± 0.126	0.841 ± 0.299	0.543 ± 0.137
Boludo	Oct04–Jan05	**1.66 ± 0.14**	**0.308 ± 0.140**	0.699 ± 0.121	0.545 ± 0.096
	Feb05–Jun05	**2.31 ± 0.44**	**0.209 ± 0.098**	0.677 ± 0.192	0.514 ± 0.110
Dominique	Oct04–Jan05	2.01 ± 0.47	0.254 ± 0.088	0.578 ± 0.180	0.567 ± 0.166
	Feb05–Jun05	1.77 ± 0.45	0.269 ± 0.193	0.624 ± 0.091	0.612 ± 0.111
Thomas	Oct04–Jan05	2.30 ± 0.79	0.289 ± 0.119	0.825 ± 0.210	0.692 ± 0.209
	Feb05–Jun05	1.85 ± 0.51	0.302 ± 0.084	0.821 ± 0.170	0.653 ± 0.182
Dunkan	Oct04–Jan05	2.58 ± 0.15	**0.258 ± 0.023**	0.894 ± 0.017	0.781 ± 0.019
	Feb05–Jun05	2.66 ± 0.05	**0.101 ± 0.005**	0.613 ± 0.244	0.608 ± 0.203
(2) Organic					
Dorothy	Oct04–Jan05	2.01 ± 0.49	0.403 ± 0.127	0.846 ± 0.090	0.663 ± 0.169
	Feb05–Jun05	1.65 ± 0.68	0.350 ± 0.119	0.860 ± 0.092	0.607 ± 0.109
Boludo	Oct04–Jan05	1.81 ± 0.35	0.293 ± 0.093	0.814 ± 0.197	0.562 ± 0.146
	Feb05–Jun05	1.65 ± 0.33	0.314 ± 0.100	0.840 ± 0.081	0.575 ± 0.107
Dominique	Oct04–Jan05	1.86 ± 0.43	0.225 ± 0.057	0.802 ± 0.191	0.553 ± 0.098
	Feb05–Jun05	1.85 ± 0.38	0.181 ± 0.080	0.746 ± 0.270	0.551 ± 0.133
Thomas	Oct04–Jan05	2.04 ± 0.30	0.355 ± 0.130	0.957 ± 0.169	0.646 ± 0.088
	Feb05–Jun05	1.73	0.217	0.795	0.577
Dunkan	Oct04–Jan05	**2.09 ± 0.37**	0.273 ± 0.074	**0.519 ± 0.102**	0.407 ± 0.070
	Feb05–Jun05	**2.74 ± 0.25**	0.277 ± 0.064	**0.724 ± 0.087**	0.451 ± 0.042
(3) Hydroponic					
Dorothy	Oct04–Jan05	1.70 ± 0.24	0.308 ± 0.071	0.699 ± 0.165	0.614 ± 0.081
	Feb05–Jun05	1.62 ± 0.17	0.247 ± 0.065	0.770 ± 0.192	0.551 ± 0.078
Dunkan	Oct04–Jan05	1.80 ± 0.31	0.353 ± 0.097	0.862 ± 0.096	**0.686 ± 0.121**
	Feb05–Jun05	1.52 ± 0.32	0.283 ± 0.108	0.868 ± 0.224	**0.511 ± 0.073**

Significant differences ($p < 0.05$) between mean values are indicated in bold.

Boludo cultivars, the mean Cu concentrations of the tomatoes produced in the February–June 2005 period were lower ($p < 0.05$) than were those of the October 2004–January 2005 period. Similar mean Zn concentrations were found in both sampling periods for all the tomato cultivars. The mean Mn concentrations tended to be higher in the tomatoes collected in the October 2004–January 2005 period. Organic Dorothy, Boludo and Thomas tomatoes produced in the October 2004–January 2005 period had higher mean Fe concentrations, with the inverse occurring in the Dunkan cultivar. The mean Cu and Mn concentrations were very similar in both sampling periods and for all the cultivars of tomatoes considered. The mean Zn concentrations in Dunkan tomatoes obtained in the February–June 2005 period were higher ($p < 0.05$) than were those concentrations obtained in tomatoes collected in the October 2004–January 2005 period. Hydroponic tomatoes belonging to the Dorothy and Dunkan cultivars did not present significant differences between the mean trace element concentrations according to the sampling period, except for Mn in the Dunkan cultivar. The mean Mn concentration in the Dunkan tomatoes collected in the October 2004–January 2005 period was higher than that mean concentration found in the tomatoes of the February–June 2005 period. Besides this, the mean concentrations of Fe and Cu tended to be higher in the first sampling period.

Some mineral contents in the tomato samples must be influenced by the region of production, which is mainly influenced by the mineral contents of the cropping soils and of the water for irrigation. This has been observed previously in the metallic contents of other vegetable foods analyzed by us (Casañas Rivero, Suárez Hernández, Rodríguez Rodríguez, Darías Martín, & Díaz Romero, 2003; Forster, Rodríguez Rodríguez, Darias Martín, & Díaz Romero, 2002). The influence of the production soil and /or the water for irrigation on the mineral and trace element contents was studied for two cultivars of tomatoes, Dorothy and Boludo. For this purpose several tomato samples, belonging to both cultivars, were sampled in the western and southern regions of the island. Fig. 1a and b shows the results obtained from this comparison. The mean Na concentrations in the tomato samples collected in the South were significantly lower than the mean concentrations of the tomatoes from the West of the island, for both cultivars. This could be related to a higher influence of marine aerosol in the western region because the altitude of the cultivation (below 100 m) in this region is lower than in the southern region (100–300 m). Besides, the mean concentrations of Ca and Mg in the Dorothy cultivar sampled in the southern region were lower and higher, respectively, than the those in corresponding tomatoes from the West. No significant differences between the mean Ca and Mg

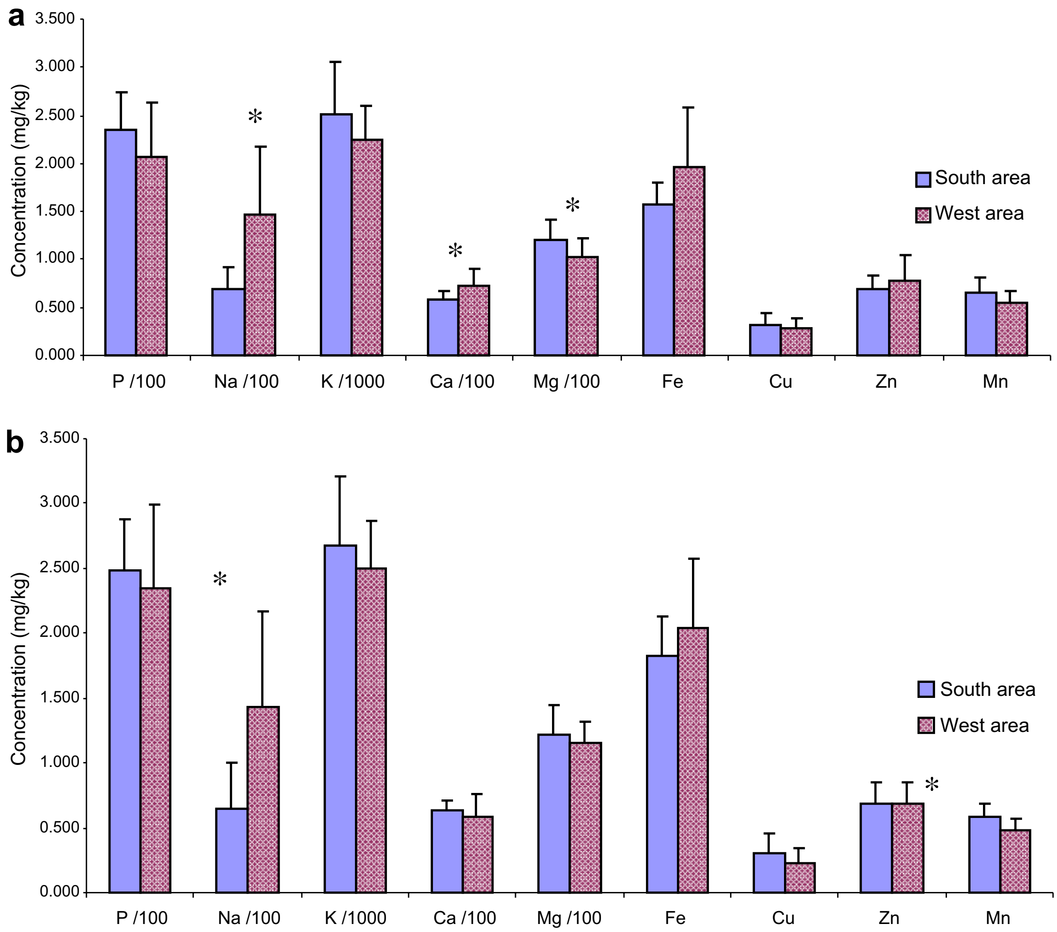

Fig. 1. Influence of the region of production on the mineral and trace element concentrations in the Dorothy (a) and Boludo (b) cultivars.

concentrations, for both regions, were found for the Boludo cultivar. This contrasts with reports by most investigators (Grattan & Grieve, 1999) who indicate a lower Ca content in tomatoes irrigated with water of high salinity. The Boludo cultivar from the South had a higher Mn concentration than had that from the West. Alam, Naqvi, and Azmi (1989) have indicated that salinity reduces the Mn concentration in tomatoes, which is not in agreement with the results obtained by us. No significant differences were observed for the rest of the minerals and trace elements analyzed. However, the mean concentrations of P, K and Cu were lower, and the mean Fe concentration was higher, in both cultivars of tomatoes collected in the western region, which had a higher concentration of Na. This agrees with a report by Grattan and Grieve (1999), who indicated that the tomatoes with a higher salinity presented lower P, K and Ca concentrations and a higher the Fe concentration.

3.2. Multivariate analysis

A statistical study of correlation between the minerals and trace elements analyzed was previously developed to discover associations between measured pairs of mineral and trace elements. The double logarithmic matrix correlation is shown in Table 6. Many significant ($p < 0.05$) correlations were observed which are due to the common and complex metal interactions occurring in soils, water and plants. Most of the correlations between minerals and trace elements were positive, which indicates that, when the concentration of one mineral or trace element increases, the concentration of the other also increases. However, it is notable that Na showed significant and negative correlations with P, Ca, Cu, Zn and Mn. The antagonism of the Na with these elements could explain these negative correlations. A decreased Ca uptake has been described in several studies (Adams & Ho, 1993; Brown & Ho, 1993; Ehret & Ho, 1986; Larcher, 2003) when the salinity is increased. With the rest of the minerals and trace elements (K, Mg, and Fe), the correlations were positive. The influence and precipitation of marine aerosol in the cropping soils could affect the bioavailability, and uptake by the plants, of the metals from the soils. These negative correlations with Cu, Zn and Mn were observed in previous works carried out on vegetable foods, such as potatoes belonging to the genus *Solanum* (Casañas Rivero et al., 2003). Phosphorus showed positive correlations with the trace elements considered, emphasizing the correlations with Mn and Zn.

Table 6
Double logarithmic matrix correlation for all the samples

	Na	K	Ca	Mg	Fe	Cu	Zn	Mn
P	−0.297[a] (0.000)[b]				0.243 (0.002)	0.270 (0.000)	0.488 (0.000)	0.411 (0.000)
Na		0.197 (0.011)	−0.249 (0.001)	0.473 (0.000)	0.261 (0.000)	−0.353 (0.000)	−0.281 (0.000)	−0.406 (0.000)
K				0.600 (0.000)				
Ca						0.172 (0.026)		0.171 (0.027)
Mg								−0.219 (0.004)
Fe							0.336 (0.000)	0.163 (0.035)
Cu							0.512 (0.000)	0.226 (0.003)
Zn								0.436 (0.000)

Significant correlations only are shown.
[a] Coefficient correlation of Pearson.
[b] Signification level ($p < 0.05$).

Potassium was the mineral with the lowest number of significant correlations, presenting a high correlation only with the Mg and a weak correlation with Na. In the correlations among the trace elements considered (Fe, Cu, Zn and Mn), Zn and Mn showed significant correlations with all the trace elements. The relationships Zn–Mn and Zn–Cu are notable for their relatively high correlation coefficients.

Discriminant analysis (DA) was performed on the studied mineral and trace elements to differentiate the tomato samples according to the cultivation method (intensive, organic and hydroponic). After application of stepwise DA to all the data, two discriminant functions were extracted by selecting three minerals: P, Na, and Mg. A low percentage (54.5%, and 52.7% after cross-validation) of correct classification was obtained. This percentage increased to 61.7% (55.1% after cross-validation) when all the variables were introduced. The stepwise DA was repeated on the samples corresponding to each tomato cultivar in an independent manner (Table 7). Only the Na was selected for the Dorothy cultivar, and low percentages of correct classifications were obtained, with the intensive tomatoes being the best classified (76.0%). The percentage of correct classifications for the Boludo cultivar was 76.1% (63.0% after cross-validation) when selecting the variables Mg, Fe, Zn and Mn. All the hydroponic tomatoes were clearly classified whereas the organic and the intensive tomatoes were mixed together in one group. The Dunkan tomatoes showed a complete classification 100% (88.9% after cross-validation) and the variables selected were Na, Fe, Cu and Mn. Fig. 2a, shows the clear separation of the hydroponic tomatoes from intensive and organic tomatoes in the Boludo cultivar. Besides this, the organic and intensive tomatoes belonging to the Boludo cultivar tended to be graphically differentiated. Fig. 2b shows the total differentiation of the three methods for tomatoes of the Dunkan cultivar. The Dominique and Thomas cultivars did not have samples in hydroponic cultivation. The Dominique cultivar showed a moderate classification, 78.9% (78.9% after cross-validation), when only selecting Cu and Zn. The Thomas cultivar presented a correct classification percentage of 84.0% (84.0% after cross-validation). When the DA was applied by introducing all variables, the correct classification percentage increased in all the cultivars: Dorothy 67.3% (38.8% after cross-validation); Boludo 82.3% (63.0% after cross-validation); Dunkan 100% (85.2% after cross-validation); Dominique 84.2% (57.9% after cross-validation); and Thomas 96.0% (92.0% after cross-validation). The same DA was carried out to differentiate the tomato cultivars for all the tomatoes and grouping the tomatoes in function of the cultivation methods. In all cases, low correct classification percentages ($\leqslant$50%) were obtained.

Table 7
Results of the stepwise discriminant analysis for all the cultivars considered to differentiate the cultivation method

Cultivar	% of correct classification			Selected variables
	Intensive	Organic	Hydroponic	
Overall	54.2%	44.8%	76.9%	P, Na, Mg
	(54.5% of tomato samples well classified, 52.7% after cross-validation)			
Dorothy	76.0%	57.1%	18.2%	Na
	(58.0% of tomato samples well classified, 58.0% after cross-validation)			
Boludo	67.9%	85.7%	100%	Mg, Fe, Zn, Mn
	(76.1% of tomato samples well classified, 63.0% after cross-validation)			
Dominique	80.0%	77.8%	–	Cu, Zn
	(78.9% of tomato samples well classified, 78.9% after cross-validation)			
Thomas	87.5%	77.8%	–	Na, Mg
	(84.0% of tomato samples well classified, 84.0% after cross-validation)			
Dunkan	100%	100%	100%	Na, Fe, Cu, Mn
	(100% of tomato samples well classified, 88.9% after cross-validation)			

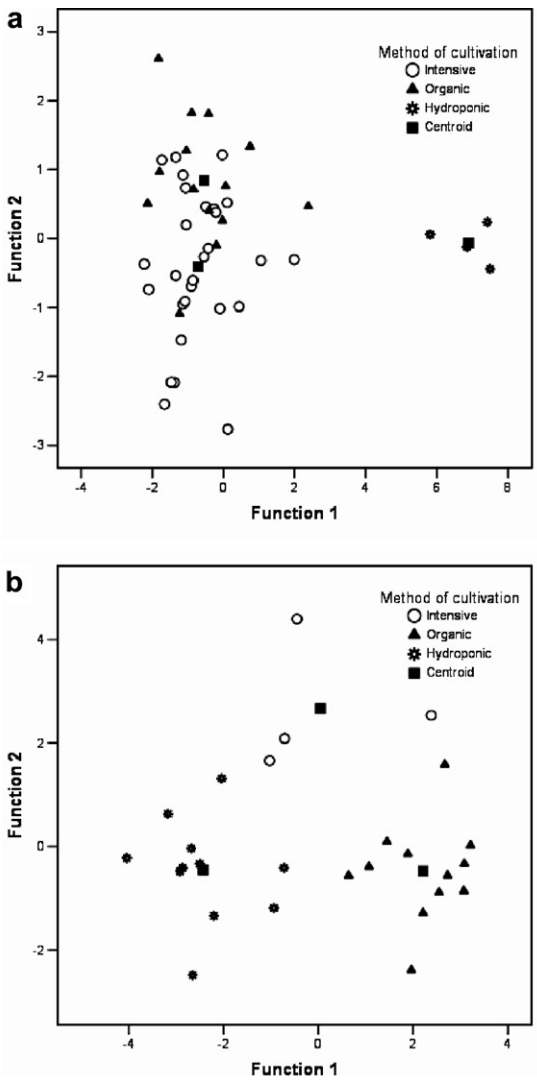

Fig. 2. Scatter diagram on the axes representing the first two discriminant functions according to the cultivation method in the Boludo (a) and Dunkan (b) cultivars.

Therefore, it can be deduced that the concentrations of mineral and trace elements analyzed do not permit a differentiation of the tomato cultivars.

A subsequent stepwise DA was carried out using the sampling period as a criterion for comparison (Table 8). An 80.8% (77.8% after cross-validation) of correct classification was obtained, and the variables selected were the minerals P, Na. K, Ca and Mg. This study was repeated for the intensive, organic and hydroponic tomatoes in an independent manner. The intensive tomatoes presented 88.0% (85.5% after cross-validation) of correct classification and also the same minerals were selected (P, Na. K, Ca and Mg). The percentage of the tomatoes well classified in organic tomatoes according to the sampling period was lower, 82.8% (75.9% after cross-validation), and the selected variables were P, Ca, Mn and Cu. An almost complete classification was obtained for hydroponic tomatoes i.e. 96.2% (92.3% after cross-validation) when selecting only K and Mg. Only one tomato sample of the February–June 2005 period was erroneously included in the group of tomatoes collected in the October 2004–January 2005 period. If all the variables were included in the DA, the correct classification percentage increased for organic and hydroponic tomatoes. When the cultivar of tomatoes was considered according to each cultivation method, and the DA was carried out, including all the variables, a complete classification (100%) of the tomato samples was obtained. However, the percentage of classification in cross-validation decreased dramatically in many cases, which could be due to the few data within each group.

Table 9
Results of the stepwise discriminant analysis of the Boludo and Dorothy cultivar according to the cultivation region

	Zone	Predicted group	
		South	West
(a) Boludo			
Initial group	South	11 (84.6%)	2 (15.4%)
	West	3 (20.0%)	12 (80.0%)
Cross-validation	South	11 (84.6%)	2 (15.4%)
	West	3 (20.0%)	12 (80.0%)
(82.1% samples well classified; 82.1% after cross-validation)			
(b) Dorothy			
Initial group	South	8 (88.9%)	1 (11.1%)
	West	2 (12.5%)	14 (87.5%)
Cross-validation	South	8 (88.9%)	1 (11.1%)
	West	2 (12.5%)	14 (87.5%)
(88.0% samples well classified; 88.0% after cross-validation)			

Table 8
Results of the stepwise discriminant analysis for all the cultivars considered to differentiate the cultivation method and the sampling period

Cultivar	% of correct classification		Selected variables
	Oct04–Jan05	Feb05–Jun05	
Overall	79.8%	82.9%	P, Na, K, Ca, Mg
	(80.8% of tomato samples well classified, 77.8% after cross-validation)		
(1) Intensive	91.3%	83.8%	P, Na, K, Ca, Mg
	(88.0% of tomato samples well classified, 85.5% after cross-validation)		
(2) Organic	77.1%	91.3%	P, Ca, Cu, Mn
	(82.8% of tomato samples well classified, 75.9% after cross-validation)		
(3) Hydroponic	100%	92.3%	K, Mg
	(96.2% of tomato samples well classified, 92.3% after cross-validation)		

A new stepwise DA was performed on intensively cultivated Dorothy and Boludo cultivars to differentiate the region of production. The results for all the tomatoes and for the Dorothy and Boludo cultivars in an independent manner are shown in Table 9. In both cases, the selected minerals were Na and Mg, and a high differentiation of the tomatoes was obtained as a function of the cultivation region.

4. Conclusions

There are many factors influencing the mineral and trace element concentrations, such as cultivar, cultivation method, production region or sampling period. All these factors are acting at the same time, and therefore, it is difficult to come to definitive conclusions. The contribution to the intake of the minerals and trace elements was low, except for K and Mg. The influence of the cultivation method on the mineral and trace element contents depends on the cultivar. Boludo and Dunkan were the cultivars with the greatest differences in the mineral and trace element concentrations according to the cultivation method. Trace elements seem to be more influenced by the cultivar than are the minerals, and the cultivation method affected the minerals more than the trace element contents. The sampling period had an important influence on the mineral and trace elements. Many significant correlations between the analyzed minerals and trace elements were found, which indicates metabolic relationships between them. Sodium shows antagonistic effects on other mineral and trace elements. The results obtained in the DA indicate that the sampling period, region of production and cultivation method have greater influences on the mineral and trace element concentrations than does the cultivar. Bearing in mind the stepwise DA on the data of each tomato cultivar in an independent manner, one can see a clear tendency to differentiation of the intensive and organic tomatoes.

Acknowledgements

This work was financed by the Project (I + D) Reference AGL 2003-09559 of the National Plan for Scientific Research, Development and Technological Innovation, Spain. Marcos Hernández Suárez wishes to express his gratitude for a grant. We also gratefully acknowledge the help of Patrick Dennis for improving the English in this paper.

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