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Effects of Organic and Conventional Cultivation Methods on Composition of Eggplant Fruits

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Organic food is associated by the general public with improved nutritional properties, and this has led to increasing demand for organic vegetables. The effects of organic and conventional cultivation methods on dry matter, protein, minerals, and total phenolic content has been studied for two successive years in two landraces and one commercial hybrid of eggplant. In the first year, organically produced eggplants had higher mean contents (expressed on a fresh weight basis) of K (196 vs 171 mg 100 g^{-1}), Ca (11.1 vs 8.7 mg 100 g^{-1}), Mg (6.0 vs 4.6 mg 100 g^{-1}), and total phenolics (49.8 vs 38.2 mg 100 g^{-1}) than conventionally grown eggplants. In the second year, in which matched plots having a history of organic management were cultivated following organic or conventional fertilization practices, organically produced eggplants still had higher contents of K (272 vs 249 mg 100 g^{-1}) and Mg (8.8 vs 7.6), as well as of Cu (0.079 vs 0.065 mg 100 g^{-1}), than conventionally fertilized eggplants. Conventionally cultivated eggplants had a higher polyphenol oxidase activity than organically cultivated ones (3.19 vs 2.17 enzyme activity units), although no differences in browning were observed. Important differences in mineral concentrations between years were detected, which resulted in many correlations among mineral contents being significant. The first component of the principal component analysis separates the eggplants according to year, whereas the second component separates them according to the cultivation method (organic or conventional). Overall, the results show that organic management and fertilization have a positive effect on the accumulation of certain beneficial minerals and phenolic compounds in eggplant and that organically and conventionally produced eggplants might be distinguished according to their composition profiles.

KEYWORDS: Composition; conventional agriculture; eggplant; minerals; organic agriculture; total phenolics; ***Solanum melongena***

INTRODUCTION

Organic vegetables are associated by the general public with healthier and more flavorsome food, as well as to noncontaminating sustainable agricultural practices (*1*, *2*). This has led to increasing demand for organic vegetables. For example, the area devoted to organic vegetables cultivation in the United States increased by > 2-fold in the period from 1997 (19517 ha) to 2005 (39872 ha) (*3*). European production statistics also reveal a sustained expansion of the area devoted to the production of organic vegetables (*4*).

Several reviews (see, e.g., refs *5*−*7*) show that organically produced vegetables generally have higher levels of micronutrients and health-promoting secondary metabolites, such as phenolics, than conventionally grown vegetables. Among others, explanations for these differences include “nutrient dilution” caused by the inverse relationship between yield and micronutrient concentrations (*8*), a higher dry matter of organic vegetables compared to conventional ones (*9*, *10*), and higher levels of accumulation of inducible secondary metabolites responsible of plant defense in organic cultivation (*11*).

Production of vegetables in organic conditions presents more technical challenges than conventional cultivation, because many practices, such as the use of non-natural agrochemicals, are not permitted in organic production under the regulations of many countries (see, e.g., ref *12*). As a consequence, organic production is sometimes difficult, especially in environments with high levels of pest and disease pressure. In this respect, vegetables having a lower susceptibility to biotic stresses may be more suited to organic farming.

Eggplant adapts well to organic cultivation, mostly because it is resistant or tolerant to many diseases and pests that affect other vegetable crops of the same family (Solanaceae), such as tomato or pepper (*13*). For example, the organic cultivation of tomato in our region of Valencia (Spain) is difficult because of a high incidence of viruses, such as tomato spotted wilt virus (TSWV) and tomato yellow leaf curl virus (TYLCV), transmitted by insect pests that are best controlled with conventional phytosanitary treatments (*14*), but no viruses have an economic impact on the production of eggplant in our region. Furthermore, eggplant is

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Table 1. Main Characteristics of the Eggplant Cultivars Used and Their Average Yields in the Experimental Plots of the Present Study

				yield (kg/m^2)	
cultivar	cultivar type	origin	fruit color	2007	2008
CS16	landrace	Cataluña, Spain	black	8.92	3.93
IVIA371	landrace	Comunidad Valenciana, Spain	white background with purple stripes	8.30	
H15	landrace	Castilla-La Mancha, Spain	green background and purple color in sun-exposed parts		3.80
Cristal	F1 hybrid	Semillas Fitó SA, Barcelona, Spain	intense black	8.08	5.35

able to withstand high populations of pests without a significant loss of yield, which facilitates the cultivation of this crop under organic cultivation.

At the nutritional level, eggplant is especially important because of its high content in P, K, and Cu and also for its high levels of phenolics (*15*). The high antioxidant capacity of eggplant pulp is attributed to its content in phenolics (*16*, *17*), mostly hydroxycinnamic acid conjugates (*18*). Apart from free radical scavenging activity, eggplant phenolics have antitumoral and anticholeresterolemic properties (*19*−*21*). Although increases in the content of total phenolics in eggplant are desirable, oxidation of phenolics, which is mediated by polyphenol oxidases (PPO) and affected by other factors, such as intracellular pH, can cause browning of the eggplant flesh, and this may reduce the apparent quality of eggplant (*22*, *23*).

Eggplant composition is affected by several factors, such as growing conditions or the cultivar used. Previous studies have shown that environmental conditions and growing techniques can influence the composition of eggplant (*17*, *24*−*27*). Also, an important genetic diversity among cultivars has been found for eggplant composition (*15*, *23*, *27*, *28*). To our knowledge, the effect of organic cultivation on the composition of eggplant has only been reported in two recent studies. In one of those, Lima et al. (*29*) compared the content in polyamines, flavonoids, and total phenolics in the peel of an important number of vegetables purchased from producers that used either organic or conventional cultivation methods. Lower levels of polyamines were found in organically cultivated eggplants, and no significant differences between conventional and organic production for the levels of flavonoids and total phenolics were determined. However, it is unknown if the organic and conventional materials used in that study corresponded to the same cultivar or if they were produced in the same area. More recently, Singh et al. (*17*), using two eggplant cultivars grown under organic and conventional conditions in a single year, found that one cultivar ('Millionaire') had a higher content in phenolics under organic conditions, whereas the other ('Blackbell') had a higher content under conventional conditions. This suggests the need to analyze additional eggplant samples to study the effect of organic cultivation on the phenolic content in eggplant.

The aim of our study was to identify the interactive cultivation method and cultivar on the composition of eggplant, including the dry matter, proteins, macro- and microminerals, and total phenolic contents, as well as traits related to browning. This will provide relevant information on the effects of organic cultivation on the quality of eggplant fruits.

MATERIALS AND METHODS

Plant Material. Four cultivars (landraces CS16, IVIA371, and H15 and the commercial hybrid Cristal) were evaluated in 2007 (CS16, IVIA371, and Cristal) and 2008 (CS16, H15, and Cristal). The reason for substituting IVIA371 with H15 in 2008 was the poor germination of IVIA371 in 2008 and the availability of H15 seedlings in this year. The main characteristics of each of the cultivars are presented in **Table 1**.

Experimental Design. For the first year, the experiment was aimed at studying if there was a difference in the composition of eggplants grown under organic or conventional cultivation methods in plots from the same growing area. These plots share the same climatic conditions and soil type and differ in the management, which has been organic-certified for seven years in one case and conventional for the lpast few decades in the other. Organic and conventional cultivation was performed in two neighboring farms (one organic and one conventional). The organic farm belongs to a regional association of farmers (Unió de Llauradors i Ramaders), whereas the conventional farm belongs to a local farmer who cooperates with the Unió de Llauradors i Ramaders in agricultural experiments. Within each of the organic and conventional farms, a completely randomized design was used with two plots, three cultivars, three replicates per each combination of plot and cultivar, and 10 plants per replicate. This makes a total of 60 plants per combination of cultivar and cultivation method and 360 plants for the experiment of 2007.

In the second year (2008), the experiment was aimed at studying if there was a difference in the composition of eggplants grown using organic or conventional fertilization practices in plots with a history of organic cultivation. Our aim was studying if there was an effect of organic versus conventional fertilization in eggplant composition after ruling out a possible effect of soil difference as a consequence of long-term organic or conventional practices.

Organic and conventional cultivation methods were carried out on the Unió de Llauradors i Ramaders farm and consisted of two matched pairs of organic and conventional plots on soil that previously had been organic-certified for seven years. Each pair of matched plots was considered as a block in the analyses of variance. For each of these two matched pairs of plots (one organic and one conventional plot), a completely randomized design was used with three cultivars, three replicates per each combination of plot and cultivar, and 10 plants per replicate. As in 2007, this makes a total of 60 plants per combination of cultivar and cultivation method and 360 plants for the 2008 experiment.

Growing Conditions. In each of the experiments, seeds were germinated in Petri dishes with wet filter paper. For the conventional cultivation method 3 mL of Tiram 0.1% fungicide were added to each Petri dish; for the organic cultivation method no fungicide was added. Plantlets of both cultivation methods were raised in seedling trays filled with organic compost and kept in an insect-free climate chamber until transplanted. No fertilization or phytosanitary treatments were applied before the transplant.

In both years, plants were cultivated in the summer cycle (transplant at the end of May) in the municipality of Sagunto in the Marjal del Moro area. This area is situated in former marshy areas that were drained in the past century and has a dark soil with high phreatic layer. The soil of this area is a clay loam soil, with a pH of 7.7, nonsaline, with a mean electrical conductivity of the 1:5 soil−water extract (EC1:5) of 320−360 μS cm^{-1}.

In 2007, for both organic and conventional cultivation methods, plants were spaced 1.1 m between rows and 0.8 m within the row and flood irrigated. Basal fertilizer for the organic plots consisted of a mixture of sheep and goat manure at a rate of 15 t ha^{-1}, whereas for the conventional plots the basal fertilizer consisted of urea (46% N) at a rate of 60 kg ha^{-1}. No further fertilizer was applied to the organic plots, whereas for the conventional ones, 75 kg ha^{-1} of ammonium nitrate (33% N) and 100 kg ha^{-1} of potassium nitrate (13% N, 44% K_2O) were applied as dressing fertilizer at the onset of fruit set. Phytosanitary treatments in the organic plots consisted of the authorized use of *Bacillus thuringinesis* against Lepidoptera, and sulfur powder against spider mites and as a preventive treatment against powdery mildew. In the conventional plots, treatments consisted of applications of the synthetic pyrethroid teflutrin against Lepidoptera and the synthetic acaricide clofenzetine against spider mites. Phytosanitary treatments were made at the rates recommended by the manufacturers.

Table 2. Dry Matter, Protein, and Mineral Contents (on a Fresh Weight Basis) of Eggplant Fruits Grown under Conventional and Organic Conditions in 2007 and Probability (p Value) for the Significance of Differences among Means for the Effects of Cultivar, Cultivation Method, and Their Interaction

			minerals[a] (mg 100 g^{-1})							
treatment	dry matter[a] (g 100 g^{-1})	protein[a] (g 100 g^{-1})	Na	K	P	Ca	Mg	Fe	Cu	Zn
cultivar										
CS16	9.06	0.84 a	27.4	202 b	20.1	11.7 b	6.0	0.136	0.037	0.132 ab
IVIA371	8.39	0.99 b	24.4	180 ab	20.2	9.4 a	5.0	0.134	0.049	0.155 b
Cristal	8.80	0.90 ab	25.4	169 a	17.3	8.7 a	4.9	0.087	0.044	0.121 a
p value	0.223	0.037*	0.163	0.043*	0.092	0.033*	0.148	0.062	0.219	0.041*
cultivation method										
organic	8.60	0.89	25.9	196 b	19.4	11.1 b	6.0 b	0.134	0.044	0.125
conventional	8.90	0.93	25.6	171 a	19.0	8.7 a	4.6 a	0.103	0.044	0.147
p value	0.379	0.332	0.817	0.029*	0.776	0.017*	0.010*	0.125	0.975	0.060
cultivar × cultivation method										
CS16, organic	8.94	0.82	27.4 b	209	19.6	13.7	6.5 b	0.123	0.037 ab	0.117
CS16, conventional	8.18	0.86	27.4 b	195	20.5	9.7	5.4 ab	0.150	0.037 ab	0.146
IVIA 371, organic	8.12	0.97	22.5 a	189	20.8	10.1	4.8 ab	0.177	0.039 ab	0.143
IVIA 371, conventional	8.65	1.00	26.2 ab	172	19.7	8.7	5.3 ab	0.091	0.060 c	0.167
Cristal, organic	8.74	0.87	27.7 b	191	17.8	9.6	6.6 b	0.104	0.055 bc	0.115
Cristal, conventional	8.85	0.92	23.0 a	146	16.9	7.7	3.2 a	0.069	0.033 a	0.127
p value	0.854	0.983	0.045*	0.389	0.742	0.481	0.009**	0.059	0.018*	0.813

[a] Mean values within each main factor (cultivar or cultivation method) or interaction separated by different letters are significantly different (p < 0.05) according to the Student−Newman−Keuls test. * and ** indicate significance at p <0.05 and <0.01, respectively.

In 2008, for both organic and conventional cultivation methods, plants were spaced 1.2 m between rows and 1 m within the row. One of the matched pairs of conventional−organic plots was flood irrigated, whereas the other matched pair was drip irrigated. As indicated above, each of the matched pairs was considered as a block in the experimental design. For both organic and conventional cultivation methods, basal fertilizer consisted of a mixture of sheep and goat manure at a rate of 15 t ha^{-1}. No further fertilizer was applied to the organic plots, whereas for the conventional plots, 200 kg ha^{-1} of Nitrofoska Perfekt (Compo Agricultura, Barcelona, Spain; 15% N, 5% P_2O_5, 20% K_2O, 2% MgO, 0.02% B, and 0.01% Zn) was applied as dressing fertilizer at the onset of fruit set. Levels of pests were low in 2008, and no phytosanitary measures were required in either the organic or conventional cultivation methods.

In both years, common practices of transplanting, weeding, training, pruning, and harvesting were followed in both cultivation methods. Lower yields in 2008, compared to 2007, are attributed to seasonal environmental conditions that led to a reduced plant growth and development in 2008. No decrease in the yield of organic plots compared to the conventional ones was observed in either year.

Preparation of Samples. For each of the replications, a sample of 10−15 commercially ripe fruits (evaluated by the color and glossiness of the fruit skin) were harvested and brought to the laboratory and were washed and peeled. Fruits were longitudinally cut into halves, and the halves corresponding to each replication were bulked. For each replication, one bulk sample was weighed, dried at 105 °C until constant weight, powdered with a home mechanical grinder, and used for the determinations of dry matter, ash, protein content, and concentrations of minerals.

The other fruit bulk sample was used for measuring fruit browning degree (2008), total phenolics (2007 and 2008), and PPO activity, soluble solids content (SSC), and pH (2008). After measurement of the fruit flesh browning, fruit halves were squeezed using a domestic juice extractor, and immediately after the juice extraction, a 5 mL aliquot of the homogenate corresponding to each repetition was poured on 10 mL of an extracting solution of acetone (70% v/v) and glacial acetic acid (0.5% v/v), left for 1 h at room temperature for extraction of total phenolics and frozen at −20 °C until analyzed. Another 5 mL aliquot (only in 2008) was frozen at −20 °C for measurement of PPO activity. The rest of the homogenate (only in 2008) was used for the determination of SSC and pH.

Traits Measured. Dry matter was determined as 100(dry weight/fresh weight) and expressed in grams per 100 grams of fresh weight. Protein concentration was estimated from the content in N, which was determined through the Kjeldahl method using a Kjeltec 2100 Distillation Unit (Foss Tecator, Högamäs, Sweden), as N × 6.25.

For the analyses of minerals, 2 g of the dried samples was calcined in a furnace at 450 °C for 2 h and weighed. The ashes were then dissolved in 2 mL of concentrated HCl. The mixture was heated until the first vapors appeared, and immediately distilled water (2−3 mL) was added. Subsequently, the mixture was filtered and the extract was brought to 100 mL with distilled water. P was analyzed according to the molybdovanadate method using a Jenway 6305 UV−vis spectrophotometer (Jenway, Essex, U.K.), K and Na were analyzed by flame photometry using a Jenway PFP7 flame photometer, and the rest of the minerals (Ca, Mg, Fe, Cu, and Zn) were analyzed by atomic absorption spectrophotometry using a Thermo Elemental (SOLAAR AA Spectrometers, Cambridge, U.K.) spectrometer (*30*).

For fruit browning measurement, fruits halves were cut transversally at the midpoint between the blossom and stem ends and the color was measured with a Minolta CR-300 chromameter (Minolta Co. Ltd., Osaka, Japan) immediately after being cut (0 min) and 10 min later. The degree of browning (DB) (*23*) was measured as $DB = DW_{10} - DW_0$, where DW_{10} and DW_0 are the distances to pure white ($L^* = 100$; $a^* = 0$; $b^* = 0$) of the fruit flesh at 10 min (DW_{10}) and at 0 min after the fruit was cut (DW_0) and calculated using the formula $DW = ((100 - L^*)^2 + a^{*2} + b^{*2}))^{0.5}$).

Total phenolic content was determined according to the Folin−Ciocalteu procedure (*31*). An aliquot of 1.3 mL of the supernatant of the extracted phenolic sample was mixed with 1 mL of diluted (10% v/v) Folin−Ciocalteu reagent (Sigma-Aldrich Chemie, Steinheim, Germany) and allowed to stand at room temperature for 5 min. One milliliter of a sodium carbonate solution (60 g L^{-1}) was then added to the mixture, and the absorbance was measured at 760 nm in a Jenway 6305 UV−vis spectrophotometer after the mixture had stood for 90 min at room temperature. Chlorogenic acid (Sigma-Aldrich Chemie) was used as standard. The phenolic acid content was expressed as chlorogenic acid equivalents in milligrams per 100 g of fresh weight.

For the measurement of PPO activity, 5 mL of juice was centrifuged at 8050g for 5 min. Two aliquots of 0.5 mL of the supernatant were taken. One of the juice aliquots was used for measuring the PPO activity, and the other was heated to 95 °C in a water bath for 5 min and served as a control with no PPO activity. One milliliter of 0.05 M phosphate buffer (pH 6) containing catechol at a concentration of 0.005 M was added to the juice aliquots. Absorbance at 420 nm was measured immediately after the catechol solution was added and after 2 min. One unit of enzyme activity was defined as the change in absorbance per minute.

Table 3. Dry Matter, Protein, and Mineral Contents (on a Fresh Weight Basis) of Eggplant Fruits Grown under Conventional and Organic Conditions in 2008 and Probability (*p* Value) for the Significance of Differences among Means for the Effects of Cultivar, Cultivation Method, and Their Interaction

			minerals[a] (mg 100 g^{-1})							
treatment	dry matter[a] (g 100 g^{-1})	protein[a] (g 100 g^{-1})	Na	K	P	Ca	Mg	Fe	Cu	Zn
cultivar										
CS16	8.14 a	1.02 a	35.6	248 a	28.9 b	10.1 b	8.0	0.204	0.072 b	0.193 a
H15	8.56 b	1.23 b	38.1	276 b	34.5 c	8.8 a	8.5	0.214	0.090 c	0.251 b
Cristal	8.36 ab	0.98 a	38.1	257 ab	25.2 a	8.9 a	8.0	0.177	0.055 a	0.178 a
p value	0.047*	<0.001**	0.057	0.040*	<0.001**	0.035*	0.537	0.084	<0.001**	<0.001**
cultivation method										
organic	8.26	1.04	38.1	2725 b	29.7	9.2	8.8 b	0.205	0.079 b	0.213
conventional	8.45	1.12	36.4	249 a	29.4	9.4	7.6 a	0.191	0.065 a	0.202
p value	0.178	0.061	0.088	0.017*	0.653	0.597	0.017*	0.304	0.024*	0.089
cultivar × cultivation method										
CS16, organic	8.21	0.98	36.8	271	29.8	10.4 c	8.9	0.213	0.074	0.204
CS16, conventional	8.07	1.06	34.4	226	28.1	9.7 bc	7.1	0.194	0.069	0.182
H15, organic	8.32	1.18	39.1	278	33.9	7.9 a	9.4	0.206	0.102	0.253
H15, conventional	8.80	1.28	37.2	274	35.1	9.7 bc	7.7	0.223	0.077	0.249
Cristal, organic	8.25	0.94	38.4	265	25.5	9.2 abc	8.0	0.197	0.061	0.182
Cristal, conventional	8.46	1.02	37.8	249	25.0	8.7 ab	8.0	0.157	0.049	0.174
p-value	0.170	0.971	0.705	0.154	0.367	0.035*	0.199	0.233	0.368	0.427

[a] Mean values within each main factor (cultivar or cultivation method) or interaction separated by different letters are significantly different ($p < 0.05$) according to the Student−Newman−Keuls test. * and ** indicate significance at p <0.05 and <0.001, respectively.

Soluble solids content (SSC) was measured in the supernatant of a centrifuged (8050*g* for 5 min) sample of juice with a N-8 α hand-held refractometer (Atago Co. Ltd., Tokyo, Japan). The pH of the juice was measured with an MP 220 digital pH-meter (Mettler Toledo, Barcelona, Spain).

Statistical Analysis. For each year, data were subjected to a two-factor analyses of variance (ANOVA) using a fixed-effects model for the effect of cultivar and cultivation method. The significance of the main effects and interactions was obtained from the ANOVAs, and differences among main treatments and combinations of treatments were identified with Student−Newman−Keuls multiple-range tests. Pearson linear coefficients of correlation (r) between traits were calculated from regression analyses between pairs of traits. Principal component analysis (PCA) was performed on data measured in both years.

RESULTS

Proximate Composition and Mineral Content. The only significant differences detected for the two proximate composition traits studied (dry matter and protein contents, both of them expressed on a fresh weight basis) corresponded to the cultivar factor (**Tables 2** and **3**). In this respect, for the 2007 experiment, landrace IVIA371 had a significantly higher protein content (0.985 g 100 g^{-1} of fresh weight) than landrace CS16 (0.843 g 100 g^{-1}); for the 2008 experiment, H15 had a significantly higher dry matter content (8.56 g 100 g^{-1}) than CS16 (8.14 g 100 g^{-1}) and a higher protein content (1.233 g 100 g^{-1}) than either CS16 or Cristal (1.022 and 0.983 g 100 g^{-1}, respectively). No significant effects of cultivation method or cultivar × cultivation method interaction were observed in either year for these traits.

Potassium was the most abundant mineral in the fruit in both years (**Tables 2** and **3**). Mean tissue mineral concentrations (expressed on a fresh weight basis), apart from Ca, were generally higher in 2008 compared to 2007. For the 2007 experiment, cultivar significantly affected the contents of K, Ca, and Zn, cultivation method affected the contents of K, Ca, and Mg, and the cultivar × cultivation method was a significant influence on Na, Mg, and Cu (**Table 2**). The CS16 cultivar had a significantly higher content of K (202 mg 100 g^{-1}) than Cristal (169 mg 100 g^{-1}) and also a higher content of Ca (11.7 mg 100 g^{-1}) than either IVIA371 or Cristal (9.4 and 8.7 mg 100 g^{-1}, respectively). IVIA371 fruit had a higher Zn content (0.155 mg 100 g^{-1}) than Cristal (0.121 mg 100 g^{-1}). When the effect of cultivation method was considered, eggplants grown in the organic cultivation method had higher mean values of K, Ca, and Mg than those grown under the conventional cultivation method (196 vs 171 mg 100 g^{-1} for K, 11.1 vs 8.7 mg 100 g^{-1} for Ca, and 6.0 vs 4.6 mg 100 g^{-1} for Mg). The cultivar × cultivation method interactions indicated that Cristal had significantly higher Na and Mg contents under the organic cultivation method than under the conventional cultivation method, whereas for the other cultivars there were no significant differences. Cristal also had higher Cu content in the organic cultivation method than in the conventional cultivation method, whereas the contrary was found for IVIA371. The mineral nutrient content of CS16 was not affected by the cultivation method (**Table 2**).

For the 2008 experiment, cultivar significantly affected the contents of K, P, Ca, Cu, and Zn, cultivation method affected the contents of K, Mg, and Cu, and the cultivar × cultivation method interaction significantly affected Ca content (**Table 3**). H15 had a significantly higher content of K (276 mg 100 g^{-1}) than either Cristal or CS16 (257 and 248 mg 100 g^{-1}, respectively). H15 had the highest P content (34.5 mg 100 g^{-1}), followed by CS16 (28.9 mg 100 g^{-1}) and Cristal (25.2 mg 100 g^{-1}). CS16 had a higher content of Ca (10.1 mg 100 g^{-1}) than either Cristal or H15 (8.9 and 8.8 mg 100 g^{-1}, respectively). H15 had the higher Cu content (0.090 mg 100 g^{-1}), followed by CS16 (0.072 mg 100 g^{-1}) and finally by Cristal (0.055 mg 100 g^{-1}). Organically grown eggplants had higher K, Mg, and Cu contents than conventionally grown eggplants (272 vs 249 mg 100 g^{-1} for K, 8.8 vs 7.6 mg 100 g^{-1} for Mg, 0.079 vs 0.065 mg 100 g^{-1} for Cu, respectively). The only significant cultivar × cultivation method interaction term found was for Ca; H15 had a higher Ca content under the conventional cultivation method, whereas for the other cultivars there was no significant difference (**Table 3**).

Total Phenolic Content and Browning-Related Traits. In 2007, significant differences for the effects of cultivar and cultivation method, but not for the interaction cultivar × cultivation method, were found for the content in total phenolics (**Table 4**). CS16 had a significantly higher total phenolic content (47.9 mg 100 g^{-1}, expressed on a fresh weight basis) than Cristal (39.9 mg 100 g^{-1}),

Table 4. Total Phenolics (2007 and 2008; on a Fresh Weight Basis), PPO Activity, SSC, pH, and Degree of Browning (2008 Only) of Eggplant Fruits Grown under Conventional and Organic Conditions and Probability (*p* Value) for the Significance of Differences among Means for the Effects of Cultivar, Cultivation Method, and Their Interaction

year 2007		year 2008						
treatment	total phenolics[a] (mg 100 g^{-1})	treatment	total phenolics[a] (mg 100 g^{-1})	PPO activity[a] (enzyme activity units)	SSC[a] (%)	pH[a]	degree of browning[a]
cultivar		cultivar					
CS16	47.9 b	CS16	39.8	2.46	5.69	5.10 b	5.27
IVIA371	44.2 ab	H15	42.4	2.71	5.50	4.89 a	6.41
Cristal	39.9 a	Cristal F1	41.2	2.88	5.72	5.16 b	7.02
p value	0.034*	*p* value	0.529	0.247	0.177	<0.001***	0.113
cultivation method		production					
organic	49.8 b	organic	41.7	2.17 a	5.69	5.06	6.31
conventional	38.2 a	conventional	40.6	3.19 b	5.58	5.04	6.17
p value	<0.001***	*p* value	0.568	<0.001***	0.313	0.541	0.833
cultivar × cultivation method		cultivar × cultivation method					
CS16, organic	56.3	CS16, organic	34.8 a	2.01	5.79	5.15	5.88
CS16, conventional	39.5	CS16, conventional	44.7 ab	2.91	5.58	5.05	4.66
IVIA 371, organic	47.6	H15, organic	49.0 b	1.99	5.58	4.85	7.17
IVIA 371, conventional	40.8	H15, conventional	35.8 a	3.42	5.42	4.93	5.67
Cristal, organic	45.5	Cristal, organic	41.1 ab	2.52	5.68	5.19	5.88
Cristal, conventional	34.3	Cristal, conventional	41.2 ab	3.24	5.75	5.14	8.17
p value	0.233	*p* value	<0.001***	0.327	0.489	0.069	0.052

[a] Mean values within each main factor (cultivar or cultivation method) or interaction separated by different letters are significantly different ($P < 0.05$) according to the Student−Newman−Keuls test. * and ** indicate significant at $p < 0.05$ and <0.001, respectively.

Table 5. Pearson Linear Correlations (*r*) between the Traits Studied for the Data Obtained in the Two Years of Study (2007 and 2008)[a]

	protein	Na	K	P	Ca	Mg	Fe	Cu	Zn	total phenolics	PPO activity	SSC	pH	degree of browning
dry matter	0.211	0.095	0.054	0.125	0.314**	0.318**	−0.068	−0.040	0.134	0.056	0.140	0.361*	−0.534***	0.399**
protein		0.467***	0.593***	0.736***	0.052	0.378**	0.582***	0.392**	0.756***	−0.224	0.207	−0.055	−0.526**	0.120
Na			0.828***	0.783***	−0.085	0.676***	0.536***	0.578***	0.720***	−0.222	−0.134	0.150	−0.329	0.295
K				0.818***	0.066	0.662***	0.682***	0.525***	0.774***	−0.160	−0.171	0.084	−0.165	0.002
P					−0.069	0.595***	0.639***	0.684***	0.933***	−0.218	0.028	−0.064	−0.648***	−0.030
Ca						0.265*	0.207	−0.111	−0.161	0.151	0.172	0.350*	−0.203	0.138
Mg							0.451***	0.460***	0.546***	−0.010	−0.158	0.367*	−0.539***	0.350*
Fe								0.435***	0.638***	−0.122	−0.150	−0.107	−0.317	−0.111
Cu									0.691***	−0.164	−0.239	−0.121	−0.522**	−0.043
Zn										−0.233	−0.077	−0.078	−0.627	0.044
total phenolics											−0.281	−0.172	−0.285	−0.007
PPO activity												−0.063	−0.018	0.099
SSC													0.158	0.261
pH														−0.220

[a] For the correlations of PPO activity, SSC, pH, and browning, correlations were obtained with data from 2008 only. *, **, and *** indicate significance at p<0.05, <0.01, and <0.001, respectively.

and eggplants from organic cultivation had a considerably higher content in total phenolics (49.8 mg 100 g^{-1}) than eggplants from conventional cultivation (38.2 mg 100 g^{-1}). In 2008, the only significant effects observed were the effect of cultivar on pH, cultivation method on PPO activity, and cultivar × cultivation method interaction on total phenolic content. H15 fruit had a lower pH (4.89) than either Cristal or CS16 (5.16 and 5.10, respectively), and PPO activity was higher under the conventional cultivation method (3.19 enzyme activity units) than under the organic cultivation method (2.17 enzyme activity units). Finally, H15 had a significantly higher content of total phenolics under the organic cultivation method (49.0 mg 100 g^{-1}) than under the conventional cultivation method (35.8 mg 100 g^{-1}).

Correlations among Traits. Many significant correlations among traits were detected (**Table 5**). Most of the correlations detected were positive correlations between minerals, with the exception of Ca concentration, which was correlated positively only with the content of Mg, and also between protein and, with the exception of Ca, content in minerals. Other significant correlations involved a positive correlation of dry matter with Ca, Mg, SSC and browning; SSC with Ca and Mg; and Mg with browning. By contrast, the only significant negative correlations were found for pH with dry matter, protein, P, Mg, and Cu (**Table 5**).

Principal Component Analysis. The first and second components of the PCA accounted, respectively, for 53.4 and 18.6% of the total variation. For the first component dry matter, Ca, and total phenolic contents had positive values, whereas protein and the rest of the minerals had negative values (**Figure 1**). Regarding the second component, Ca, total phenolics, Mg, K, Na, and Fe had positive values, whereas dry matter, protein, P, Cu, and Zn had negative values (**Figure 1**). The projections of the combinations of year, cultivar, and cultivation method on the PCA graph clearly show that the first component mostly separates years, with 2007 having positive values and 2008 having negative values for this component (**Figure 2**). This first component also separates cultivars in the year 2008. The second component clearly separates the cultivation methods, such that in each year, for each cultivar, values for organic production were higher than those of

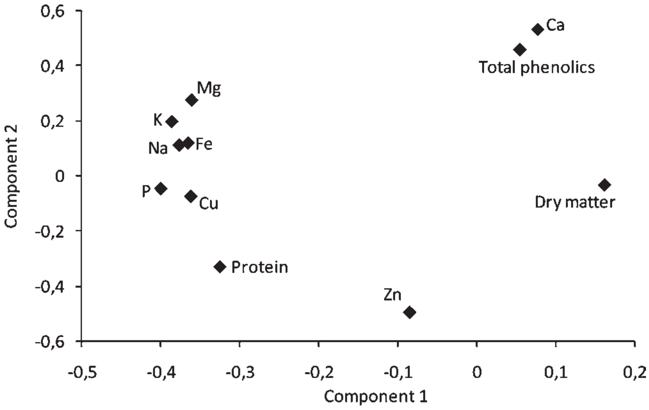

Figure 1. Diagram showing relationships among composition traits studied in 2007 and 2008 based on the two first principal components of PCA (53.4 and 18.6% of the total variation, respectively).

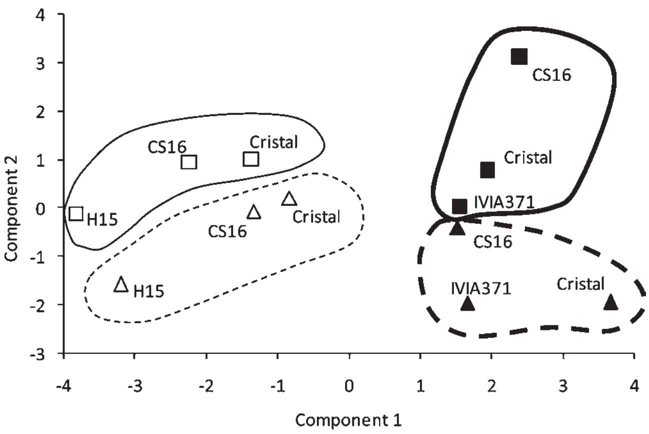

Figure 2. Diagram showing relationships among combinations of year, cultivar, and cultivation method based on the two first principal components of PCA (53.4 and 18.6% of the total variation, respectively). Years are represented by solid (2007) and open (2008) symbols; cultivation methods are represented by squares (organic) and triangles (conventional).

conventional production for this second component. This effect was more pronounced in 2007 (**Figure 2**).

DISCUSSION

The materials used in this paper come from conventional and organic plots in which no differences in yield were observed between cultivation methods. Colla et al. (*32*) found similar results in tomato, with no differences in yield between the organic and conventional cultivation methods. This is important for this study, as the differences found here in composition between organic and conventional cultivation methods cannot be attributed to differences in yield. It is also important to emphasize the fact that yields in 2008 were lower than in 2007, which may be attributed to differences in environmental conditions that resulted in reduced growth and development, and consequently lower yield, in 2008. This lower yield may result in differences between years in composition, as there is a well-known relationship between yield and the concentrations of some nutrients (*8*).

Differences between cultivars have been found for some of the fruit composition traits studied, confirming published data suggesting considerable genetic diversity in eggplant fruit composition (*15*, *23*, *27*, *28*, *33*). On the other hand, cultivar × cultivation method interactions are very frequent in the comparison of organic and conventional cultivation methods (*34*). In our experiments significant cultivar × cultivation method interactions were found for some composition traits, suggesting that some cultivars may be more suited to growing in either organic or conventional cultivation methods.

We have found considerable differences in the composition of organically and conventionally grown eggplants. These differences were larger in the comparison of fruit from plots that have long history of organic or conventional production (2007 experiment). In this respect, in the 2007 experiment, organically grown eggplants had higher contents of K, Ca, Mg, and total phenolics than conventionally grown eggplants. These results are in agreement with other reports of higher concentrations of minerals and other nutrients in organically grown crops (*7*, *32*, *35*). In the 2008 experiment, the soil used had been organically managed for years until this experiment was performed, and the conventional plots differed from the organically managed plots only in the fertilization applied; the differences between organically and conventionally grown eggplants were smaller. However, organically grown eggplants still had a higher K, Mg, as well as Cu, content than eggplants from conventional plots. This suggests that, although the effects on eggplant fruit composition of the change from organic to conventional (and very likely from conventional to organic) management may be gradual, differences can be apparent already in the first year of the change of management cultivation method, which might be caused by differences among cultivation methods in the supply or availability of some nutrients.

The lower contents of K and Mg in conventionally managed eggplants in 2008 seems paradoxical, as conventionally managed plots had a higher level of K and Mg fertilization than those managed according to organic agriculture. However, this result may be caused by the fact that the dressing fertilizer in this year also included important quantities of NH_4^+-N, which may have depressed the K and Mg absorption in the conventional plots (*36*−*38*).

The high antioxidant activity of eggplant fruit is attributed to its content in phenolics (*16*, *17*, *27*). Here we have found that in plots subjected to long-term organic management, the content of total phenolics in fruit was higher than under conventional conditions, with a mean increase of 30% in the organic cultivation method. Increases in phenolic contents under organic conditions have been reported in other related crops, such as tomato or pepper (*39*−*41*), and this increase improves the nutritional value of eggplant fruits. However, when a plot that had been managed organically for many years is cultivated using conventional fertilization, the increase in total phenolics was detected in only one cultivar. In this respect, several authors have found that higher levels of fertilization, in particular N fertilization, result in a reduction in the content in phenolics (*41*, *42*).

PPO activity, which was measured only in 2008, increased considerably in the conventional cultivation method. PPO seems to be induced under conditions of stress or attack of pathogens (*43*). However, we observed a low level of pests and of disease problems, and other factors must account for this increased level of PPO activity. It is also remarkable that despite the increase in PPO activity in conventionally cultivated eggplants, no significant differences were found for browning between organically and conventionally cultivated eggplants.

With the exception of Ca, which has a reduced mobility in the plant (*44*), the contents in other minerals and also of proteins were positively correlated, indicating that different growing conditions may increase or reduce the accumulation of minerals in eggplant fruit. These high values for the correlations are mostly a consequence of the large differences between 2007 and 2008 in minerals (except for Ca). Conditions in which yield was lower, such as those of 2008, may favor a greater accumulation of minerals and proteins (*8*). In a single-year study in which an important number of cultivars were grown under the same conditions (*15*), we found that the number of significant correlations was much lower than found here, very likely because those correlations were based on a single (greenhouse) environment not like here, in which we tested several environments.

In fact, the PCA shows that an important part of the variation observed in composition among the combinations of years, cultivars, and cultivation methods is due to the effect of year, so that the first component clearly separates data from both years. This is again a clear indication that environmental conditions, in this case possibly seasonal weather, may have a great influence over composition in eggplant (*24*−*27*). However, it is true that this same PCA also clearly separates eggplants grown under organic conditions from those that have been grown under conventional conditions, indicating that PCA may be a powerful tool as a chemometric classification procedure for discriminating organically and conventionally cultivated eggplants, as long as they are from concurrent harvests from the same area of production (*45*).

In other related vegetable crops, such as tomato or pepper, it has also been found that production under organic conditions has an effect on fruit composition, which normally consists of an increase in the content of antioxidants and minerals (*39*−*41*). Here we have found that organically grown eggplants have higher contents of compounds that may have positive effects on health, such as some minerals (K, Ca, Mg, or Cu) and total phenolics. These results suggest that organically grown eggplants produce fruits that have a higher nutritional value, which gives an added value to this crop as well as having a lower impact on the environment.

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