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Article

Comparative Nutritional and Antioxidant Compounds of Organic and Conventional Vegetables during the Main Market Availability Period

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Abstract: Seven winter and five summer vegetables produced under organic and conventional systems were collected from a supermarket seven times between January and April and between July and October for winter and summer vegetables, respectively, and their ascorbic acid and total phenolic content (compounds with proven antioxidant activity) as well as total antioxidant capacity, soluble solids and nitrates were determined. The results clearly indicated that, from the three factors studied (vegetable species, cropping system and sampling time), vegetable species made the highest contribution to ascorbic acid, phenolics, antioxidant capacity, soluble solids and nitrates. Results for each vegetable species showed that most organic vegetables appear to have lower nitrate content, some have higher phenolics, antioxidant capacity and soluble solids, and only few have higher ascorbic acid compared with conventional vegetables. The significance of the differences in nutritional and antioxidant value between organic and conventional vegetables is questionable, since vegetable species and sampling time can affect their nutritional value to a great or greater extent than the cropping system.

Keywords: antioxidant activity; ascorbic acid; nitrates; phenolics

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1. Introduction

Considerable evidence has made known the importance of vegetable consumption in protecting human health from various chronic diseases that have their origin in oxidative stress. This is due to the fact that vegetables are considered one of the main sources of ascorbic acid and antioxidants for human nutrition [1,2]. Based on the eating habits of adult consumers in the European Union, it is estimated that approximately 33% of the daily intake (65–138 mg) of vitamin C comes from the consumption of vegetables, among 21 foods or food groups; in this percentage, juices and other forms of products containing vegetables have not been included [3]. The biological functions of ascorbic acid in man appear to be related to its antioxidant properties [4–6]. Phenolic compounds are secondary metabolites in vegetables; their functions in plants are not always known, but some are structural polymers, UV screens, antioxidants and attractants, while others are involved in non-specific defense mechanisms [7]. One of the principal roles that have been proposed as part of the actions of phenolics in man is that of an antioxidant [8,9].

On the other hand, vegetables are also the major dietary source of nitrates, contributing over 80% of the nitrate intake in the European diet, which constitutes a serious threat to man's health [10].

There are several factors affecting the content of nutritional compounds in vegetables, e.g., genetic, environmental and agricultural factors [11], as well as postharvest handling and conditions [12,13]. Of the factors studied, much attention has been paid in the last decades to the cropping systems. Most studies have focused on comparative aspects of quality of organically and conventionally produced vegetables, but as concluded in most recent reviews [11,14–32], inconsistent differences in nutritional compounds were detected; only for nitrate and ascorbic acid content were systematic tendencies apparent, with lower and higher levels in organic vegetables, respectively. On the other hand, in most studies, only macronutrients, vitamins or minerals were determined, while regarding antioxidants, data on vegetables are scarce [33] and the published results are contradictory [34].

From the point of view of consumers, the question remains: is there a difference in human nutrition between organically and conventionally produced vegetables? In order to accurately draw any conclusions, it is necessary to continue investigating the effects, if any, that the organic system has on the nutritional compounds of produced vegetables.

There are three ways of undertaking studies to compare conventionally and organically produced vegetables: cultivation tests, surveys and market-orientated supply studies, all having both advantages and disadvantages [35,36]. Taking into consideration the fact that the quality of fresh produce, as seen in the marketplace, can often differ from what might be expected from the produce that was harvested [37], the best way to evaluate differences between organic and conventional vegetables, facing the consumer, is to sample the products as purchased from the market [38], so that all factors which are not only related to the cropping system but which do influence product quality to a large degree are considered. For example, it is well-known [12,13] that most of the vegetables are highly perishable, and postharvest handling and conditions greatly affect their nutritional quality.

However, only a small number of studies have taken the approach of measuring nutritional value of vegetables purchased from the market [38,39]. Conklin and Thompson (1993) reported visible quality characteristics [40], Smith (1993) analyzed a range of minerals [41], Pither and Hall (1990) and Stopes et al. (1998) reported among others results on ascorbic acid and nitrates [42,43], while Faller and Fialho (2010) evaluated polyphenol content and antioxidant capacity of organically and conventionally produced vegetables from retail outlets [44]. No consistent differences between organic and conventional vegetables and a considerable range of values were reported. The most recent survey of consumers showed no significant differences between the sensory attributes of a range of organic and conventional fruits and vegetables available to the Irish consumer [38].

The present work is considered a retail market study which seeks to compare the nutritional quality of vegetables produced under organic and conventional systems. The quality parameters studied included ascorbic acid and total phenolics (compounds with proven antioxidant activity), total antioxidant capacity, soluble solids and nitrates in seven winter and five summer vegetables largely consumed, purchased from the retail market seven times at 15-day intervals during the main market availability period.

2. Materials and Methods

2.1. Plant Material and Handling

Vegetables included in the study were those that are widely consumed and also were available as certified organic products, e.g., cabbage (*Brassica oleracea* L. Capitata), carrot (*Daucus carota* L.), leek (*Allium porrum* L.), leaf and romaine lettuce (*Lactuca sativa* L.), potato (*Solanum tuberosum* L.) and spinach (*Spinacea oleracea* L.) (winter vegetables) as well as cucumber (*Cucumis sativus* L.), eggplant (*Solanum melongena* L.), green sweet pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill.) and zucchini (*Cucurbita pepo* L.) (summer vegetables). Samples were purchased seven times in total, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket in Thessaloniki, Greece.

In each sampling date, the samples were collected in a quantity of 500–1000 g for each of the three replicates for each vegetable, with the exception of cabbage, in which a larger quantity was used (one head per replicate), thoroughly washed with tap water and stored in sealed plastic bags at −30 °C, prior to analysis. After partial thawing, only the edible part of each vegetable was used, based on common household practices (e.g., peeling of carrots and potatoes as well as removal of other non-edible parts such as fruit pedicel and calyx), and then macerated in a Waring blender. The macerated material was used for the determination of ascorbic acid, total soluble phenols, soluble solids, nitrates and antioxidant capacity.

2.2. Methods

2.2.1. Ascorbic Acid

For the extraction of ascorbic acid, 30 g of the macerated material was homogenized with 50 mL 1% oxalic acid solution in a Polytron (Kinematika GmbH, Eschbach, Germany) and centrifuged at 5000× *g* for 20 min. The ascorbic acid was measured in the filtrate by using Reflectoquant ascorbic acid test strips and an RQflex portable reflectometer (Merck, Darmstadt, Germany).

2.2.2. Total Soluble Phenols

Total soluble phenols were extracted by homogenizing samples of 10 g macerated material with 20 mL of 95% ethanol in a Polytron (Kinematika GmbH). The pellet, after centrifugation at 5000× *g* for 20 min, was again extracted with 95% ethanol and then once more with 5% ethanol in the same procedure. The total soluble phenols in the combined supernatants were determined using the Folin–Ciocalteu assay [45]. The standard curve was developed using gallic acid and the results are expressed as mg gallic acid equivalent (GAE) per g fw.

2.2.3. DPPH Radical Scavenging Activity

Radical scavenging activity of 2,2-diphenyl-1-picrylhydrazyl (DPPH) was determined using a modified method of Brand-Williams et al. (1995) [46]. Samples of 5 g macerated material were homogenized with 25 mL 95% methanol in a Polytron (Kinematika GmbH) and centrifuged at 5000× *g* for 10 min. The supernatant was diluted with 95% methanol up to 25 mL, and 50 µL of the extract was added to 2950 µL of 100 µM DPPH methanolic solution in a test tube. The tubes were covered with parafilm, vortexed thoroughly and kept in the dark at room temperature. The reduction in the absorbance of the resulting solution was measured at 517 nm after 30 min. The control solution consisted of 50 µL methanol and 2950 µL DPPH. The standard curve was developed using ascorbic acid and the results are expressed as mg ascorbic acid equivalents antioxidant capacity (AEAC) per 100 g fw.

2.2.4. Soluble Solids

Soluble solid content was measured in the juice of the macerated material using a portable Atago PR-1 refractometer (Atago Co. Ltd., Tokyo, Japan).

2.2.5. Nitrates

For the extraction of nitrates, 10 g of the macerated material was homogenized with 50 mL distilled water in a Polytron (Kinematika GmbH) and centrifuged at 5000× *g* for 20 min. Nitrates were determined in the filtrate as described by Cataldo et al. (1975) [47].

For each organic to conventional comparison, a percent difference was calculated: (organic − conventional)/conventional × 100.

2.3. Data Analysis

Data analyses for both winter and summer vegetables were done by an analysis of variance (ANOVA) using the MSTAT version 4.00/EM (Michigan State University) as a completely randomized design, with three replications. The percent of the total variance for each of the main effects and their interactions were calculated from the sum of squares.

ANOVA for the main effects (vegetable species, farming system and sampling time) and their interactions showed that all three main factors as well as their interactions had a significant effect on the nutritional quality parameters measured for both winter and summer vegetables, but most of the total variance in both winter (60.3, 87.5, 61.3, 70.6 and

61.2% for ascorbic acid, total phenolics, antioxidant capacity, soluble solids and nitrates, respectively) and summer (53.5, 78.6, 62.6, 46.7 and 53.4% for ascorbic acid, total phenolics, antioxidant capacity, soluble solids and nitrates, respectively) vegetables was accounted for by differences between vegetable species. For this reason, ANOVA was performed again for each vegetable species separately.

3. Results

3.1. Ascorbic Acid

Farming system had a significant effect on ascorbic acid content of cabbage, leek, romaine lettuce, cucumber, eggplant, tomato and zucchini but not on the content of carrot, leaf lettuce, potato, spinach and green sweet pepper (Table 1). On the other hand, sampling time significantly affected ascorbic acid content in all vegetables studied, while a significant interaction between farming system and sampling time was also detected for all vegetables with the exception of cabbage. However, most of the total variance for ascorbic acid in all winter and two summer vegetables (eggplant and green sweet pepper) was accounted for by differences between sampling times, while in cucumber, tomato and zucchini, most of the total variance was attributed to the farming system × sampling time interaction.

Table 1. Analysis of variance for ascorbic acid of seven winter and five summer vegetable species produced under two cropping systems (organic and conventional) and purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket.

Source of Variance	DF	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV
Winter Vegetables		**Cabbage**		**Carrot**		**Leek**		**Leaf Lettuce**		**Romaine Lettuce**		**Potato**		**Spinach**	
Cropping system (A)	1	***	13.6	ns	0.7	***	11.8	ns	0.0	*	2.0	ns	2.4	ns	0.2
Sampling time (B)	6	***	49.4	***	56.0	***	66.5	***	73.2	***	47.7	***	59.0	***	58.9
A × B	6	ns	10.0	***	33.4	**	10.5	***	16.8	***	38.0	**	16.7	***	26.2
Error	28														
Summer Vegetables		**Cucumber**		**Eggplant**		**Pepper**		**Tomato**		**Zucchini**					
Cropping system (A)	1	***	12.7	***	6.4	ns	2.9	**	5.8	***	24.6				
Sampling time (B)	6	***	40.8	***	56.5	***	41.3	***	25.5	***	24.9				
A × B	6	***	41.0	***	24.9	***	34.9	***	51.2	***	39.9				
Error	28														

DF, degrees of freedom; MS, mean square; %TV, % of total variance; ns, not significant effect. * Significant effect at the 0.05 level; ** significant effect at the 0.01 level; *** significant effect at the 0.001 level.

Among the vegetables studied, spinach from winter vegetables and green sweet pepper from summer vegetables had the highest ascorbic acid content with 32.1 and 17.8 mg/100 g fw, respectively, as an average of the seven sampling times and the two cropping systems. For winter vegetables, as an average of the both cropping systems, the highest ascorbic acid content was found in cabbage, carrot, romaine lettuce and potato from middle of January to middle of February, while for leaf lettuce, leek and spinach, it was found from the end of January to middle of February (data not shown).

As an average of the seven sampling times, organic cabbage, leek and zucchini had higher ascorbic acid content by 64, 46 and 29%, respectively, than the conventional ones, while organic cucumber, tomato, romaine lettuce and eggplant had lower ascorbic acid content by 33, 26, 20 and 17%, respectively, than the conventional ones (Table 2).

Table 2. Ascorbic acid, total phenolics, antioxidant capacity, soluble solids and nitrates of seven winter and five summer organically produced vegetable species as % of those produced conventionally. Samples were purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket. Data are presented as an average of the seven sampling times.

	Ascorbic Acid	Total Phenolics	Antioxidant Capacity	Soluble Solids	Nitrates
Winter Vegetables					
Cabbage	+64.0	−12.0	−16.8	−11.0	ns
Carrot	ns	−15.2	−22.8	+4.9	+74.3
Leek	+46.0	+33.8	+32.5	+16.7	−15.3
Leaf lettuce	ns	ns	ns	+29.6	−15.9
Romaine lettuce	−19.7	−15.8	+13.1	ns	−24.5
Potato	ns	ns	ns	−8.6	ns
Spinach	ns	+36.7	+45.4	+21.4	−30.3
Summer Vegetables					
Cucumber	−32.6	+19.5	ns	+7.8	−40.0
Eggplant	−17.0	ns	−20.1	ns	−30.4
Pepper	ns	ns	−20.4	ns	−45.7
Tomato	−26.2	+29.4	+67.3	ns	−13.8
Zucchini	+28.9	+16.1	+13.4	+8.0	ns

ns, not significant.

3.2. Phenolics

Farming system had a significant effect on phenolic content of cabbage, carrot, leek, romaine lettuce, spinach, cucumber, tomato and zucchini but not on the content of leaf lettuce, potato, eggplant and green sweet pepper (Table 3). On the other hand, sampling time significantly affected phenolic content in all vegetables studied, while a significant interaction between farming system and sampling time was also detected for all vegetables studied. However, most of the total variance for phenolics only in three vegetables (cabbage, spinach and cucumber) was accounted for by differences between farming system; in six vegetables (carrot, leaf and romaine lettuce, eggplant, green sweet pepper and zucchini) this was accounted for by differences between sampling times; and in three vegetables (leek, potato and tomato), most of the total variance was attributed to the farming system × sampling time interaction.

Table 3. Analysis of variance for total phenolics of seven winter and five summer vegetable species produced under two cropping systems (organic and conventional) and purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket.

Source of Variance	DF	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV
Winter Vegetables		**Cabbage**		**Carrot**		**Leek**		**Leaf Lettuce**		**Romaine Lettuce**		**Potato**		**Spinach**	
Cropping system (A)	1	***	41.7	***	12.5	***	35.9	ns	0.0	**	18.2	ns	0.0	***	56.8
Sampling time (B)	6	***	37.5	***	50.0	***	12.8	***	47.6	**	27.3	***	18.8	***	13.5
A × B	6	***	12.5	***	25.0	***	41.0	**	23.8	*	18.2	***	68.8	***	20.7
Error	28														
Summer Vegetables		**Cucumber**		**Eggplant**		**Pepper**		**Tomato**		**Zucchini**					
Cropping system (A)	1	***	88.9	ns	0.0	ns	0.0	***	32.4	***	16.7				
Sampling time (B)	6	***	5.9	***	52.0	***	40.4	***	19.1	***	55.6				
A × B	6	***	4.4	**	24.0	**	26.3	***	44.9	*	11.1				
Error	28														

DF, degrees of freedom; MS, mean square; %TV, % of total variance; ns, not significant effect. * Significant effect at the 0.05 level; ** significant effect at the 0.01 level; *** significant effect at the 0.001 level.

Among the vegetables studied, spinach and green sweet pepper had the highest phenolic content with 112 and 80 mg gallic acid equivalents/100 g fw, respectively, as an average of the seven sampling times and the two cropping systems (data not shown). No clear tendency in the phenolic content was observed throughout the sampling period.

As an average of the seven sampling times, organic spinach, leek, tomato, cucumber and zucchini had higher phenolic content by 37, 34, 29, 20 and 16%, respectively, than the conventional ones, while organic romaine lettuce, carrot and cabbage had lower phenolic content by 16, 15 and 12%, respectively, than the conventional ones (Table 2).

3.3. Antioxidant Capacity

Farming system had a significant effect on antioxidant capacity of cabbage, carrot, leek, romaine lettuce, spinach, eggplant, green sweet pepper, tomato and zucchini but not on the capacity of leaf lettuce, potato and cucumber (Table 4). On the other hand, sampling time significantly affected antioxidant capacity in all vegetables studied, while a significant interaction between farming system and sampling time was also detected for all vegetables studied with the exception of carrot, romaine lettuce, cucumber and eggplant. However, most of the total variance for antioxidant capacity was accounted for by differences between sampling times in all vegetables, with the exception of spinach and tomato, in which most of the total variance was attributed to the farming system × sampling time interaction.

Table 4. Analysis of variance for antioxidant capacity of seven winter and five summer vegetable species produced under two cropping systems (organic and conventional) and purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket.

Source of Variance	DF	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV
Winter Vegetables		**Cabbage**		**Carrot**		**Leek**		**Leaf Lettuce**		**Romaine Lettuce**		**Potato**		**Spinach**	
Cropping system (A)	1	***	9.1	***	5.3	***	13.5	ns	0.1	*	3.6	ns	1.4	***	16.4
Sampling time (B)	6	***	59.3	***	79.5	***	44.3	***	71.3	***	67.3	***	70.8	***	27.8
A × B	6	**	14.5	ns	4.6	***	25.1	***	16.3	ns	6.5	*	9.6	***	43.3
Error	28														
Summer Vegetables		**Cucumber**		**Eggplant**		**Pepper**		**Tomato**		**Zucchini**					
Cropping system (A)	1	ns	0.0	*	6.6	*	7.4	***	27.4	**	4.2				
Sampling time (B)	6	**	41.9	***	56.6	***	41.0	***	18.8	***	60.7				
A × B	6	ns	3.9	ns	1.7	*	21.3	***	43.2	***	26.0				
Error	28														

DF, degrees of freedom; MS, mean square; %TV, % of total variance; ns, not significant effect. * Significant effect at the 0.05 level; ** significant effect at the 0.01 level; *** significant effect at the 0.001 level.

Among the vegetables studied, spinach and tomato had the greatest antioxidant capacity with 27.7 and 20.7 mg ascorbic acid equivalents/100 g fw, respectively, as an average of the seven sampling times and the two cropping systems. As an average of the both cropping systems, the highest antioxidant capacity was found in winter vegetables from the beginning of March to middle of April, while in summer vegetables (with the exception of sweet pepper) from the end of January to middle of February (data not shown).

As an average of the seven sampling times, organic tomato, spinach, leek, zucchini and romaine lettuce had higher antioxidant capacity by 67, 45, 33, 13 and 13%, respectively, than the conventional ones, while organic carrot, green sweet pepper, eggplant and cabbage had lower capacity by 23, 20, 20 and 17%, respectively, than the conventional ones (Table 2).

3.4. Soluble Solids

Farming system had a significant effect on soluble solids content of cabbage, carrot, leek, leaf lettuce, potato, spinach, cucumber and zucchini but not on the content of romaine lettuce, eggplant, green sweet pepper and tomato (Table 5). On the other hand, sampling time significantly affected soluble solids content in all vegetables studied, while a significant interaction between farming system and sampling time was also detected for all vegetables studied, with the exception of green sweet pepper. However, most of the total variance for soluble solids was accounted for by differences between sampling times in all vegetables, with the exception of carrot, potato, cucumber and tomato, in which most of the total variance was attributed to the farming system × sampling time interaction.

Table 5. Analysis of variance for soluble solids of seven winter and five summer vegetable species produced under two cropping systems (organic and conventional) and purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket.

Source of Variance	DF	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV
Winter Vegetables		**Cabbage**		**Carrot**		**Leek**		**Leaf Lettuce**		**Romaine Lettuce**		**Potato**		**Spinach**	
Cropping system (A)	1	***	12.7	***	8.5	***	21.3	***	11.2	ns	0.1	***	23.1	***	17.9
Sampling time (B)	6	***	45.0	***	35.2	***	33.9	***	58.9	***	37.1	***	31.2	***	57.8
A × B	6	***	30.6	***	40.1	***	24.5	***	20.9	**	32.9	***	34.1	***	17.6
Error	28														
Summer Vegetables		**Cucumber**		**Eggplant**		**Pepper**		**Tomato**		**Zucchini**					
Cropping system (A)	1	**	9.3	ns	2.4	ns	2.5	ns	0.0	***	14.4				
Sampling time (B)	6	*	18.4	***	49.8	***	49.4	***	32.5	***	46.4				
A × B	6	***	44.4	***	29.6	ns	9.2	***	45.0	**	17.3				
Error	28														

DF, degrees of freedom; MS, mean square; %TV, % of total variance; ns, not significant effect; * Significant effect at the 0.05 level; ** significant effect at the 0.01 level; *** significant effect at the 0.001 level.

Among the vegetables studied, leek from winter vegetables and zucchini from summer vegetables had the highest soluble solids content with 9.44 and 4.63%, respectively, as an average of the seven sampling times and the two cropping systems (data not shown). No clear tendency in the soluble solids content was observed throughout the sampling period.

As an average of the seven sampling times, organic leaf lettuce, spinach, leek, zucchini, cucumber and carrot had higher soluble solids content by 30, 21, 17, 8, 8 and 5%, respectively, than the conventional ones, while organic cabbage and potato had lower soluble solids content by 11 and 9%, respectively, than the conventional ones (Table 2).

3.5. Nitrates

Farming system had a significant effect on nitrate content of carrot, leek, leaf and romaine lettuce, spinach, cucumber, eggplant, green sweet pepper and tomato but not on the content of cabbage, potato and zucchini (Table 6). On the other hand, sampling time significantly affected nitrate content in all vegetables studied, while a significant interaction between farming system and sampling time was also detected for all vegetables studied, with the exception of cabbage. However, most of the total variance for ascorbic acid in all winter vegetables, with the exception of carrot, and in three summer vegetables (eggplant, tomato and zucchini) was accounted for by differences between sampling times, while in carrot, cucumber and green sweet pepper, this was accounted for by differences between farming systems.

Among the vegetables studied, romaine lettuce from winter vegetables and zucchini from summer vegetables had the highest nitrate content with 330 and 193 mg/kg fw, respectively, as an average of the seven sampling times and the two cropping systems (data not shown). No clear tendency in the nitrate content was observed throughout the sampling period.

As an average of the seven sampling times, organic green sweet pepper, cucumber, eggplant, spinach, romaine lettuce, leaf lettuce, leek and tomato had lower nitrate content by 46, 40, 30, 30, 25, 16, 15 and 14%, respectively, than the conventional ones, while only organic carrot had higher nitrates by 74%, than the conventional one (Table 2).

Table 6. Analysis of variance for nitrates of seven winter and five summer vegetable species produced under two cropping systems (organic and conventional) and purchased at seven sampling times, every 15 days, between January and April and between July and October for winter and summer vegetables, respectively, from a supermarket.

Source of Variance	DF	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV	MS	%TV
Winter Vegetables		**Cabbage**		**Carrot**		**Leek**		**Leaf Lettuce**		**Romaine Lettuce**		**Potato**		**Spinach**	
Cropping system (A)	1	ns	1.3	***	45.8	***	5.6	*	3.3	***	17.7	ns	1.2	***	12.9
Sampling time (B)	6	**	37.2	***	25.7	***	54.2	***	58.9	***	45.6	***	47.6	***	45.6
A × B	6	ns	12.3	***	19.3	***	28.8	**	16.5	***	19.9	**	23.4	***	38.7
Error	28														
Summer Vegetables		**Cucumber**		**Eggplant**		**Pepper**		**Tomato**		**Zucchini**					
Cropping system (A)	1	***	39.5	***	31.9	***	48.7	**	3.2	ns	1.3				
Sampling time (B)	6	*	16.3	***	36.5	***	32.1	***	48.7	***	49.5				
A × B	6	*	16.8	***	21.8	*	7.8	***	40.8	***	38.3				
Error	28														

DF, degrees of freedom; MS, mean square; %TV, % of total variance; ns, not significant effect. * Significant effect at the 0.05 level; ** significant effect at the 0.01 level; *** significant effect at the 0.001 level.

4. Discussion

The present study evaluated the levels of the main nutritional and antioxidant compounds which are actually available in vegetables when the consumers purchase them from the retail market. Three main factors were considered: vegetable species, cropping system and sampling time. The results clearly indicated that from the three factors studied, the vegetable species had the highest contribution in ascorbic acid, phenolics, antioxidant capacity, soluble solids and nitrates.

On the other hand, results for each of the vegetable species, when examined separately, showed that although cropping system affected the measured level of nutritional and antioxidant compounds in most of the vegetables studied, the highest contribution was found only in phenolic content of cabbage, spinach and cucumber, as well as in nitrate content of carrot, cucumber and green sweet pepper (Tables 1 and 3–6).

Based on the comparison of the farming system, only nitrates had an apparent consistent tendency, with lower levels in organic vegetables (Table 2). This was in accordance with the conclusions of the recent reviews [11,14–32]. As an average, organic farming lead to an approximately 22% reduction in the intake of nitrates by humans from winter leafy vegetables. It should be mentioned that the major sources for nitrates in Western diets are potatoes and leafy winter vegetables, the first because they are consumed in the largest quantity and the latter due to its high nitrate content [10].

Throughout the sampling period, the nitrate content for the samples analyzed did not exceed a level of 480 mg/kg fw. More important, the highest measured content of 477, 473 and 328 mg/kg fw for conventional leaf and romaine lettuce and spinach, respectively, were lower (one-eighth) than the specified maximum limits for these vegetables by the European Commission Regulation. Overall, the levels of nitrate content of vegetables found in this study were very similar to values that have been reported in the USA. In contrast, the corresponding values, especially for leafy vegetables, were much lower than values reported in Northwestern Europe [48]. This is in agreement with values found in previous surveys for nitrate content in leafy vegetables in Greece [49].

Such differences in nitrate content between organic and conventional vegetables may be attributed mainly to cultivation practices, since no appreciable changes for nitrate content in vegetables have been reported under normal postharvest handling conditions [50]. It is well-known than high nitrogen availably in the soil results in nitrate accumulation [10]. In the conventional systems, higher fertilization rates are usually applied with readily available mineral nutrients when compared with organic systems, in which organic fertilizers release nutrients more slowly than mineral fertilizers.

When it comes to secondary metabolites such as ascorbic acid and phenolics, which are the most abundant antioxidants in fruit and vegetables [51], inconsistent differences were found between vegetables produced under the two cropping systems examined (Table 2). For example, for potatoes, no significant differences were detected between cropping systems. Potatoes are considered the major source of both ascorbic acid [4] and total phenolics [52] in the European diet.

Accumulation of ascorbic acid is increased whenever nitrogen available in the soil is low [53]; thus it should be expected that organic vegetables produced under low nitrogen availability would contain higher ascorbic acid levels. However, this was not confirmed by the results of our study with vegetables purchased from the market. The differences in the ascorbic acid content found in our study may be attributed mainly to other factors than the cultivation practices; it is well-known [53] that postharvest handling and conditions significantly affect its content in fruit and vegetables. Temperature management during postharvest handling and operations is the most important factor to maintain ascorbic acid in vegetables; its loss is accelerated at higher temperatures and with longer storage durations.

It has been reported [54] that organic foods had elevated antioxidant levels in about 85% of the cases studied and that these levels were on average about 30% higher compared to foods produced conventionally. The collected data for phenolics compounds from 15 studies showed that their content in organic crops relative to those in conventional crops was in the range of −57 to +732% [11]. However, for vegetables produced under similar environmental conditions, inconsistent results have been reported. According to a study [55], both green and red sweet pepper fruit harvested from plants grown with the organic method showed significantly higher (about 42 and 27%, respectively) content of total phenolics compared with fruit from plants grown with the conventional method. On the contrary, two varieties of sweet peppers in a three-year study [56] and bell pepper fruits supplied by 24 commercial greenhouses during two consecutive growing seasons [57] did not display any differences due to cropping system when harvested at both green and red maturity stages. Moreover, it was reported that overall differences between harvesting times or between years were far greater than those due to the cropping system [57]. On the other hand, no differences were detected in the levels of individual and total phenolics in leaf lettuce and collards when they were cultivated under organic or conventional practices [34].

Few statistical differences were observed for polyphenol content and antioxidant capacity of six vegetables (potato, broccoli, onion, carrot, tomato and white cabbage) purchased from three different local markets in Rio de Janeiro, Brazil. Both nutritional parameters tended to be higher in organic vegetables [44]. In some organic vegetables (leek, romaine lettuce, spinach, tomato and zucchini), we also found higher antioxidant capacity by 13–67%, while in some others (cabbage, carrot, eggplant and green sweet pepper), it was lower by 17–23% when compared with conventional vegetables (Table 2).

In our study, most of the organic vegetables (carrot, leek, leaf lettuce, spinach, cucumber and zucchini) contained more soluble solids than the conventional ones (Table 2). Higher content of dry matter (the biggest part of which is soluble solids) has been reported for organic vegetables [35] that may be associated with better storage quality, resulting in less extensive decay [11]. Moreover, reduced water content may lead to a higher concentration of plant compounds and thus to a better taste in tomato [58].

5. Conclusions

The results clearly indicated that from the three factors studied (vegetable species, cropping system and sampling time), vegetable species had the highest contribution on ascorbic acid, phenolics, antioxidant capacity, soluble solids and nitrates. Results for each vegetable species showed that most of the organic vegetables appear to have lower nitrate content, some have higher phenolics, antioxidant capacity and soluble solids, and only a few have higher ascorbic acid compared with conventional vegetables. Therefore, the suspected differences between vegetables from the two cropping systems are not sufficiently consistent, and dietary importance is expected to cause a difference in nutritional value. Vegetable species and sampling time can affect their nutritional value to a great or greater extent than cropping system. Moreover, it should be emphasized that it is difficult to guarantee that the choice of organic rather than conventional vegetables will result in a higher concentration of bioactive compounds, since the cultivar would also play a crucial role in this respect, in addition to the vegetable species.

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References

1. Lampe, J.W. Health effects of vegetables and fruit: Assessing mechanisms of action in human experimental studies. *Am. J. Clin. Nutr.* **1999**, *70*, 475S–490S. [CrossRef] [PubMed]
2. Yahia, E.M.; Maldonado Celis, M.E.; Svendsen, M. The contribution of fruit and vegetable consumption to human health. In *Vegetable Phytochemicals: Chemistry and Human Health, Volume I*, 2nd ed.; Yahia, E.M., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2018; pp. 3–52.
3. European Food Safety Authority (EFSA). Scientific opinion on dietary reference values for vitamin C. EFSA Panel on dietetic products, nutrition, and allergies (NDA). *EFSA J.* **2013**, *11*, 3418.
4. Davey, M.W.; Van Montagu, M.; Inzé, D.; Sanmartin, M.; Kanellis, A.; Smirnoff, N.; Benzie, I.J.J.; Strain, J.J.; Favell, D.; Fletcher, J. Plant L-ascorbic acid: Chemistry, function, metabolism, bioavailability and effects of processing. *J. Sci. Food Agric.* **2000**, *80*, 825–860. [CrossRef]
5. Mellidou, I.; Koukounaras, A.; Chatzopoulou, F.; Kostas, S.; Kanellis, A.K. Plant vitamin C: One single molecule with a plethora of roles. In *Vegetable Phytochemicals: Chemistry and Human Health, Volume I*, 2nd ed.; Yahia, E.M., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2018; pp. 463–498.
6. Rivière, C.; Hennebelle, T. Plant kingdom as source of vitamins. In *Handbook of Dietary Phytochemicals*; Xiao, J., Sarker, S.D., Asakawa, Y., Eds.; Springer: Singapore, 2020; pp. 1–125.
7. Saltveit, M.E. Synthesis and metabolism of phenolic compounds. In *Vegetable Phytochemicals: Chemistry and Human Health, Volume I*, 2nd ed.; Yahia, E.M., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2018; pp. 115–124.
8. Parr, A.J.; Bolwell, G.P. Phenols in the plant and in man. The potential for possible nutritional enhancement of the diet by modifying the phenols content or profile. *J. Sci. Food Agric.* **2000**, *80*, 985–1012. [CrossRef]
9. Quirós Sauceda, A.E.; Sáyago-Ayerdi, S.G.; Ayala-Zavala, J.F.; Wall-Medrano, A.; De la Rosa, L.A.; González-Aguilar, G.A.; Álvarez-Parrilla, E. Biological actions of phenolic compounds. In *Vegetable Phytochemicals: Chemistry and Human Health, Volume I*, 2nd ed.; Yahia, E.M., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2018; pp. 125–138.
10. Santamaria, P. Nitrate in vegetables: Toxicity, content, intake and EC regulation. *J. Sci. Food Agric.* **2006**, *86*, 10–17. [CrossRef]
11. Rembiałkowska, E. Quality of plant products from organic agriculture. *J. Sci. Food Agric.* **2007**, *87*, 2757–2762. [CrossRef]
12. Kader, A.A. Postharvest biology and technology: An overview. In *Postharvest Technology of Horticultural Crops*; Special Publication 3311; Kader, A.A., Kasmire, R.F., Mittchell, F.G., Reid, M.S., Sommer, N.F., Thompson, J.F., Eds.; Cooperative Extension University of California: Oakland, CA, USA, 1985; pp. 3–7.
13. Yahia, E.M.; Serrano, M.; Valero, D.; González-Aguilar, G.A. Influence of postharvest technologies and handling practices on phytochemicals in fruits and vegetables. In *Vegetable Phytochemicals: Chemistry and Human Health, Volume I*, 2nd ed.; Yahia, E.M., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2018; pp. 611–628.
14. Zhao, X.; Carey, E.E.; Wang, W.; Rajashekar, C.B. Does organic production enhance phytochemical content of fruit and vegetables? Current knowledge and prospects for research. *HortTechnology* **2006**, *16*, 449–456. [CrossRef]
15. Dangour, A.D.; Dodhia, S.K.; Hayter, A.; Allen, E.; Lock, K.; Uauy, R. Nutritional quality of organic foods: A systematic review. *Am. J. Clin. Nutr.* **2009**, *90*, 680–685. [CrossRef]

16. Hoefkens, C.; Vandekinderen, I.; De Meulenaer, B.; Devlieghere, F.; Baert, K.; Sioen, I.; De Henauw, S.; Verbeke, W.; Van Camp, J. A literature-based comparison of nutrient and contaminant contents between organic and conventional vegetables and potatoes. *Br. Food J.* **2009**, *111*, 1078–1097. [CrossRef]
17. Lairon, D. Nutritional quality and safety of organic food. A review. *Agron. Sustain. Dev.* **2010**, *30*, 33–41. [CrossRef]
18. Lima, G.P.P.; Vianello, F. Review on the main differences between organic and conventional plant-based foods. *Int. J. Food Sci. Technol.* **2011**, *46*, 1–13. [CrossRef]
19. Smith-Spangler, C.; Brandeau, M.L.; Hunter, G.E.; Bavinger, J.C.; Pearson, M.; Eschbach, P.J.; Sundaram, V.; Liu, H.; Schirmer, P.; Stave, C.; et al. Are organic foods safer or healthier than conventional alternatives? A systematic review. *Ann. Intern. Med.* **2012**, *157*, 348–366. [CrossRef] [PubMed]
20. Sobieralski, K.; Siwulski, M.; Sas-Golak, I. Nutritive and health-promoting value of organic vegetables. *Acta Sci. Pol. Technol. Aliment.* **2013**, *12*, 113–123. [PubMed]
21. Johansson, E.; Hussain, A.; Kuktaite, R.; Andersson, S.C.; Olsson, M.E. Contribution of organically grown crops to human health. *Int. J. Environ. Res. Public Health* **2014**, *11*, 3870–3893. [CrossRef] [PubMed]
22. Bernacchia, R.; Preti, R.; Vinci, G. Organic and conventional foods: Differences in nutrients. *Ital. J. Food Sci.* **2016**, *28*, 565–578.
23. Ceglie, F.G.; Amodio, M.L.; Colelli, G. Effect of organic production systems on quality and postharvest performance of horticultural produce. *Horticulturae* **2016**, *2*, 4. [CrossRef]
24. Garcia, G.M.; Teixeira, P. Organic versus conventional food: A comparison regarding food safety. *Food Rev. Int.* **2017**, *33*, 424–446. [CrossRef]
25. Mditshwa, A.; Magwaza, L.S.; Tesfay, S.Z.; Mbili, N. Postharvest quality and composition of organically and conventionally produced fruits: A review. *Sci. Hortic.* **2017**, *21*, 148–159. [CrossRef]
26. Mie, A.; Andersen, H.R.; Gunnarsson, S.; Kahl, J.; Kesse-Guyot, E.; Rembiałkowska, E.; Quaglio, G.; Grandjean, P. Human health implications of organic food and organic agriculture: A comprehensive review. *Environ. Health* **2017**, *16*, 111. [CrossRef]
27. Fess, T.L.; Benedito, V.A. Organic versus conventional cropping sustainability: A comparative system snalysis. *Sustainability* **2018**, *10*, 272. [CrossRef]
28. Gomiero, T. Food quality assessment in organic vs. conventional agricultural produce: Findings and issues. *Appl. Soil Ecol.* **2018**, *123*, 714–728. [CrossRef]
29. Yu, X.; Guo, L.; Jiang, G.; Song, Y.; Muminov, M.A. Advances of organic products over conventional productions with respect to nutritional quality and food security. *Acta Ecol. Sin.* **2018**, *38*, 53–60. [CrossRef]
30. Popa, M.E.; Mitelut, A.C.; Popa, E.E.; Stan, A.; Popa, V.I. Organic foods contribution to nutritional quality and value. *Trends Food Sci. Technol.* **2019**, *84*, 15–18. [CrossRef]
31. Suciu, N.A.; Ferrari, F.; Trevisan, M. Organic and conventional food: Comparison and future research. *Trends Food Sci. Technol.* **2019**, *84*, 49–51. [CrossRef]
32. Vigar, V.; Myers, S.; Oliver, C.; Arellano, J.; Robinson, S.; Leifert, C. A systematic review of organic versus conventional food consumption: Is there a measurable benefit on human health? *Nutrients* **2019**, *12*, 7. [CrossRef] [PubMed]
33. Brandt, K.; Mølgaard, J.P. Organic agriculture: Does it enhance or reduce the nutritional value of plant foods? *J. Sci. Food Agric.* **2001**, *81*, 924–931. [CrossRef]
34. Young, J.E.; Zhao, X.; Carey, E.E.; Welti, R.; Yang, S.S.; Wang, W. Phytochemical phenolics in organically grown vegetables. *Mol. Nutr. Food Res.* **2005**, *49*, 1136–1142. [CrossRef]
35. Woese, K.; Lange, D.; Boess, C.; Bögl, K.W. A comparison of organically and conventionally grown foods—Results of a review of the relevant literature. *J. Sci. Food Agric.* **1997**, *74*, 281–293. [CrossRef]
36. Magkos, F.; Arvaniti, F.; Zampelas, A. Organic food: Nutritious food or food for thought? A review of the evidence. *Int. J. Food Sci. Nutr.* **2003**, *54*, 357–371. [CrossRef]
37. Harker, F.R. Organic food claims cannot be substantiated through testing of samples intercepted in the marketplace: A horticulturalist's opinion. *Food Qual. Pref.* **2004**, *15*, 91–95. [CrossRef]
38. Tobin, R.; Moane, S.; Larkin, T. Sensory evaluation of organic and conventional fruits and vegetables available to Irish consumers. *Int. J. Food Sci. Technol.* **2013**, *48*, 157–162. [CrossRef]
39. Bourn, D.; Prescott, J. A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Crit. Rev. Food Sci. Nutr.* **2002**, *42*, 1–34. [CrossRef] [PubMed]
40. Conklin, N.C.; Thompson, G. Product quality in organic and conventional produce: Is there a difference? *Agribusiness* **1993**, *9*, 295–307. [CrossRef]
41. Smith, B.L. 1993. Organic foods vs supermarket foods: Elemental levels. *J. Appl. Nutr.* **1993**, *45*, 35–39.
42. Pither, R.; Hall, M.N. *Analytical Survey of the Nutritional Composition of Organically Grown Fruit and Vegetables*; Technical Memorandum, Campden Food and Drink Research Association, No 597; Ministry of Agriculture, Fisheries, and Food: London, UK, 1990.
43. Stopes, C.; Woodward, L.; Forde, G.; Vogtmann, H. The nitrate content of vegetable and salad crops offered to the consumer as from "organic" or "conventional" production systems. *Biol. Agric. Hortic.* **1988**, *5*, 215–221. [CrossRef]
44. Faller, A.L.K.; Fialho, E. Polyphenol content and antioxidant capacity in organic and conventional plant foods. *J. Food Compos. Anal.* **2010**, *23*, 561–568. [CrossRef]

45. Singleton, V.L.; Rossi, J.A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158.
46. Brant-Williams, W.; Cuvelier, M.E.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *LWT Food Sci. Technol.* **1995**, *28*, 25–30. [CrossRef]
47. Cataldo, D.A.; Haroon, M.; Schrader, L.E.; Youngs, V.L. Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun. Soil Sci. Plant Anal.* **1975**, *6*, 71–80. [CrossRef]
48. Corré, W.J.; Breimer, T. *Nitrate and Nitrite in Vegetables*; Centre for Agricultural Publishing and Documentation: Wageningen, The Netherlands, 1979.
49. Siomos, A.S.; Dogras, C.C. Nitrates in vegetables produced in Greece. *J. Veg. Crop Prod.* **1999**, *5*, 3–13. [CrossRef]
50. Chung, J.C.; Chou, S.S.; Hwang, D.F. Changes in nitrate and nitrite content of four vegetables during storage at refrigerated and ambient temperatures. *Food Addit. Contam. Part A* **2004**, *21*, 317–322. [CrossRef] [PubMed]
51. Kalt, W. Effects of production and processing factors on major fruit and vegetable antioxidants. *J. Food Sci.* **2005**, *70*, R11–R19. [CrossRef]
52. Mattila, P.; Hellström, J. Phenolic acids in potatoes, vegetables, and some of their products. *J. Food Comp. Anal.* **2007**, *20*, 152–160. [CrossRef]
53. Lee, S.K.; Kader, A.A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **2000**, *20*, 207–220. [CrossRef]
54. Benbrook, C.M. *Elevating Antioxidant Levels in Food through Organic Farming and Food Processing*; An Organic Center, State of Science Review; The Organic Center for Education and Promotion: Washington, WA, USA, 2005.
55. Del Amor, F.M.; Serrano-Martínez, A.; Fortea, I.; Núñez-Delicado, E. Differential effect of organic cultivation on the levels of phenolics, peroxidise and capsidiol in sweet peppers. *J. Sci. Food Agric.* **2008**, *88*, 770–777. [CrossRef]
56. Chassy, A.W.; Bui, L.; Renaud, E.N.C.; Van Horn, M.; Mitchell, A.E. Three year comparison of the content of antioxidant microconstituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers. *J. Agric. Food Chem.* **2006**, *54*, 8244–8252. [CrossRef]
57. Flores, P.; Hellín, P.; Lacasa, A.; López, A.; Fenoll, J. Pepper antioxidant composition as affected by organic, low-input and soilless cultivation. *J. Sci. Food Agric.* **2009**, *89*, 2267–2274. [CrossRef]
58. Hobson, G. How the tomato losts its taste. *New Sci.* **1988**, *29*, 46–50.