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Original Research

Heavy Metals and Nitrate Content in Tomato Fruit Grown in Organic and Conventional Production Systems

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Abstract

The objective of this study was to investigate whether there were any differences in the heavy metals and nitrate contents in organic and conventional tomatoes (Robin-F1, Amati-F1, and Elpida-F1). The tomato as a fruit vegetable is not characterized by high accumulation of heavy metals and nitrates. We found significantly greater concentrations of Pb, Zn, Cu, and Ni in conventional tomatoes, but we found the growing method to have no influence on cadmium Cd, Co, and Cr 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. The concentrations of heavy metals in tomato fruit decreased in the order Zn>Pb>Cu>Cr>Ni>Co>Cd. This study confirms that the most important variable in the nitrate content of tomatoes is cultivar. The lowest content of nitrates is registered in the variety Elpida, especially in the organically fertilized (20 $mg \cdot kg^{-1}$). 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 systems.

Keywords: *Solanum lycopersicum* L., production methods, contaminants, heavy metals

Introduction

The tomato (*Solanum lycopersicum* L.) 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 healthly aspects and nutrition. In the human diet, it is an important source of micronutrients, certain minerals (notably potassium), carboxylic acids, and carotenoids (in particular lycopene and phenolic compounds) [2, 3]. Most importantly, tomato consumption has been shown to reduce the risks of cardiovascular disease and certain types of cancer, such as prostate, lung, and stomach [4]. 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 has imposed the need to evaluate the quality and nutritional value of organic tomatoes.

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 [5-7]. Organic tomatoes achieve higher prices and a guaranteed placement compared to conventional tomatoes [8], because these products are often linked to protecting the environment and to having better quality (taste, storage), and most people believe that they

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Table 1. Monthly meteorological data from January to December 2008-10 from Sapes meteorological stations.

Month	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010		2008	2009	2010	
January	4.5	6.8	4.7	-0.5	1.8	-0.3	8.2	9.3	8.1	1.6	4.4	1.2	193.6	33.6	30.4	26.0	48.7
February	5.8	4.2	7.0	-0.1	-1.7	1.1	9.4	7.4	11.4	2.8	1.5	3.1	261.7	4.8	24.4	145.6	103.1
March	11.2	8.7	8.2	2.9	0.4	-0.1	15.0	12.0	13.8	8.1	5.8	3.8	382.0	153.8	15.4	49.4	149.9
April	13.7	13.2	13.7	0.6	0.1	0.6	17.0	17.7	20.3	10.6	9.4	7.8	476.2	68.8	30.6	24.2	104.0
May	18.0	19.6	18.9	-0.3	1.3	0.6	21.8	23.2	26.0	14.0	16.2	12.6	601.9	9.8	1.0	20.2	29.8
June	23.0	22.1	22.6	-0.1	-1.0	-0.5	27.5	26.3	29.5	18.8	18.4	16.9	654.2	19.6	29.8	78.2	144.2
July	24.9	25.8	25.1	-0.9	0.0	-0.7	29.5	30.2	32.2	20.3	22.2	18.9	753.6	3.6	0.4	81.0	146.8
August	26.0	24.7	28.3	0.6	-0.7	2.9	31.2	29.8	36.2	21.4	20.5	21.3	669.9	86.2	0.4	0.0	222.1
September	19.5	20.1	21.5	-1.6	-1.0	0.4	23.6	24.5	28.6	16.0	16.7	15.7	523.4	8.8	85.6	11.6	131.4
October	15.9	17.0	13.2	0.3	1.4	-2.4	20.1	20.5	18.1	12.3	14.0	9.3	319.2	19.2	123.0	136.0	183.6
November	11.4	11.2	14.6	0.6	0.4	3.8	15.1	16.6	19.6	7.9	7.0	10.8	230.3	84.0	32.1	53.2	64.1
December	4.8	9.2	8.4	-2.3	2.1	1.3	7.8	12.5	12.2	2.6	5.8	5.1	141.3	6.4	76.4	39.4	47.9
	TS			TOD			TX			TM			MSR	RR			RO

TS – Mean monthly air temperature (ºC)
TOD – Temperature deviation (ºC), i.e. deviation from 1951-97 average
TX – Mean daily temperature maximum for the month (ºC)
TM – Mean daily temperature minimum for the month (ºC)
MSR – Mean daily solar radiation ($MJ \cdot m^{-2}$)
RR – Precipitation amount (mm)
RO – Deviation of monthly values of precipitation (%) from the 1951-97 average

are healthier. Organic systems enhanced optimal production levels but with higher cultivation costs (certification procedures, higher cost per unit of fertilizer, phytosanitary treatments applied, more labor, etc.) compared with conventional farming.

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 [9]. 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 systems), and the pesticide types applied (preventive in the organic system and preventive or healing with variable periods of effectiveness in the conventional one) [10].

Organic production methods by definition do not guarantee a higher quality product [11]. Research results on the effects of organic and conventional production on fruit quality are sometimes contradictory. Factors influencing tomato quality are complex and interrelated, and additional studies are necessary to consolidate knowledge about the real interdependences.

The presence of heavy metals and nitrate reduces the nutritional value of the tomato. The aims of this paper is to determine the content of heavy metals and nitrate in different tomato cultivars, and to evaluate the change in chemical composition according to the cultivation method.

Materials and Methods

Three tomato varieties (Robin, Amati, and Elpida) have been tested in greenhouse production (plastic tunnels 3.5m high, covered with termolux 180 µm) during 2008-10, located in the Sapes, northeastern Greece (longitude: 25º42'E, latitude: 41º01'N,), using two different growing systems: organic and conventional. Mild weather conditions, the low level agrochemical pollution, and the small size family-farms all promote the production of organic tomato in Greece with good organoleptic properties.

Monthly meteorological data from January to December 2008-10 from Sapes meteorological stations were used (Table 1); air temperatures during the growing period were measured using a thermograph (Casella, London, UK).

Organic tomato production (after the conversion period) was certified by the certification bodies (DIO-ΔΗΩ) in full compliance with the EU regulation 2092/91 for organic production (standard certification: 834/2007). After extensive controls, the Certification commision annually renewed the contract issued by the farmer (from 2002 until today) and confirmed his code number (21431020096).

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 organic production. In conventional cultivation mineral fertilizers and chemical plant protection were applied.

Table 2. Chemical analysis of soil in organic and conventional production.

Production system	Depth	pH		$CaCO_3$	Humus	N total	P_2O_5	K_2O
	(cm)	KCl	H_2O	%				
Organic	0-20	6.00	6.46	2.94	6.73	0.44	179.35	37.36
	20-40	5.99	6.62	2.10	1.96	0.13	51.62	62.21
	40-60	5.72	6.71	3.36	1.39	0.09	22.04	37.81
Conventional	0-20	6.46	7.70	2.10	1.28	0.08	25.20	15.68
	20-40	5.89	6.87	3.36	1.38	0.09	15.79	26.99
	40-60	5.42	6.50	2.52	0.95	0.06	7.89	26.54

The differences between production systems were the fertilizers used, including organic (goat manure 3 tons/ha; N 1.92%; P_2O_5 1.14%; K_2O 2.05%) and conventional (mineral fertilizer NPK (12:12:17), plus nitrophos blue special + 2MgO +8S +Trace elements – 400 kg/ha), the number of phytosanitary (solarization) treatments (larger in organic system), and the pesticide types applied (preventive in the organic systems and preventive or healing with variable period of effectiveness in the conventional one).

The substrate for seedling production consisted of 30% soil, 50% manure, and 20% peat, and a small part of marble. Tomato seeds were sown on the first week of February each year in seed trays containing a peat and perlite mixture. At the third true leaf stage, the seedlings were transplanted to the soil with a plant density of 2.64 plant/m^2. Soil solarization against nematodes was applied before transplanting. It was an early-medium production. Planting was done on April 18 and the harvest period lasted from mid-June to late August.

The plants were grown in medium-heavy clay loam (classified as Inceptisol and Entisol) in the experimental garden in Sapes (146 m ASL). River sand was used in order to repair the structure of land for the establishment of greenhouse production (Table 2).

All plants were irrigated using drip irrigation. As the plants grew, all lateral shoots were manually removed and poles were used to support single stem plants. Plants were topped after the sixth truss. Bumblebees were used for pollination during organic tomato production in the greenhouse. Tomato samples (20 fruits) at the pink stage of ripening, determined by visual inspection, were collected from the third to sixth floral branches (each year from June till August) for quality analyses.

For each growing method the experiments were laid out in a randomized complete block design for the three tomato cultivars as treatments. The treatments were replicated 3 times for each growing method.

All analyses were carried out at the Technological Faculty of Novi Sad, Serbia, and the analytical laboratory of Biolab Epirus (Tzimas s. Bioepirus Ltd) in Ioannina, Greece.

To study the heavy metals accumulation in tomato, the fruits were oven dried (110ºC) for 24 h. The ground samples (0.3 g) were digested in 1:3 HNO_3 and HCl mixture. Digested samples were filtered throught a Whatman filter (No. 42) before metal analysis, and the concentrations of metals were determined on an atomic absorption spectrophotometer.

The analysis of nitrates was performed following the colorimetric procedure according to SRPS EN 12014-2 (Serbian standard).

All statistical analyses were performed using sas procedure (sas institute, cary, nc) for analyses of variance. Means were compared by tukey's multiple range test.

Results and Discussion

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 plant species [12]. 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 [13]. 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 metal accumulation [14].

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 [15].

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 0.14 mg·100g^{-1}. 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

Table 3. Heavy metals contents ($mg\cdot100g^{-1}$ f.w.) of organic and conventional tomatoes.

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

Distinct letters in the row indicate significant differences according to Tukey's test ($P \leq 0.05$)

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 $mg\cdot kg^{-1}$) in comparison with conventional methods (0.10 $mg\cdot100g^{-1}$). The lead content in Amati' is significantly lower in organic (0.07 $mg\cdot kg^{-1}$) than in conventional production (0.11 $mg\cdot100g^{-1}$).

The zinc content in tomato fruits in our studies was just below 20 $mg\cdot100g^{-1}$. 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 $mg\cdot kg^{-1}$) was obtained in 'Robin' in organic production (Table 3).

The concentrations of Zn in tomato were generally higher than Cu contents [16]. Copper content in organic fruit production is lower, ranging from 0.5 $mg\cdot100g^{-1}$ hybrids Robin and Amati to 0.7 $mg\cdot100g^{-1}$ hybrids Elpida. The copper content in conventional tomato production is twice as high in the hybrids Robin (0.10 $mg\cdot100g^{-1}$) and Amati (0.13 $mg\cdot100g^{-1}$) in relation to organic production. The copper content in the hybrid Elpida is 0.11 $mg\cdot100g^{-1}$. In contrast, significantly greater concentrations of Cd (33 $\mu g\cdot kg^{-1}$) and Pb (37.8 $\mu g\cdot kg^{-1}$) were found in organic tomatoes, but at the same time a lower Cu content (0.46 $mg\cdot kg^{-1}$) was observed [17]. 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 $mg\cdot100g^{-1}$) and cobalt (0.007 $mg\cdot100g^{-1}$) 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 $\mu g\cdot kg^{-1}$ for Pb and 50 $\mu g\cdot kg^{-1}$ for Cd (EU Regulation 1881/2006). The concentrations of heavy metals in tomato fruit decreased in the order Zn>Pb>Cu>Cr>Ni>Co>Cd. In contrast, the overall metal concentration pattern in vegetables (pepper, beans, eggplant) in Turkey was Pb>Cr>Ni> Zn>Cu> Cd [18].

Nitrate Content

Nitrate content of vegetables depends on a number of external and internal factors [20, 21]. 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. [22, 23]. 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 [20]. Chinese cabbage is a good indicator of the level of an area with heavy metals and nitrates and nitrites [19]. Vegetables that are consumed with their roots, stems and leaves have a high nitrate accumulation (up to 2000 $mg\cdot kg^{-1}$), whereas those with only fruits and melons as consumable parts have a low nitrate accumulation [24]. The tomato belongs to the vegetable plants, which accumulate fewer nitrates than other vegetables (100 to 150 $mg\cdot kg^{-1}$). The effect of climate on nitrate accumulation has been studied [25], and it was found that nitrate content was lower in years that had high rainfall. In warm and wet years, increased accumulation of nitrate is possible, regardless of whether the nitrogen originates from organic or mineral sources [26]. A comparable study performed in Austria on 17 vegetables found lower nitrate contents (-40% to -86%) in organic vegetables, with spinach being an exception [28]. In Germany, a comparison on carrots showed 61% fewer nitrates in organic ones [29]. In contrast, two other studies performed on tomato in Israel [27] and carrot in Norway did not show noticeable differences [30].

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 [31]. 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 [32].

Differences in nitrate content between cultivars in organic production are present. The lowest nitrate concen-

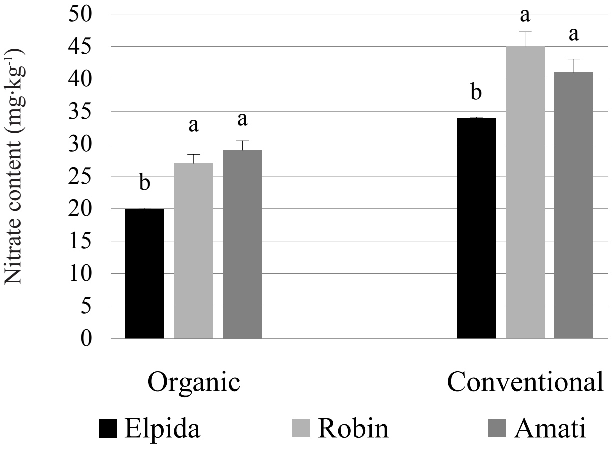

Fig. 1. Nitrate content (mg·kg^{-1}) in tomato fruit from organic and conventional production.

tration was observed in Elpida (20 mg·kg^{-1}), and it was statistically significantly ($p<0.05$) lower than 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. 1).

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 [33].

Conclusions

This study confirms that the most important variable in the heavy metals and nitrate content of tomatoes is the tomato cultivar. The identification of cultivars with lower levels of contaminants represents a useful approach to selecting 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 far fewer heavy metals (Pb, Zn, Cu, Ni)
2) Organic tomatoes contain fewer nitrates, about 30-40% less

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