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Tomato Fruit Quality from Organic and Conventional Production

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1. Introduction

The tomato (*Solanum lycopersicum* L.) is one of the world's most important vegetables, with an estimated total production of about 159.347 million tonnes in 2011 (FAOSTAT 2011). It is the second most widely consumed vegetable after the potato [1]. Tomatoes are important not only because of the large amount consumed, but also because of their high health and nutritional contributions to humans. The tomato processing industry has made tremendous advances, developing many forms of tomato-based foods, such as sauces, catsup (ketchup), puree, pastes, soups, juices and juice blends, and canned tomatoes either whole or in diced, sliced, quartered or stewed form [2]. The tomato's attractive color and flavor have made it a dietary staple in many parts of the world. Nutritional considerations also bring the tomato to the forefront.

In the human diet, it is an important source of micronutrients, certain minerals (notably potassium) and carboxylic acids, including ascorbic, citric, malic, fumaric and oxalic acids [3; 4]. Tomatoes and tomato products are rich in food components that are antioxidant and considered to be a source of carotenoids, in particular lycopene and phenolic compounds [5; 6; 7; 8], but low in fat and calories, as well as being cholesterol-free. Most importantly, tomato consumption has been shown to reduce the risks of cardiovascular disease and certain types of cancer, such as cancers of prostate, lung and stomach [9]. The health promoting benefits of tomatoes and tomato products have been attributed mostly to the significant amount of lycopene contained. The results of various studies suggest that lycopene plays a role in the prevention of different health issues, cardiovascular disorders, digestive tract tumors and in inhibiting prostate carcinoma cell proliferation in humans [10].

As a potent antioxidant, lycopene is presently marketed as a fortified nutritional supplement [2]. Another carotenoid, β -carotene, a precursor of vitamin A, is also abundant in tomato. The carotenoid content of tomatoes is affected by cultural practices on one side – genotype and

agronomic technique [11; 12] on the other side. The levels of carotenoids and phenolics are very variable and may be affected by ripeness, genotype and cultivation methods [13; 14; 15].

Tomato quality is a function of several factors including the choice of cultivar, cultural practices, harvest time and method, storage, and handling procedures. Increased interest in organic tomato production imposed the need to evaluate the quality and nutritional value of organic tomato.

Some studies have shown higher levels of bioactive compounds in organically produced tomato fruits compared to conventional ones, but not all studies have been consistent in this respect [16; 17; 18]. Organic tomatoes achieve higher prices and a guaranteed placement compared to conventional tomatoes [19], because these products are often linked to protecting the environment and to having better quality (taste, storage), and most people believe that they are healthier. Organic system enhanced optimal production level but with higher cost of cultivation (certification procedures, higher cost per unit of fertilizer, phytosanitary treatments applied, more labor etc.), compared with conventional farming.

2. Production methods and fruit quality

Both conventional and organic agricultural practices include combinations of farming practices that vary greatly depending upon region, climate, soils, pests and diseases, and economic factors guiding the particular management practices used on the farm [20]. These differences between organic and conventional production are reflected in the fertilizer used (organic-manure; conventional-mineral fertilizer), the number of phytosanitary treatments (larger in organic system), and the pesticide types applied (preventive in the organic system and preventive or healing with variable period of effectiveness in the conventional one) [21].

Organic production methods by definition do not guarantee a higher quality product [22]. Research results on the effects of organic and conventional production on fruit quality are sometimes contradictory. In terms of quality, some studies report better taste, higher vitamin C contents and higher levels of other quality related compounds for organically grown products [20; 23], whereas several other studies have found the opposite or no differences in quality characteristics between organically and conventionally grown vegetables [23]. The factors influencing tomato quality are complex and interrelated, and additional studies are necessary to consolidate the knowledge about the real interdependences.

One major problem in comparative studies might be that genuine organic and conventional production systems differ in many factors and that a simple measurement of food composition does not reflect its quality. Other scientists have argued that a valid comparison of nutritional quality would, for example, require that the same cultivars are grown at the same location, in the same soil and with the same amounts of nutrients [24; 25]. However, there is little information on the effect of different forms of cultivation on the antioxidant potential of tomatoes.

3. Materials and methods

Three tomato varieties (Robin F₁, Amati F₁ and Elpida F₁) have been tested in greenhouse production (plastic tunnels 3.5m high, covered with termolux 180 µm) during 2008-2010, located in the Sapes, Northeastern Greece, using two different growing systems: organic and conventional. Greenhouse technology and horticultural practices differ little. The main variations concerned pest control, fertilization and fertility of soil, which was of much better quality in the organic production. In conventional cultivation mineral fertilizers and chemical plant protection were applied. The differences between production systems were the fertilizers used (organic: goat manure 3 tonnes/ha; conventional: mineral fertilizer NPK (12:12:17), nitrophos blue special+2MgO+8S+Trace elements – 400 kg/ha), the number of phytosanitary (solarization) treatments (larger in organic system), the pesticide types applied (preventive in the organic systems and preventive or healing with variable period of effectiveness in the conventional one). It was an early-medium production; planting was done between 15 April and 20 April at a density of 2.64 plants/m².

At the pink stage of ripening determined by visual inspection, samples were collected for quality analyses (colour, firmness, total soluble solids, total sugar, total acidity content of vitamin C, content of carotenoids and lycopene). For sensory evaluation fruits were evaluated by trained descriptive panelists on the day of harvest (red stage). Tomato samples (20 fruits) were collected each year from June till August and were taken from the third to sixth floral branches.

Determination of total soluble solids (TSS) was carried out by a refractometer. The results were reported as °Brix at 20 °C. The titrable acidity (TA) was measured with 5 ml aliquots of juice that were titrated at pH 8.1 with 0.1 N NaOH (required to neutralize the acids of tomatoes in phenolphthalein presence) and the results were expressed as citric acid percentages.

Pigment extraction from tomato fruits, preparation of extracts for analysis and calibration plots of standard components were determined according to a described method [26].

Approximately 0.5 g of freeze-dried sample was weighed into porcelain crucibles that had previously been heated for 3 hr at 550° C and was converted to white ash at this same temperature over 12–18 hr. Each ashed sample was dissolved in 20 mL of 3 M HCl, and K, Ca, Na, Mg, Fe, Zn, Mn and Cu levels were determined by atomic absorption spectrophotometry.

Besides, a taste index and the maturity were calculated using the equation proposed by X et al. [27] and Y and co-workers [28] starting from the Brix degree and acidity values which were determined in a previous paper [29].

$$\text{Taste index} = \frac{\text{Brix degree}}{20 \times \text{Acidity}} + \text{Acidity} \qquad \text{Maturity} = \frac{\text{Brix degree}}{\text{Acidity}}$$

4. Phytochemicals

The levels of some phenolic compounds are known to be higher in organic fruit. Plants create phenolic compounds for many reasons, but a major reason is to make plant tissues less attractive to herbivores, insects and other predators. Accordingly, it is important to sort out if higher levels of phenolic compounds affect the taste of organic fruits and vegetables when compared to conventionally grown produce [30].

The organic growing system affects tomato quality parameters such as nutritional value and phenolic compound content. The effect of variety, season, harvest time, maturity, as well as environmental factors such as light, water and nutrient supply on the antioxidant content of tomatoes are reviewed by Dumas et al. [31].

Vitamin C of tomato fruits accounts for up to 40% of the recommended dietary allowance for human beings. Farm management skills combined with site-specific effects contribute to high vitamin C levels, and the choice of variety significantly influences the content of ascorbic acid [32]. The variation in vitamin C content in tomatoes depends mainly on environmental conditions. Exposure to light is a favorable factor for ascorbic acid accumulation [31; 33]. Therefore, it is important to compare organic and conventional foods that are planted and harvested during the same season of the year and that originate from regions with similar incidence of solar radiation.

Ascorbic acid content in organically fertilized tomatoes ranges between 29% and 31% [23, 34], which is higher than the results obtained from tomatoes that were fertilized with mineral solutions. Similarly, ascorbic acid content in tomatoes cultivated with an organic substrate was higher than hydroponically cultivated tomatoes [35]. Many citations from literature confirm that tomatoes coming from organic cultivation procedures present higher vitamin C content than fruits from conventional cultivation [36; 37]. It was also found that fertilizer that was rich in soluble nitrogen (N) could cause a decrease in the ascorbic acid content, probably for indirect reasons, since the nitrogen supply increased the plants' leaf density, which promoted shading over the fruits.

Amati		Robin		Elpida	
Organic	Conventional	Organic	Conventional	Organic	Conventional
11.73	13.8	12.6	13.87	14.33	13.7

LSD 5% 5.69 3.15 6.13
LSD 1% 13.12 7.26 14.15

Table 1. Vitamin C content (mg 100g⁻¹) in tomato at the organic and conventional production system

The results demonstrate consistent differences in vitamin C content between tomato cultivars and method of cultivation. Thus, Elpida' tomato fruit in organic production system contained the highest level of vitamin C. Irrespective of the cultivation method used, 'Elpida' on average

also contained the highest level of vitamin C (14.3 mg 100g⁻¹) in comparison to the rest of the examined tomato cultivars. The conventionally grown Amati and Robin tomato fruits contained more vitamin C than their organically grown counterparts [38].

5. Lycopene content

The color of the fruits is an important consumer quality parameter. The typical color changes during tomato ripening from green to red are associated with chlorophyll breakdown and the synthesis of carotenoid pigments due to the transformation of chloroplasts to chromoplasts [39]. Pigment synthesis in tomato is closely related to the initiation and progress to ripening and red color of the fruit results from the accumulation of lycopene [40], so that lycopene has been suggested as a good indicator of the level of ripening. Lycopene is considered the predominant carotenoid of tomato fruit (80-90%), followed by β -carotene (5-10%) [41].

The lycopene level of tomato fruit is determined by the genetic potential of the cultivar. Most commonly, lycopene levels range within 4.9 and 12.7 mg 100g⁻¹ [42] or between 3.5 and 6.9 mg100g⁻¹ fresh weight (f.w.) [43]. Lycopene content ranged from 4.3 to 116.7 mg kg⁻¹ on a fresh weight basis, with cherry tomato types having the highest lycopene content [11]. The distribution of lycopene in the tomato fruit is not uniform. The skin of the tomato fruit contains high levels of lycopene, comprising an average of 37% of the total fruit lycopene content [45], or 3- to 6-fold higher than in whole tomato pulp [44]. About 12 mg of lycopene per 100 g fresh weight was found in tomato skin, while the whole tomato fruit contained only 3.4 mg 100g⁻¹ fresh weight [47]. The outer pericarp constitutes the largest amount of total carotenoids and lycopene, while the locule contains a high proportion of carotene [46].

The lycopene content of tomato fruit also varies due to growing and environmental conditions, mainly temperature and light. In general, field-grown tomatoes have higher levels of lycopene than greenhouse grown fruit [13]. The lycopene content determined in 39 tomato genotype varieties ranged from 0.6 to 6.4 mg/100 g and 0.4 to 11.7 mg/100 g for greenhouse and field-grown tomatoes, respectively [11]. Similarly, different cultivar varieties have been shown to possess varied lycopene concentrations [13; 48; 49; 45]. Fruits from the indeterminate tomato cultivar Daniela grown in the greenhouse had a higher lycopene content than field grown fruit [50]. Lycopene content also changes significantly during maturation and accumulates mainly in the deep red stage [51].

Tomatoes grown organically contained substantial amounts of lycopene when ripened to firm red or soft red stages. About half of the total lycopene found in soft red tomatoes was present in pink tomatoes and 70 percent in light-red fruit. Fruit picked at unripe stages (breaker through light red) gained as much or more lycopene as those picked at the firm or soft red stages. Results indicate that fruit could be harvested well before full visible red color without loss of lycopene [52].

Tomatoes grown by the conventional or organic agricultural practices did not show any significant difference in the carotenoid content [23]. Thus, the absence of any difference

between the organic and conventional tomatoes could be due to the control over the ripening, transportation and storage conditions [54].

The results showed that the lycopene content in organic tomatoes was higher than in conventional tomatoes. The average content of this pigment in the organic fruit was $2.92 \text{ mg } 100^{-1} \text{ g f.w.}$, while for conventional tomatoes it was $2.84 \text{ mg } 100^{-1} \text{ g f.w.}$ (Fig. 1).

Different tomato cultivars produce different lycopene levels. 'Elpida' in organic production contained more lycopene in fruit than the other two cultivars ($3.75 \text{ mg } 100^{-1} \text{ g f.w.}$). Differences in sunlight and temperature between the years might be a cause for the contradictory observations.

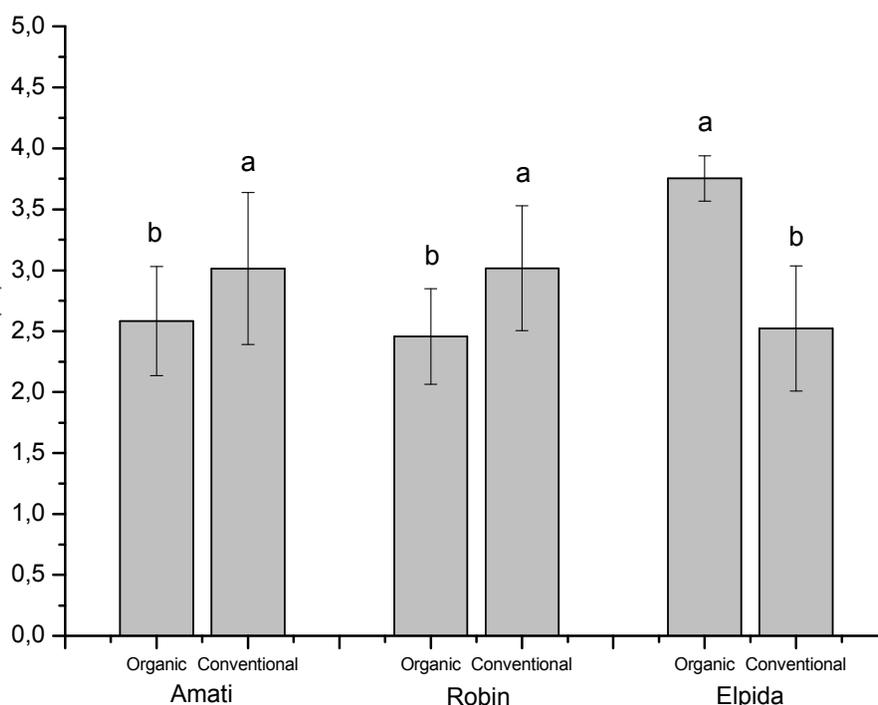


Figure 1. Lycopene content ($\text{mg } 100\text{g}^{-1}$) in organic and conventional tomato cultivars

Tomatoes from organic cultivation contained more carotenoids compared to conventional cultivation. The cultivar 'Amati' contained the lowest level of carotenoids in fruit in both cultivation systems. These differences were statistically significant ($p=0.05$). Organically grown 'Robin' produced the highest level of carotenoids in fruit ($4.03 \text{ mg } 100\text{g}^{-1}$) comparing to the other two cultivars (Fig. 2).

Studies on carotene and lycopene contents in organic tomatoes, have reported different results including both higher levels [52] and lower levels [53] when compared with conventional methods. No consistent effect of the farming system on the content of bioactive antioxidant compounds [32; 19] was also reported.

Differences between organic and conventional tomatoes can be explained by the fertilizer used in both cases. 'Organic farming doesn't use nitrogenous fertilizers; as a result, plants respond

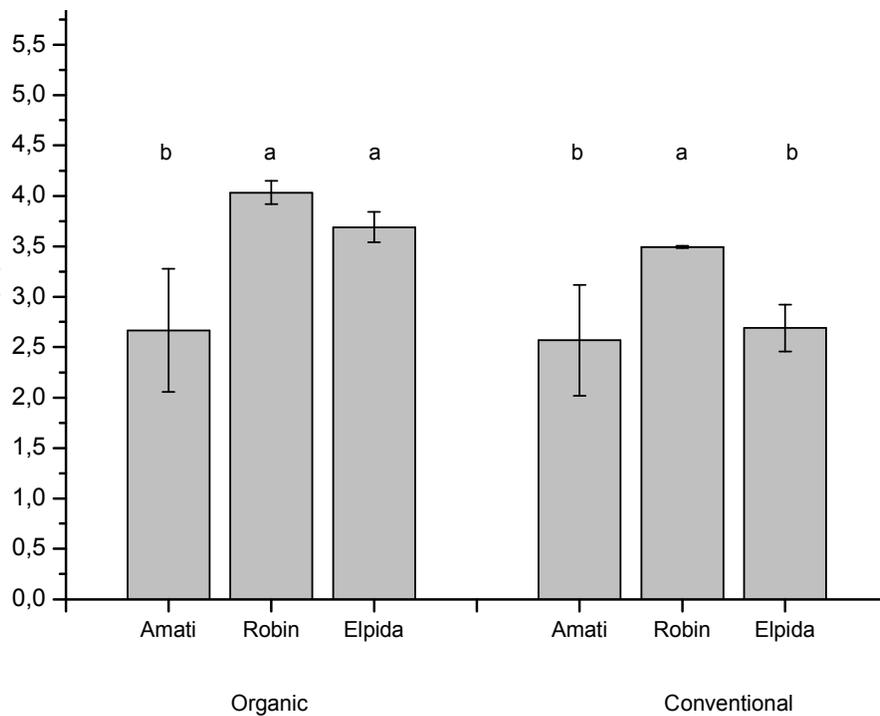


Figure 2. Carotenoids content (mg 100g⁻¹) in organic and conventional tomato cultivars

by activating their own defense mechanisms, increasing the levels of all antioxidants. The more stress plants suffer, the more polyphenols they produce,' these authors point out [55]. Tomato fruits from organic farming experienced stressing conditions that resulted in oxidative stress and the accumulation of higher concentrations of soluble solids as sugars and other compounds contributing to fruit nutritional quality such as vitamin C and phenolic compounds [56].

Flavonoid content in tomatoes seems to be related to available N [34]. Plants with limited N accumulate more flavonoids than those that are well-supplied. If differences in flavonoid content reflect fundamental differences in the behavior of soil N between conventional and organic systems, then the N available to tomatoes late in the season may have declined in organic plots in recent years in response to the cumulative effects of a decrease in compost application rates [57].

Interestingly, yellow flavonoids and anthocyanins did not follow the pattern of total phenolics (Table 2). For instance, the concentration of yellow flavonoids was 70% higher in organic fruits when compared to fruits from conventional growing system, but only at the harvesting stage, which is consistent with similar observations previously [57]. The concentration in anthocyanins was lower in the fruits from organic farming at all three stages of fruit development [56]. These discrepancies indicate that organic farming had the effect of modifying the levels of transcripts or the activities of enzymes controlling intermediary steps of the biosynthetic pathway of phenolic compounds. In spite of the changes in antioxidants, the total antioxidant activity was not significantly different among the organic and conventional tomatoes (Table 2).

Stage of maturity	Organic	Conventional
<i>Total phenolics (mg GAE kg⁻¹)</i>		
Immature	308.563.04 Ab	249.165.65 Aa
Mature	508.361.51 Aa	299.862.39 Ba
Ripe	556.565.40 Aa	232.560.62 Ba
<i>Anthocyanins (mg kg⁻¹)</i>		
Immature	5.160.10 Ba	8.060.19 Aa
Mature	2.560.05 Ba	9.060.16 Aa
Ripe	3.660.09 Ba	9.960.11 Aa
<i>Yellow Flavonoids (mg kg⁻¹)</i>		
Immature	27.860.15 Bb	37.460.33 Aa
Mature	26.160.33 Bb	33.360.43 Aab
Ripe	43.760.49 Aa	25.760.33 Bb
<i>Total Vitamin C (mg kg⁻¹)</i>		
Immature	134.16 ±0.20 Ac	89.46±0.05 Bb
Mature	220.56±0.12 Ab	175.36±0.20 Ba
Ripe	264.76±0.40 Aa	170.96±0.16 Ba
<i>Antioxidant Activity (mMTrolox g⁻¹ FW)</i>		
Immature	98.726±38.65 Aa	98.186±30.42Aa
Mature	143.546±44.52 Aa	161.236±6.15 Aa
Ripe	128.346±22.89 Aa	136.286±57.54Aa

(Oliveira et al., 2013)

Table 2. Quality parameters of tomatoes cultivated organically and conventionally

6. Mineral content

Growing method and cultivar had significant influence on K, Ca, Na or Mg contents in tomato fruits. Organic tomatoes achieved significantly greater concentrations of minerals [58]. The main factor influencing tomato micronutrient content was cultivar [59]. We found significantly greater concentrations of P, K, Ca and Mg in organic tomatoes, but in conventionally grown tomato we found greater content of Zn, Fe and Cu [60]. Our results show that the potassium content in organic tomatoes (153.05-164.31 mg 100g⁻¹) is higher than in conventional tomatoes (126.79-142.54 mg 100g⁻¹). Organically grown Elpida produced the highest level of potassium in fruit (164.31 mg100 g⁻¹) comparing to the other two cultivars. Potassium concentrations were similar to those (191.42–236.54 mg 100g⁻¹) [29]. Our results show that the calcium content in organic tomato (8.08-9.00 mg100g⁻¹) is higher than in conventional tomatoes (7.84-8.58 mg 100g⁻¹). Calcium concentrations (15.97– 23.13 mg 100g⁻¹) were higher in the reported literature [59] than those found in our studies. Significantly greater concentrations of Ca and Mg in organic tomatoes also represented [58]. Magnesium concentrations in organic (17.36-22.22 mg 100g⁻¹) and conventional tomato (18.75-19.16 mg 100g⁻¹) were higher than those found (10.30– 11.88 mg 100g⁻¹) [59], but similar to those found in a comparable study [29].

The ranges of measured iron concentration in this study were 0.51-0.64 mg 100g⁻¹ in organic and 0.69-0.72 mg 100g⁻¹ in conventional tomato respectively. In another study, the iron concentration was higher: 0.54-1.37 mg 100g⁻¹ [59]. We observed no significant influence of

growing method, which in the case of iron is in keeping with earlier findings [62]. On the contrary, significantly greater concentrations of these minerals in organic tomatoes were found in the report by Kelly & Bateman [58].

Copper concentration (0.11-0.13 mg 100g⁻¹) in conventional tomatoes was higher than in organic tomato (0.5-0.7 mg 100g⁻¹). The ranges of measured copper concentrations (0.05-0.11 mg 100g⁻¹) [59] were higher than those reported by [29; 61]. There were no significant differences in zinc concentrations between organic (0.16-0.18 mg 100g⁻¹) and conventional tomatoes (0.18-0.19 mg100g⁻¹). Zinc concentrations (0.14–0.33 mg 100 g⁻¹) were higher [59] than those reported by Hernández-Suárez et al. and Gundersen et al. [29; 61].

	Moisture %	TotalN	P	K	Ca	Mg	B	Mn	Zn	Fe	Cu
(mg 100g⁻¹ fresh weight)											
<i>Conventional production</i>											
Elpida	93.19	191.80	33.74	126.79	7.84	18.75	0.02	0.08	0.19	0.69	0.11
Robin	94.28	214.32	29.18	137.59	8.58	19.16	0.03	0.09	0.18	0.73	0.10
Amati	93.62	223.41	27.10	142.54	8.29	18.81	0.03	0.08	0.19	0.82	0.13
<i>Organic production</i>											
Elpida	93.27	218.77	43.43	164.31	8.08	22.22	0.03	0.08	0.17	0.64	0.07
Robin	92.86	248.73	46.75	159.17	8.92	22.13	0.03	0.08	0.16	0.59	0.05
Amati	93.57	193.02	45.34	153.05	9.00	17.36	0.03	0.07	0.18	0.51	0.05

Table 3. Mineral contents of conventionally and organically grown tomatoes

We found the growing method to have no influence on zinc content, in agreement with previous observations [62]. On the contrary, significantly greater concentrations of Zn in organic tomatoes were found [58]. There were insignificant differences of manganese content between conventional (0.08-0.09 mg 100g⁻¹) and organic tomato (0.07-0.08 mg 100g⁻¹). Manganese concentrations (0.05–0.13 mg 100g⁻¹) found by [59], were similar to those reported by [61] and lower than those measured by [29] and were significantly influenced by both cultivar and growing method. Mn levels seem unaffected by the growing method [62]. We found the growing method to have no influence on zinc content (Table 3) like [62]. On the contrary, significantly greater concentrations of Zn in conventional tomatoes were found [58]. On the other hand, in the present study, one possible hypothesis that may explain the insignificant differences in the majority of the minerals could be that the tomato plants of the two cultivation methods managed to have similar soil conditions and irrigation. Previous studies support such a claim. Significant differences in the concentration of Na, Ca, Mg and Zn in tomatoes grown in two different production regions of the island of Tenerife (Spain) have been reported [29]. Some mineral contents in the tomato fruit 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 [29].

7. Index of maturity and taste index

The organic acid in a tomato fruit consist of mainly citric and malic acid with a range of 0.3 to 0.6%. Conventional tomatoes contained more organic acids in comparison to those cultivated by organic methods, in all periods of analysis, being approximately about 0.48% [21].

	Organic production		Conventional production	
	TA (%)	TSS (Brix°)	TA (%)	TSS (Brix°)
Amati	0.41± 0.01c	4.83± 0.4b	0.48± 0.02 a	4.95± 0.5a
Robin	0.44± 0.01b	4.76± 0.5b	0.47± 0.02a	4.85± 0.6a
Elpida	0.47± 0.01a	5.08± 0.5a	0.48± 0.01a	4.59± 0.5b

Table 4. Total acidity (TA) and total soluble solid (TSS) content of three tomato cultivars from organic and conventional production system

At the same time, it should be noted that Elpida tomatoes were richer in organic acids in comparison to other examined cultivars, independently from the used cultivation system (Table 4). As with the sugars, the organic acids are crucial to the flavour of the fruits. The average contents Brix degree and acidity were 4.6 and 0.50 g 100⁻¹ of citric acid, respectively [64].

The concentration of sugars may vary from 1.66 to 3.99% and 3.05 to 4.65% of the fresh matter, as a function of the cultivar and cultivation conditions, respectively [63]. As with the sugars, the organic acids are crucial to the flavour of the fruits. The average contents Brix degree and acidity were 4.6 and 0.50 g 100g⁻¹ of citric acid, respectively [29]. The taste index is calculated by applying the equation using the values of Brix degree and acidity [27].

The Elpida cultivar from organic production system had a mean value (1.1) of the taste index higher ($P < 0.05$) than those values determined for the organic Robin (0.98) and Amati (1.0) cultivars (Table 5). No significant differences were found between the cultivars in the mean taste index obtained for conventionally cultivated tomatoes. 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 analyzed are tasty. If the value of the taste index is lower than 0.7, the tomato is considered as having little taste [27].

Another parameter related with the taste index is the maturity index 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. Significantly greater maturity index in organic Amati fruit (11.7) and lower maturity index in conventional Elpida fruit (9.6) were found [21]. The maturity index in this study (in all cultivars in both production systems) were higher than those found by maturity index reported by [64] was 9.4 and therefore, it can

	Amati F1		Robin F1		Elpida F1	
	Organic	Conventional	Organic	Conventional	Organic	Conventional
Maturity Index	11.7a	10.3b	10.8b	10.3b	10.8b	9.6b
Taste index	1.00b	1.00b	0.98b	0.98b	1.10a	0.96b

Table 5. Index of maturity and taste index of tomato from organic and conventional production

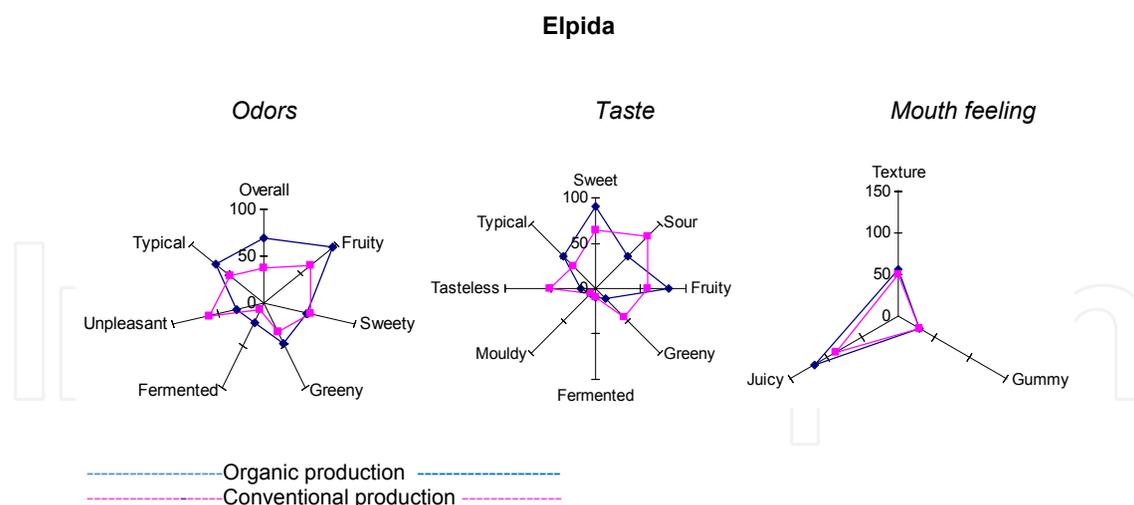
be deduced that the maturity levels of the analyzed tomatoes were adequate for consumption. This ratio can also be affected by climate, cultivar and horticultural practices [28]. The cultivar is a more influential factor than cultivation methods in the differentiation of the tomato samples according to the chemical characteristics. However, quality is more than this and can be defined as the sum of all characteristics that make a consumer satisfied with the product [65]. Apart from functional and nutritional characteristics, quality can include aspects of production method, environment or ethics, as well as availability of and information about a product [66]. For all nutrients examined, cultivar differences were greater than differences because of cultivation method. This study confirms that the most important variable in the micronutrient content of tomatoes is the cultivar; organically grown tomato is no more nutritious than conventionally grown tomato when soil fertility is well managed [59]. Greenhouse tomato production offers advantages compared to production at the open field with regard to quality assurance principally, because the plants are not exposed directly to the rapid changes of climate conditions. An important role for this purpose is also the cultivar selection by using tomato hybrid varieties with a high yield potential and a good fruit quality.

8. Sensory attributes

During tomato fruit ripening, a series of quantitative and qualitative changes take place, changing tomato flavor and aroma volatile profiles [67; 68]. Regarding aroma, several descriptors are present in tomatoes and volatiles are part of the tomato aroma profile. 3-Methylbutanol is an amino acid related compounds, which has a pungent/earthy aroma [69]. Hexanal is one of the major aldehydes in tomatoes and is considered important for fresh tomato flavour.

Panelists could perceive a difference between conventional and organic tomatoes by smell or taste with high reliability. Organic tomatoes were perceived by some of the panelist to be *softer*, and were preferred because of their taste, flavor, texture and juiciness. Alternatively, conventional tomatoes were described as *'not as ripe'*, *'dry'*, and having *'less aroma'* [19].

Very different patterns of correlation between nonvolatile and volatile components emerged as perceived by panelists, depending on whether the nasal passage was blocked to evaluate taste descriptors. A composite of all data collected over the three seasons revealed the 'sweet' note is positively correlated with soluble solids, total sugars, and sucrose equivalents with partitioning (taste followed by aroma).



In previous studies, strong positive correlation has been observed between trained panel response of 'sweetness' and reducing sugar and total soluble solids content [70]. Both 'tomato-like' and 'fruity' were positively correlated to acidity and negatively correlated to soluble solids in aroma plus taste trials, but not in the taste followed by aroma trials. A possible explanation in the lack of correlations with many of these descriptors is that there was little difference between these treatments in the lines selected. It is clear that evaluating for taste plus aroma was more sensitive than evaluating for aroma plus taste. It would however be impulsive to conclude that either production system is superior to the other with respect to healthy or nutritional composition [71].

The fruit quality, in terms of taste and nutritional value, did not differ significantly between tomatoes grown in organic or conventional systems. It can take a number of years for soil nutrients to reach optimal levels using organic fertilisers and nutrient availability in the organic systems had probably not been fully established in the three years of the experiments.

However, the type of tomato was more important in determining fruit quality than the type of cropping system: the older variety produced tomatoes with the highest quality index compared with the modern cultivars, implying there is a trade-off between tomato quality and yield [72]. If the aim of organic systems is to produce fruit of superior quality, it is suggested that old cultivars could be used to develop new tomato cultivars adapted for organic cultivation rather than for conventional systems.

9. Heavy metals

Some heavy metals at low doses are essential micronutrients for plants, but in higher doses they may cause metabolic disorders and growth inhibition for most of the plants species [73]. Among the contaminants found in vegetables, heavy metals may reach different levels depending on their content in the soil and the type of fertilization used [73]. For this reason the type of farming techniques can affect the heavy metal content of tomatoes. Both organic

(e.g., farmyard manure) and inorganic amendments (e.g., lime, zeolites, and iron oxides) were found to decrease the metal accumulation [74].

The tomato as a fruit vegetable is not characterized by high accumulation of heavy metals. Producers of organic vegetables, do not use mineral fertilizers and practically never use fertilizers produced by industrial waste, which are the most polluted. As a result, one might expect that organic vegetables contain lower amounts of toxic heavy metals. The effect of manure on heavy metal availability is due to the introduction of organic matter to the soil, which may retain Cd in the soil and prevent it from both leaching and from crop uptake [75].

The lead content of tomato fruit, in general, is very low and ranges depending on the hybrid and the methods of production from 0.07 to 0.19 mg 100g⁻¹ [19]. No statistical difference in the lead content between organic (0.11 mg 100g⁻¹) and conventional (0.10 mg 100g⁻¹) production of the hybrid Elpida was seen. In the other two hybrids, the lead content was lower in organic production. 'Robin' in organic production achieved lower lead content (0.08 mg kg⁻¹) in comparison with conventional methods (0.10 mg 100g⁻¹). The lead content in 'Amati' is twice lower in organic (0.07 mg kg⁻¹) than in conventional production (0.14 mg 100g⁻¹).

The zinc content in tomato fruits in our studies was just below 20 mg 100g⁻¹. The lower zinc content of the hybrids in organic farming compared to conventional production was not statistically significant. Differences in the content of zinc exist between the individual hybrids. Thus, the lowest zinc content (0.16 mg kg⁻¹) was obtained in 'Robin' in organic production.

	Pb	Zn	Cu	Ni	Cd	Co	Cr
Organic production							
Elpida	0.11	0.17	0.07	0.01	0.0027	0.0070	0.01
Robin	0.08	0.16	0.05	0.01	0.0027	0.0070	0.01
Amati	0.07	0.18	0.05	0.01	0.0027	0.0070	0.01
Conventional production							
Elpida	0.14	0.19	0.11	0.02	0.0027	0.0070	0.01
Robin	0.11	0.18	0.10	0.02	0.0027	0.0070	0.01
Amati	0.11	0.19	0.13	0.02	0.0027	0.0070	0.02

Table 6. Heavy metals contents (mg 100g⁻¹ f.w.) of conventional and organical tomato

Copper content in organic fruit production is lower, ranging from 0.5 mg 100g⁻¹ hybrids Robin and Amati to 0.7 mg 100g⁻¹ hybrids Elpida. The copper content in conventional tomato production is twice as high in the hybrids Robin (0.10 mg 100g⁻¹) and Amati (0.13 mg 100g⁻¹) in relation to organic production. The copper content in the hybrid Elpida is 0.11 mg 100g⁻¹ (Table 6). In contrast, significantly greater concentrations of Cd (33 µg kg⁻¹) and Pb (37.8 µg kg⁻¹) were found in organic tomatoes, but at the same time a lower Cu content (0.46 mg kg⁻¹)

was observed [53]. Systematic fertilization with pig and poultry manure can lead to the accumulation of heavy metals, especially copper.

We found the growing method to have no influence on cadmium ($0.0027 \text{ mg } 100\text{g}^{-1}$) and cobalt ($0.007 \text{ mg } 100\text{g}^{-1}$) levels in all cultivars. In the present study, the detected levels of contaminants were found to be markedly lower than the maximum limits allowed by Law: $100 \mu\text{g kg}^{-1}$ for Pb and $50 \mu\text{g kg}^{-1}$ for Cd (EU Regulation 1881/2006).

The concentrations of heavy metals in tomato fruit decreased in the order of $\text{Zn} > \text{Pb} > \text{Cu} > \text{Cr} > \text{Ni} > \text{Co} > \text{Cd}$.

10. Nitrate content

Nitrate content of vegetables depends on a number of external and internal factors [76; 77]. From external factors should be mentioned; supply of substrate with nitrate, light, time of day, temperature, season, supply with water, relative humidity, carbon dioxide concentration in the air, supply with biogenic elements, the influence of the accompanying cations, heavy metals, herbicides, chemical properties of the soil, location, time of sowing, time and method of harvest, storage conditions, etc. [78; 79]. Among the internal factors, the most important are the genetic specificity in the accumulation of nitrate (differences between species and differences within genotypes), the distribution of nitrate in certain parts of the plant and the age of the plants..

Nitrate content of various parts of a plant differs [76]. Vegetables that are consumed with their roots, stems and leaves have a high nitrate accumulation (up to 2000 mg kg^{-1}), whereas those with only fruits and melons as consumable parts have a low nitrate accumulation [80]. The tomato belongs to the vegetable plants which accumulate less nitrates than other vegetables (100 to 150 mg kg^{-1}). The effect of climate on nitrate accumulation has been studied [81], and it was found that nitrate content was lower in years that had a high rainfall. In warm and wet years, increased accumulation of nitrate is possible, regardless of whether the nitrogen originates from organic or mineral sources [82]. A comparable study performed in Austria on 17 vegetables found lower nitrate contents (-40% to -86%) in organic vegetables, with spinach being an exception [84]. In Germany, a comparison on carrots showed 61% less nitrates in organic ones [85]. In contrast, two other studies performed on tomato in Israel [83] and carrot in Norway did not show noticeable differences [86].

Nitrogen-rich organic fertilizers can also generate lower nitrate contents, but when mineralization conditions are very favorable they can also lead to high nitrate accumulations [87]. The use of organic fertilization with slowly or moderately available nitrogen (especially composts) is key to explaining the generally observed lower nitrate accumulation in organic vegetables [88].

Differences in nitrate content between cultivars in organic production are present. The lowest nitrate concentration was observed in 'Elpida' (20 mg kg^{-1}) and it was statistically significantly ($p < 0.05$) lower than the nitrate content in the 'Robin' and 'Amati' cultivars. The differences in

nitrate content between 'Robin' (27 mg kg⁻¹) and 'Amati' (29 mg kg⁻¹) in organic production were not statistically significant (Fig.3).

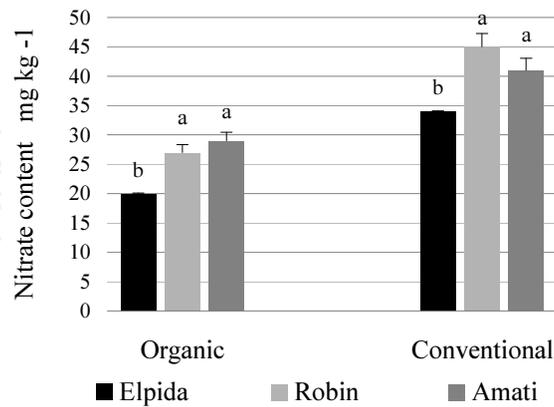


Figure 3. Nitrate content (mg kg⁻¹) in tomato fruit from organic and conventional production

The nitrate content in this study is presented as the average of all cultivars, and it was found to be lower in organic production (29%-41%) compared to conventional production.

In conventional tomato production the nitrate content was lowest in 'Elpida' (34 mg kg⁻¹). The nitrate concentration was significantly ($p < 0.05$) lower than in the other two cultivars. The difference in the nitrate content between the 'Robin' (45 mg kg⁻¹) and 'Amati' (41 mg kg⁻¹) cultivars was not statistically significant.

Rational application of organic manure instead of inorganic nutrients, use of physiologically active substances, proper spray of nitrification inhibitors and molybdenum fertilizers, and growing plants under controlled environmental conditions may all be factors that materially reduce nitrate accumulation in tomatoes.

Selection among the available genotypes/cultivars and breeding of new cultivars that do not accumulate nitrate even under heavy fertilization may also limit human consumption of nitrate through vegetables [89].

11. Conclusion

For all nutrients examined, cultivar differences were greater than differences due to cultivation method. The identification of cultivars with high nutritive value, represent a useful approach to select tomato cultivars with better health-promoting properties.

In general, the significant differences between tomatoes grown in organic or conventional production systems are:

1. organic tomatoes contain more carotenoids
2. organic tomatoes contain more minerals (P, K, Mg, Ca)

3. organic tomatoes contain far less heavy metals (Pb, Zn, Cu, Ni)
4. organic tomatoes contain less nitrates, about 30-40% less
5. organic tomatoes do not contain any pesticide residues

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