Research Article

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Effects of organic and conventional production systems on quality and nutritional parameters of processing tomatoes

Joy Rickman Pieper and Diane M Barrett*

Abstract

BACKGROUND: The impact of organic and conventional production systems on quality and nutritional parameters of fruits and vegetables is still under discussion. The objective of this study is to determine whether the production system has a significant effect on the quality and nutritional content of one variety of processing tomatoes grown on a commercial scale by comparing three different growers for two production years.

RESULTS: Conventional tomatoes appeared to be more mature at time of harvest as determined by visual inspection of color. Total and soluble solids were significantly higher and consistency was greater in organic tomatoes. Differences in nutrient content were not statistically significant between production systems. Glutamate, glutamine, and tyrosine levels were significantly higher in conventional tomatoes, as were total nitrogen and ammonium concentrations.

CONCLUSION: Results from this study show that nutritional and quality parameters vary greatly by grower, production system, and year for the same tomato cultivar. Significantly higher average soluble solids content and consistency in organic tomatoes are especially important to the processing tomato industry. The apparent slower development of organic tomatoes may be responsible for many of the significant findings in this study and may explain some of the conflicting reports in previous literature.

Keywords: tomato; organic; conventional; nutrition; quality; processing

INTRODUCTION

Processing tomatoes are an important part of California agriculture. According to the California Tomato Growers Association (http://www.ctga.org/), California produces over 90% of processing tomatoes grown in the USA. In 2005, tomatoes made up 13% by weight of all fruits and vegetables consumed in the USA, and of those nearly 80% were in the processed form (source: USDA/Economic Research Service. Last updated February 15, 2007). Their vast consumption and nutrient density make processing tomatoes a significant source of vitamin C, in addition to providing other nutrients and phytochemicals such as vitamin A, lycopene, and flavonoids.

Many research groups have studied nutritional and quality parameters in fruits and vegetables produced in organic and conventional growing systems, but conclusive evidence supporting nutritional or qualitative superiority of either production system does not currently exist. Determination of whether organic or conventional production system alone is responsible for nutritive or quality differences is challenging given the large number of variables that affect the nutrition and quality of a fruit or vegetable. These variables include cultivar, climate, soil type, fertilizer and irrigation practices, use of pesticides and herbicides, maturity at harvest, and postharvest handling. In order to determine the significance of the production system on fruit quality, such variables must be controlled and/or accounted for in the experimental design. Perhaps because of the influence of many confounding variables in previous studies, there are many discrepancies in the literature regarding effects of production system on particular nutrients. For example, some studies report higher levels of vitamin C and phenolic compounds in organic crops,[1,2] while others report no significant differences between production systems or even higher levels of vitamin C and phenolics in conventional fruits and vegetables.[3–6] In spite of these differences, some researchers have noticed a trend toward higher levels of flavonoids and other phytochemicals in organic foods.[7,8] Recently, organic tomatoes in particular have been found to be of higher quality than conventional based on soluble solids (°Brix) and Bostwick consistency values.[9,10]

Previously published studies on organic *versus* conventional production have often been carried out on only one growing location during one season. Several recent studies point to significant variation between geographical locations and years. Häkkinen and Törrönen, for example, found organic growing systems had no consistent effect on phenolic content of strawberries when multiple geographical locations were studied.[3] Barrett *et al*. compared one year's harvest from four different tomato growers with matched

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* *Correspondence to: Diane M Barrett, Food Science and Technology Department, University of California, Davis, 1 Shields Ave, Davis, CA 95616, USA. E-mail: dmbarrett@ucdavis.edu*

Food Science and Technology Department, University of California, Davis, CA 95616, USA

organic and conventional fields, and found that results in comparing the production systems often differed between the growers.[9] Chassy *et al*. found significant year-to-year variability when comparing quality and nutritional characteristics of organic and conventional fresh market tomatoes and bell peppers for 3 years at one growing location.[10] A recent study by Mitchell *et al*. reported 79% and 97% higher levels of quercetin and kaempferol, respectively, in organic tomatoes collected over a 10-year period.[11] While the finding is striking, it is important to note that all tomatoes were grown on the same research station. Most likely due to practical limitations, there is no known study published to date that has evaluated the same cultivar of crop grown in organic and conventional production systems at multiple grower sites for multiple years.

The purpose of this study was to analyze a variety of quality and nutritional parameters in organic and conventional processing tomatoes of the same variety obtained from multiple growers over two growing seasons. Such a design allows for a big-picture approach to the organic *versus* conventional quality and nutrition debate. While strict mechanistic studies regarding the effect of specific pesticides and herbicides involved in conventional agriculture are still needed, the larger question of whether or not organic systems tend to produce more nutritious and/or higher-quality crops when compared to conventional systems is important to consumers and researchers alike. Furthermore, discrepancies previously seen in the literature regarding superiority of one system or another may be explained by the lack of a holistic approach. Given all the variations in soil type, irrigation, pesticide and fertilizer applications that may take place, it is very difficult to draw broad conclusions from a small-scale experiment comparing organic *versus* conventional production systems. Although the importance of such experiments is apparent, the goal of this project was to be able to draw more general conclusions by looking at systems as a whole. Therefore, in this study three commercial growers were engaged as collaborators in 2006 and 2007, and the leading California processing tomato cultivar, AB2 (Processing Tomato Advisory Board, 2006), was evaluated. The same processing tomato cultivar was used to minimize genetic differences and utilize the processing cultivar most commonly grown in California.

MATERIALS AND METHODS

Growing sites

In each year of the study, 2006 and 2007, processing tomatoes of the same cultivar (*Lycopersicon esculentum* var. AB2) were grown from transplants and harvested at horticultural maturity from matched pairs of conventional and USDA-certified organic commercial fields from three different commercial growers. All growers were traditionally conventional producers but had at least five years experience in organic production on a commercial scale. The fields were selected such that the organic and conventional counterparts were within close proximity of each other, were of similar soil types, and were furrow irrigated. All fields were located in the central valley of California. Most of the grower collaborators were different in the 2 years of the study. One grower participated in both 2006 and 2007; however, the field locations differed due to crop and cultivar rotation. Thus, the 12 total fields studied over the course of 2 years were all different.

Organic fields used organic manures such as chicken and turkey manure in the range of 10–20t ha^{-1}. Conventional fields applied synthetic fertilizers with specific nitrogen, phosphorus and potassium ratios to obtain the soil composition desired by the individual grower. Although fields were picked based on their similar soil types, there were undoubtedly soil variations within and between the fields based on geology and historical field management. These factors, along with individual grower choice, affected the amount, type, and time of fertilizer application for each field. Pesticide applications in conventional fields also varied by field and included herbicides such as Gramoxone Max, insecticides such as Mustang, and fungicides such as Kumulus DF. Pesticide applications to organic fields were consistent with guidelines put forth by the USDA National Organic Program (www.ams.usda.gov/nop, last updated September 4, 2008), and included applications of dusting sulfur and Javelin WG B.T.

Sampling and processing

Figure 1 illustrates the sampling design used in this project. Within each field, six plots comprised of eight rows (approximately 12 m wide) by 12 m length were sampled to account for variability within the field. Exceptions to this were the plots in the 2006 harvest from the Terranova Ranch, which were four rows wide (approximately 6 m) by 6 m long. In all fields, rows consisted of a raised bed approximately 0.9 m wide surrounded on either side by furrows 0.6 m wide. Communication with the growers was vital to initially characterize the variability within these fields, which ranged in size from 4 ha to over 40 ha. Plots were chosen in consultation with the grower such that any variability within the field in terms of soil type or moisture retention was represented in the samples selected. Within each plot, eight tomato plants, 12 soil cores, and 20 petioles were chosen randomly and combined to obtain one sample of each material from each plot. Thus, six pooled replicates of tomatoes, soil and petioles were obtained for

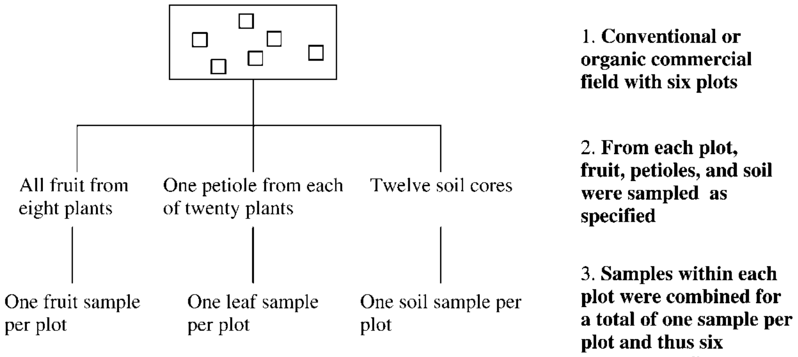

Figure 1. Sampling diagram.

each field. All analysis results are reported as an average of the six plots from each field plus or minus the standard deviations of the six plots.

Tomato plants were destructively harvested by cutting at the base of the stem and shaking all fruit into plastic lugs. Soil cores were taken from the middle of the raised beds from a depth of 0 to approximately 20 cm. Petiole samples were taken from the fourth petiole from the top of the plant to obtain the youngest mature petiole from each plant sampled. After harvest, samples were taken to the University of California Department of Food Science and Technology Pilot Processing Laboratory. All tomatoes from each plot were weighed to obtain yield. In 2006, all harvested fruit from the Terranova Ranch were sorted for visual quality inspection, but this procedure was subsequently modified due to the time requirement. It was determined that randomly withdrawing 100 tomato fruit was sufficient for a representative sample of the plot. The remaining tomatoes were sorted and washed, and only red-ripe fruit free of defects were analyzed further. These samples were then divided into subsets for either immediate quality analyses or processing for later analysis. Petiole and soil samples were dried at ambient outdoor temperature (approximately 35 °C) thoroughly before analysis.

Within one day of harvest, whole tomatoes were quartered and homogenized using a blender for approximately 45 s or until smooth. Homogenates were either frozen and held at −20 °C or freeze-dried and held at 4 °C until analysis. Also within one day of harvest, approximately 3 kg of tomatoes from each plot were canned according to established protocols in the pilot processing facility at Campbell's Research Company in Davis, CA. Tomatoes were sliced into 0.64 cm slices and heated to 82 °C in a steam-jacketed kettle. The samples were then passed through a pulper–finisher to remove seeds and peel. The resulting sauce was poured into #1 cans and seamed, then heated in a boiling water bath for 25 min.

Tomato fruit analyses

Visual inspection

Tomato fruit were sorted for color and defects, which can affect peelability and processing quality,[12] within one day of harvest. One hundred randomly selected tomato fruit were sorted first by color into the following categories: green, yellow-orange, orange, light-red, and red. All tomatoes were evaluated for the following defects: less than 3.8 cm diameter, 'limited use', yellow-eye disorder, sunburn, and remaining attached stem. These defects are commonly used for evaluating processing tomatoes by the California Processing Tomato Advisory Board (PTAB, http://www.ptab.org/order.htm). 'Limited use' is a somewhat subjective classification. PTAB uses the term 'limited use' to describe a tomato with one of the following conditions: more than 25% of skin separated from flesh; more than 50% of tomato is soft and mushy; or the tomato is broken such that seed locules are visible.

Quality analyses

Within one day of harvest, tomatoes for quality analysis underwent a microwave hot break process, described previously, to inactivate enzymes.[9] Following the hot break, tomato samples were passed through a pulper–finisher to eliminate skin and seeds. The resulting tomato juice was poured into a 2000 mL flask and de-aerated for 5 min, and then cooled to 25 °C for subsequent quality analyses. °Brix, Bostwick consistency, titratable acidity, pH, and color (*L*, *a*, and *b* values) were measured as described previously.[9]

Moisture content

Moisture content was determined using a halogen moisture analyzer (Mettler-Toledo, Columbus, OH, USA). The analyzer uses a quick-dry process via halogen heating to gravimetrically determine moisture content. Tomatoes were analyzed for moisture content the day following harvest, while canned sauce was analyzed within one month of canning.

Total vitamin C

Ascorbic and dehydroascorbic acids were determined in tomatoes and canned sauce using an enzymatic and spectrophotometric method based on that of Tsumura *et al.*[13] Tomato samples were analyzed within two days of harvest; canned samples were analyzed within one month. For determination of ascorbic acid, 1 mL of homogenized sample was centrifuged for 5 min at 16.1 × *g*, and 100 µL of the supernatant was added to a cuvette containing 2 mL of 0.1 mol L^{-1} sodium phosphate (pH 6.5), 0.4 mL water, and 5 µL of 1.0 mg mL^{-1} horseradish peroxidase. The absorbance was measured at 265 nm, after which 5 µL of 10% hydrogen peroxide was added to the mixture to oxidize ascorbic acid, and the absorbance was again measured at 265 nm. The subsequent decrease in absorbance corresponds to this oxidation and allows for quantitation of ascorbic acid in the initial sample. To determine dehydroascorbic acid (DHAA), a fresh sample in the same initial solution was used, omitting the horseradish peroxidase, and a change in absorbance at 265 nm was observed after addition of the reducing agent dithiothreitol to the sample. The increased absorbance corresponded to the conversion of dehydroascorbic acid to ascorbic acid in the sample.

Lycopene

Tomatoes and canned sauce were analyzed for lycopene within one month of harvest. The method used, described previously,[9] is based on that of Sadler *et al.*,[14] with some changes. Briefly, 100 µL of sample was extracted in a 2:1:1 mixture of hexane–ethanol–acetone, vortexed and incubated for 10 min or until color was completely extracted. 10 mL of water was then added and the mixture was vortexed. After standing for 10 min, the organic layer was read at Abs 503 nm and compared with a hexane control in a spectrophotometer (UV-1700, Shimadzu Scientific Instruments, Pleasanton, CA, USA).

Flavonols

Flavonols were determined in canned tomato sauce using a methanol extraction and reversed-phase chromatography using high-performance liquid chromatography (HPLC). Approximately 500 µL of sample was placed in a weighed, tared centrifuge tube. The sauce was spiked with 100 µL of an internal standard: quercetin-3-arabinoglucoside (Extrasynthese, Genay, France). 1 mL of methanol was added to the tube, and the tube was then vortexed and placed in the freezer for overnight extraction. The following day, samples were centrifuged and the supernatant was filtered through a 0.22 µm Teflon filter. 20 µL of the filtrate was injected on a 1200 HPLC system (Hewlett-Packard, Palo Alto, CA, USA), using a Synergi 4u Hydro-RP 80A 250 × 4.60 mm column (Phenomenex, Torrance, CA, USA). The following binary gradient was used for separation, with 2% acetic acid in water as the polar phase (A) and methanol as the non-polar phase (B): 0.01 min (A) 60%, 5 min (A) 40%, 10 min (A) 40%, 10.1 min (A) 0%, 20 min (A) 0%, 20.1 min (A) 60%, 30 min (A) 60%. Multi-wavelength UV detection was used at 260 and 370 nm. Quercetin-3-*O*-rutinoside

(Sigma Aldrich Chemical Co., St Louis, MO, USA) and quercetin-3-*O*-arabinoglucoside standards were run in varying concentrations (1, 5, 10, 20, 30, and 40 ppm) to obtain a calibration curve for quantification. Identification of quercetin-3-*O*-rutinoside was based on comparisons with standard retention time and with previous reports.[14]

Amino acids

Free amino acids were determined by the University of California Davis Molecular Structure Facility. Detailed methods may be found online at http://msf.ucdavis.edu/aaa.html. Briefly, approximately 1 mL of sample of homogenized whole tomatoes was centrifuged and 200 µL of supernatant was transferred to a new centrifuge tube. 50 µL of 10% sulfosalicyclic acid was added to this tube to remove any intact proteins. After 15 min the tube sample was centrifuged, and 100 µL of supernatant was added to 800 µL of aminoethyl cysteine buffer for a final dilution of 1 : 10. An L-800 amino acid analyzer (Hitachi, Tokyo, Japan) with a lithium–citrate buffer system was used, which employed ion-exchange chromatography for separation and a post-column ninhydrin reaction detection system. Results are reported as g kg^{-1} dry weight.

Tomato minerals, petiole and soil analyses

Freeze-dried and finely ground fruit and air-dried petiole and soil samples were submitted for mineral and nitrogen analysis by the Division of Natural Resources Analytical Laboratory at the University of California, Davis. Detailed methods may be found online at http://danranlab.ucanr.org. For tomato fruit, extractable ammonium and nitrate, total nitrogen, phosphorus, potassium, sulfur, boron, calcium, magnesium, zinc, manganese, iron, and copper were determined. Total nitrogen, phosphorus, and potassium were determined in petiole samples. Soil pH, organic matter, total Kjeldahl nitrogen, and particle size (percent sand, silt, and clay) were also measured.

^{15}N isotope analysis

Approximately 5 mg of finely ground freeze-dried tomatoes from each sample were submitted to the University of California Davis Stable Isotope Facility for ^{15}N analysis. A PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (SerCon Ltd, Crewe, UK) was used for analysis. Detailed methods may be found online at http://stableisotopefacility.ucdavis.edu/. Results are reported in δ^{15}N notation, which denotes the ratio of ^{15}N to ^{14}N in the sample relative to the atmospheric ratio.

Statistical analysis

Analysis of variance (ANOVA) was performed using the PROC MIXED procedure, followed by principal component analysis in SAS 9.1 statistical software (SAS Institute, Cary, NC, USA). Year and production system were fixed effects, and grower was treated as a random effect. Year and production system interactions were also determined; when this interaction was not statistically significant it was taken out of the analysis to allow for better determination of main effects. *P*-values less than 0.10 are reported in tables, and *P*-values less than 0.05 were considered significant. When a *P*-value less than 0.10 was found for a given comparison of organic and conventional production systems, the estimate given by the PROC MIXED procedure was used to estimate the magnitude of the difference. All values for the conventional samples were set at zero; any difference in the organic samples is given in the tables, where a positive estimate for organic indicates a larger value and a negative estimate indicates a smaller value in the organic sample, relative to conventional.

RESULTS AND DISCUSSION

Yield and visual inspection

Growers, locations, planting and harvest dates are detailed in Table 1. Tomatoes for this study were harvested within two days of commercial harvest by the grower. Yield per plant was not significantly different by production system or year, although there was only one grower with an average yield higher from the organic field (Table 2). In comparing paired organic and conventional fields at each farm location, it was apparent that the organic fruit required more days to reach the same degree of commercial maturity, as determined by the grower. This observation is supported by a comparison of both the number of days from planting to harvest (Table 1) and the percent red, green, and attached stems of tomatoes at harvest (Table 2). The average total color

Table 1. Farm locations: planting and harvest dates

	Grower	Location[a]		Approximate planting date	Harvest date	Number of days from planting to harvest
2006	Terranova Farms	Helm	Conventional	4/8	7/31	114
			Organic	4/8	7/31	114
	Button and Turkovich	Winters	Conventional	5/13	9/7	117
			Organic	5/15	9/20	128
	Rominger Brothers Farms	Winters	Conventional	5/10	8/31	113
			Organic	5/16	9/18	125
2007	Rominger Brothers Farms	Winters	Conventional	4/19	8/14	117
			Organic	4/17	8/22	127
	Joe Rominger	Winters	Conventional	4/19	8/16	119
			Organic	4/11	8/16	127
	Joe Muller and Sons	Woodland	Conventional	4/7	8/15	130
			Organic	4/9	8/15	128

[a] Closest weather station to all farms is in Winters, CA, except for Terranova Farms, whose closest weather station is in Five Points, CA.

Table 2. Yield and visual inspection of color and defects in harvested tomatoes

				(% of tomatoes)							
			Yield per plant (kg)	Red	Green	Stems	Sunburn	Yellow-eye	Limited use	<3.8 cm diameter	Defect free
2006	Terranova Farms	Conventional	4.8 ± 1.6	72.3 ± 5.5	5.1 ± 5.3	1.0 ± 0.8	15.1 ± 4.3	1.1 ± 1.7	6.4 ± 2.4	9.6 ± 3.6	67.7 ± 4.8
		Organic	3.0 ± 1.1	65.8 ± 6.9	9.4 ± 5.0	3.1 ± 1.2	10.5 ± 2.5	0.7 ± 0.6	5.9 ± 1.9	25.6 ± 13.4	61.2 ± 7.1
	Button and Turkovich	Conventional	5.3 ± 0.9	63.8 ± 12.2	12.1 ± 5.3	3.1 ± 1.8	8.8 ± 1.9	21.9 ± .0	6.2 ± 3.4	3.6 ± 3.6	59.5 ± 5.9
		Organic	3.5 ± 1.0	63.9 ± 6.2	10.2 ± 5.6	4.3 ± 1.2	9.3 ± 4.8	6.2 ± 5.8	8.0 ± 4.7	4.2 ± 4.0	72.3 ± 6.4
	Rominger Brothers Farm	Conventional	5.4 ± 1.8	59.1 ± 8.0	15.3 ± 4.1	3.6 ± 2.4	6.0 ± 3.3	12.5 ± 4.1	5.1 ± 3.1	7.4 ± 6.8	69.0 ± 6.9
		Organic	3.8 ± 1.2	52.4 ± 7.4	19.5 ± 8.8	7.9 ± 4.3	13.7 ± 5.2	0.0 ± 0.0	16.1 ± 8.1	10.1 ± 4.5	60.1 ± 12.0
2007	Rominger Brothers Farm	Conventional	5.3 ± 1.1	48.6 ± 5.6	1.0 ± 1.3	1.7 ± 1.7	16.3 ± 5.1	8.5 ± 5.4	3.2 ± 3.4	6.8 ± 8.8	65.1 ± 8.8
		Organic	4.7 ± 0.5	43.3 ± 8.3	2.8 ± 2.6	3.0 ± 1.7	9.0 ± 4.3	1.2 ± 1.0	2.8 ± 1.8	4.8 ± 2.9	82.2 ± 6.8
	Joe Rominger	Conventional	6.8 ± 2.2	50.4 ± 6.2	2.3 ± 1.7	2.2 ± 2.2	25.8 ± 6.9	7.2 ± 5.5	2.1 ± 2.0	2.7 ± 2.8	62.2 ± 5.6
		Organic	5.3 ± 1.1	46.4 ± 6.6	4.5 ± 2.8	4.2 ± 3.0	12.4 ± 4.4	2.0 ± 3.1	2.5 ± 1.9	21.4 ± 21.2	61.8 ± 15.0
	Joe Muller and Sons	Conventional	9.1 ± 1.3	55.3 ± 5.1	0.0 ± 0.0	1.2 ± 0.9	10.6 ± 5.2	2.3 ± 2.4	2.0 ± 2.7	5.4 ± 5.6	79.7 ± 5.8
		Organic	10.4 ± 1.8	47.2 ± 4.6	4.6 ± 3.7	2.2 ± 0.9	12.7 ± 3.1	2.3 ± 2.7	2.0 ± 1.5	1.7 ± 1.6	81.3 ± 5.2
P-values for production system			0.090	0.007	0.056	0.010	NS	0.046	NS	NS	NS
P-values for year			NS	0.026	0.035	NS	NS	NS	0.025	NS	NS
Year × production system			NS	NS	NS	NS	NS	NS	NS	NS	NS
Estimates for organic production system where conventional = 0			−1.0	−5.1	2.5	2.0	–	−6.9	–	–	–

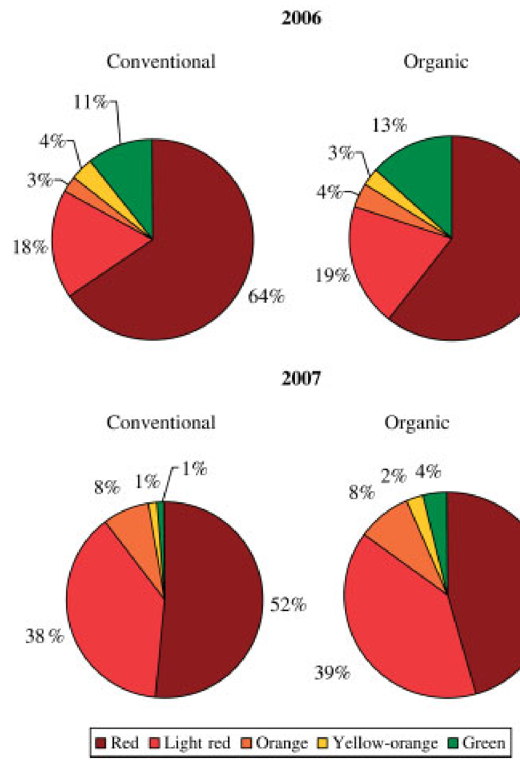

Figure 2. Average tomato color distribution for all growers at harvest by year and production system.

distribution (e.g. red, light-red, orange, yellow-orange, and green) for all growers and production systems in 2006 and 2007 is shown in Fig. 2. It is apparent from these charts that on average the organic fields produced tomatoes that were less red and more green than conventional fields. The statistical estimate suggested that the percentage of red tomatoes was 5.1% lower in organic fields. While the difference in redness between production systems was statistically significant ($P = 0.007$), the difference in greenness was not as strong ($P = 0.056$). For any one particular grower, a greater number of days after planting were required to achieve the same percent red in organic fields as conventional (data not shown). This suggests that if organic and conventional tomatoes are grown by the same farmer, and are given the same amount of development time, this may result in less mature fruit harvested from the organic field. A study by Zhao *et al*. found that conventionally managed fresh-variety tomatoes planted and harvested at the same time as organically managed tomatoes were scored higher for ripeness by a consumer sensory panel.[16] The tomatoes in that study were grown in a controlled environment to minimize variability of environmental factors, other than organic and conventional management. This observation may have a significant impact on the tomato industry as well as the design of research on organic agriculture. Furthermore, the maturity level of the fruit at harvest will have a strong impact on other quality and nutritional parameters that are analyzed.

The difference in redness between 2006 and 2007 was also significant, but could be attributed to the subjectivity of judging color. As is seen in Table 2 and Fig. 2, both more green and more red tomatoes were found in 2006, while more light-red tomatoes were found in 2007. Since the sorter varied each year, it is difficult to determine whether this played a role. Since green tomatoes are more easily distinguishable than the difference between light-red and red tomatoes, it may be more appropriate to look at the percentage of green rather than red tomatoes for year-to-year variability.

Percentage of tomatoes that were sunburned, limited-use, less than 3.8 cm diameter, and defect-free did not vary significantly by production system, and of these only limited-use varied significantly by year. A wetter spring followed by higher temperatures in 2006 (Fig. 3) might have been responsible for the finding of more limited-use tomatoes (Table 2) as well as a greater percentage of red tomatoes in 2006 (Fig. 2). Harvest dates for each year and grower were different and the average number of days from planting to harvest for all fields was 119 and 125 in 2006 and 2007, respectively. For conventional tomatoes, average number of days for both years from planting to harvest was 118 days, whereas organic tomatoes were in the ground for an average of 125 days.

Interestingly, the yellow-eye disorder appeared to be more prevalent in conventional fields, and this difference, estimated at 6.9%, was statistically significant (Table 2). Previous studies suggest that low exchangeable potassium levels in the soil may increase occurrence of the yellow-eye disorder.[17] In both years, potassium levels were significantly higher in organic fruit (Table 8); however, the correlation between yellow-eye and fruit potassium levels was not strong ($R = -0.58$). Calcium levels, however, were strongly positively correlated with the incidence of yellow-eye disorder ($R = 0.85$). Exchangeable potassium levels in the soil sampled at time of harvest were not significantly different between organic and conventional fields, but at that point in the season it was too late to identify any nutritional deficits in the soil.

Quality analyses and moisture content

Total solids as well as soluble solids (°Brix) were significantly higher and moisture content was lower in organic tomatoes in both years studied (Table 3). The statistical estimates of 0.50 °Brix and 0.69% total solids higher in organic tomatoes may be very significant to the processing industry. The higher moisture content in conventional fruit may be responsible for lower soluble and total solids contents due to dilution, and also must be considered for all other parameters measured where dilution may play a role. The reason why conventional fruit may contain more water is not entirely clear, as water uptake by the fruit and water relations within the tomato plant are complex.[18,19] While a discussion of water uptake in tomato fruit is beyond the scope of this paper, our results demonstrate that this issue may be extremely important in comparisons of organic and conventional crops.

Bostwick consistency values were also highly affected by production system each year, with organic production systems resulting in lower Bostwick values, indicating greater consistency. There is some evidence, although not statistically significant, for higher levels of titratable acidity in organic fruit (Table 3), but no significant differences were seen in pH. In a one-year study of four commercial California growers of organic and conventional processing tomatoes, Barrett *et al*. also found higher levels of °Brix and titratable acidity and lower Bostwick consistency values in organic tomatoes; however, the difference for each parameter was statistically significant for only two out of four growers.[9] It should be noted that each grower grew a different processing tomato cultivar, and this likely contributed to different findings between growers. Chassy *et al*. reported higher levels of °Brix in both varieties of organic fresh-variety tomatoes studied over a three-year period.[10]

The determination of higher levels of total and soluble solids as well as lower Bostwick consistency values and somewhat higher

Table 3. Quality analyses of tomatoes

			°Brix	Total Solids (%)	pH	Titratable acidity (meq kg^{-1})	Bostwick (cm)	Tomato moisture content (%)	Sauce moisture content (%)
2006	Terranova Farms	Conventional	6.51 ± 0.04	–[*]	4.44 ± 0.05	0.55 ± 0.05	16.0 ± 0.2	92.4 ± 0.6	93.6 ± 0.3
		Organic	6.66 ± 0.38		4.55 ± 0.03	0.51 ± 0.03	14.9 ± 0.7	92.0 ± 0.3	93.2 ± 0.4
	Button and Turkovich	Conventional	5.05 ± 0.34	5.61 ± 0.36	4.59 ± 0.03	0.40 ± 0.03	23.5 ± 1.2	94.5 ± 0.3	94.7 ± 0.3
		Organic	5.72 ± 0.47	6.44 ± 0.51	4.40 ± 0.05	0.51 ± 0.07	18.3 ± 1.6	94.0 ± 0.5	94.0 ± 0.6
	Rominger Brothers Farm	Conventional	5.47 ± 0.57	6.13 ± 0.62	4.60 ± 0.06	0.42 ± 0.05	21.5 ± 2.2	93.9 ± 0.6	94.5 ± 0.6
		Organic	5.71 ± 0.37	6.58 ± 0.39	4.59 ± 0.02	0.45 ± 0.03	17.4 ± 1.8	93.6 ± 0.5	93.3 ± 0.5
2007	Rominger Brothers Farm	Conventional	5.24 ± 0.61	5.77 ± 0.75	4.81 ± 0.04	0.44 ± 0.04	23.8 ± 2.7	94.5 ± 0.8	94.7 ± 0.8
		Organic	5.83 ± 0.50	6.45 ± 0.56	4.52 ± 0.04	0.52 ± 0.03	19.2 ± 0.8	94.1 ± 0.6	94.2 ± 0.5
	Joe Rominger	Conventional	4.91 ± 0.22	5.49 ± 0.17	4.54 ± 0.04	0.44 ± 0.04	22.0 ± 1.3	94.7 ± 0.3	95.1 ± 0.2
		Organic	6.25 ± 1.47	6.93 ± 1.46	4.60 ± 0.03	0.52 ± 0.08	19.1 ± 1.5	93.4 ± 1.2	93.9 ± 1.0
	Joe Muller and Sons	Conventional	5.04 ± 0.21	5.57 ± 0.23	4.45 ± 0.04	0.48 ± 0.02	21.4 ± 1.2	94.8 ± 0.4	95.3 ± 0.1
		Organic	5.05 ± 0.12	5.65 ± 0.13	4.54 ± 0.03	0.51 ± 0.03	19.6 ± 1.0	94.6 ± 0.3	94.9 ± 0.3
P-values for production system effects			0.052	0.037	NS	0.084	0.004	0.024	0.003
P-values for year effects			NS	NS	NS	NS	NS	NS	0.076
Year × production system			NS	NS	NS	NS	NS	NS	NS
Estimates for organic production system where conventional = 0			0.50	0.69	–	0.05	−3.27	−0.5	−0.7

[*] Total solids were not measured for Terranova Farms in 2006.

levels of titratable acidity in organic tomatoes may be related to the previous suggestion of these fruit being less mature. Garcia and Barrett found that processing tomatoes harvested at a less mature stage were more viscous (lower Bostwick values) and had higher levels of titratable acidity.[12] Renquist and Reid found the latest-set fruit (i.e., the youngest) on a tomato plant were of higher quality based on higher total solids, soluble solids and titratable acidity, and lower Bostwick consistency.[20] These authors found that pH values were more variable throughout the various fruit sets. They suggested that current research indicates a decline in °Brix towards the end of fruit ripening, and their own research suggests the highest levels of °Brix are found at the turning-red stage. In general they suggest harvesting at an earlier stage to improve fruit quality. Toor *et al*. reported that tomatoes grown in nitrate-dominant fertilizer solutions, such as used in conventional production systems, had significantly lower levels of titratable acidity than those grown with manure, mulch, or mineral solutions with lower nitrate to ammonium ratios.[21] Tomatoes from all different fertilization treatments were harvested on the same day, and no statement was made by the authors as to any observed maturation rate difference; all harvested tomatoes were reported to be at maturity stage 5 according to the Californian Tomato Commission, 2002. The authors suggest higher levels of acids could be due to reduced sulfur availability and/or excess carbon availability in manure and mulch. Titratable acidity has also been reported to be correlated with potassium content;[22] our results showed a positive correlation but the strength of correlation was questionable ($R = 0.65$).

The apparent effect of production system seen in this study on °Brix, Bostwick, and titratable acidity thus may actually be a factor of slight differences in physiological maturity at harvest. Other explanations, however, could be related to the increased vegetative growth characteristics of conventional crops. Increased carbon allocation to the leaves or increased shading of the fruit by excess foliage could decrease the total solids content, affecting levels of °Brix, Bostwick, and titratable acidity.[22] Although vegetative mass was not measured in the present study, in visual observations of conventional plants a greater amount of vegetation was noted. Future research comparing nutritional and quality parameters of organic *versus* conventional crops should include a measure of vegetative growth.

Color parameters and lycopene

Color parameters and lycopene content on a fresh and dry weight bases are presented in Table 4. Of the Hunter L, a, and b color measurements, only b values appeared to be highly affected by production system, with organic fruit being significantly more yellow. These values indicate the degree of blue to yellow, *versus* a values, which indicate green to red, and L, which indicate lightness to darkness. The impact of year was statistically significant for a values, so the slight year and production system interaction seen for a/b values is expected. In previous studies, a/b has been suggested as a ripening index for vine-ripened fruits, and has been shown to be well correlated with fruit maturity and lycopene content.[23,24] In the present study there was no significant difference in a/b with respect to production system.

Although b values were on average higher in organic fruit, the difference was relatively small, and an interaction between year and production system was observed. López Camelo and Gómez showed that b values did not change significantly during ripening of tomatoes but values were slightly higher at the pink–light-red stage.[24] This is consistent with the work by Arias *et al*., which showed that b values increased through the initial stages of tomato maturation and then decreased, and Kaur *et al*., who found decreases in b values during ripening of seven tomato cultivars.[23,25] Renquist and Reid found the youngest set fruit on tomato vines produced a significantly more yellow purée, based on a/b values.[19] Our slightly higher b values in organic fruit may again suggest that the organic fruit are slightly less ripe or younger fruit.

In the study of Barrett *et al*., the only color values to significantly differ between organic and conventional tomatoes were also the b values.[9] However, in our study b values were always higher in organic tomatoes, whereas in their study b values were sometimes higher and sometimes lower depending on the grower. It is important to note here that the previous study utilized hand-picking of red-ripe fruit off the vines, whereas our study involved destructive harvest of the entire plant and evaluation of all red fruit. Chassy *et al*. also found slightly lower values of a/b in organic over 3 years in two tomato cultivars but this result was not statistically significant.[10]

Our results suggest there is some evidence for a production system effect on lycopene content on a fresh weight basis, with somewhat higher (estimated at 12.75 g kg^{-1}) levels in organic tomatoes, but this effect is not statistically significant when lycopene content is reported on a dry weight basis. Any difference seen on a fresh weight basis may be due to dilution, since conventional tomatoes generally had higher moisture content. These results are very similar to those of Caris-Veyrat *et al*., who found higher levels of lycopene in three varieties of organic tomatoes on a fresh weight basis; however, when results were expressed on a dry weight basis this was not significant.[26] Barrett *et al*. found significant impacts of production system on lycopene; however, the results varied by grower.[9] Tomatoes from two out of four growers had higher lycopene content on a fresh weight basis in the conventional fruit, while organic tomatoes from the other two growers had higher lycopene content than their paired conventional fruit.

Total vitamin C

Table 5 shows the results for ascorbic and dehydroascorbic acid content in tomatoes and canned tomato sauce. Results suggest that any effects of year and production system are negligible when studying multiple years and growing locations. The only exception was a statistically significant difference in DHAA of canned tomato sauce on both fresh and dry weight bases between different years. This may have to do with minor differences in handling of the fresh tomatoes or in the canning processes each year. The lower values of DHAA in 2007 suggest that less ascorbic acid was converted to DHAA that year. This is also consistent with generally higher values of ascorbic acid in 2007, although differences were not statistically significant. Figure 4 illustrates that production system may affect vitamin C content when looking at a single grower, but variability between growers and years is such that conclusions regarding production system effects cannot be made.

Higher levels of vitamin C, both ascorbic and dehydroascorbic acids, have often been reported in organic foods, although on closer inspection results are inconsistent.[27] Chassy *et al*. found significantly higher levels of vitamin C in fresh market tomatoes on a fresh weight basis but not on a dry weight basis.[10] Carbonaro *et al*. reported significantly higher levels of ascorbic acid in organic compared to conventional peaches in a 3-year study; however, results were only expressed on a fresh weight basis.[28] Barrett *et al*. found that ascorbic acid in organic and conventional tomatoes,

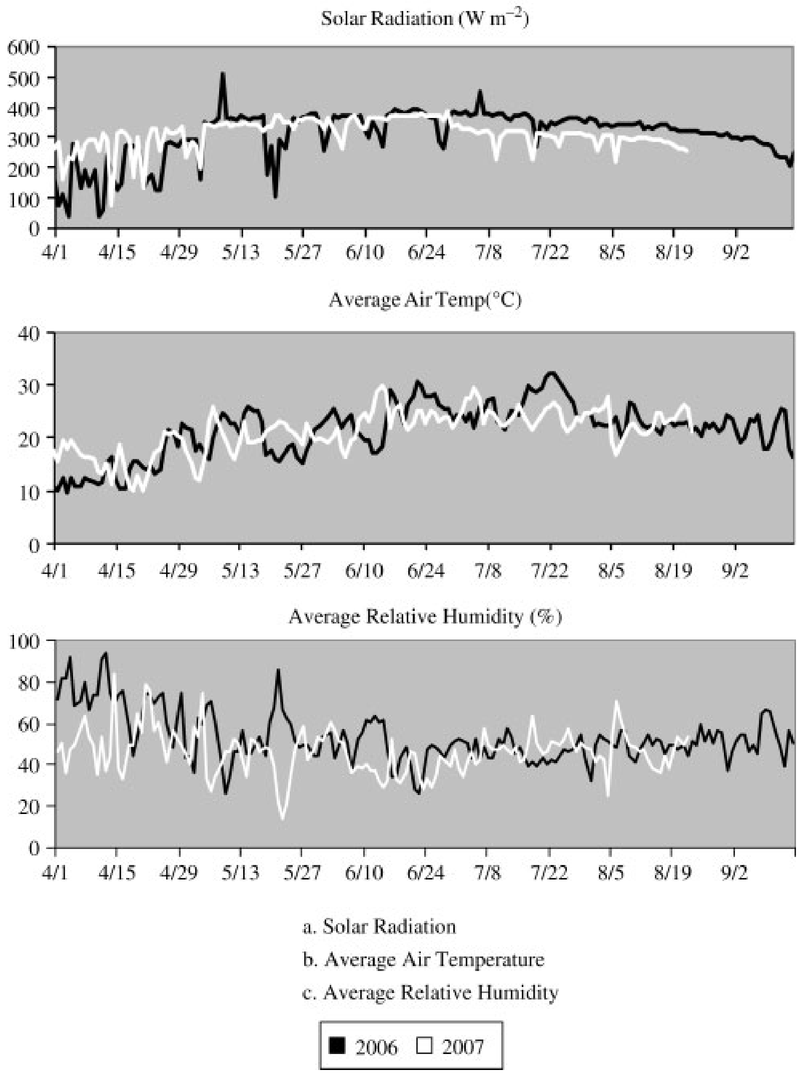

Figure 3. Average Solar Radiation, Air Temperature, and Relative Humidity in Winters, CA During the Growing Seasons of 2006 and 2007. Adapted from http://wwwcimis.water.ca.gov/cimis/data.jsp.

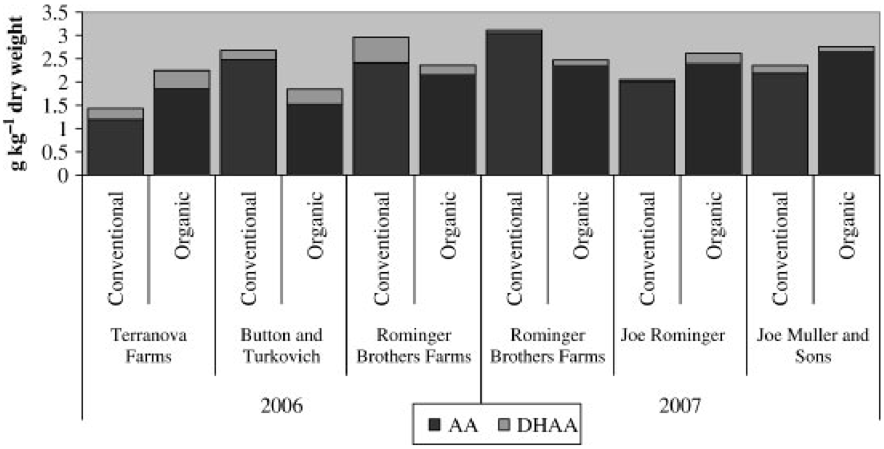

Figure 4. Total vitamin C (ascorbic acid (AA) and dehydroascorbic acid (DHAA)) in canned tomato sauce (g kg^{-1} dry weight).

Table 4. Color parameters of microwave-break tomatoes and lycopene content of canned tomato sauce

							Lycopene (g kg^{-1})	
			L	*a*	*b*	*a*/*b*	FW	DW
2006	Terranova Farms	Conventional	26.67 ± 0.35	29.73 ± 0.39	14.08 ± 0.09	2.11 ± 0.03	98.53 ± 7.46	1547.90 ± 125.48
		Organic	26.65 ± 0.32	29.26 ± 0.39	14.27 ± 0.09	2.05 ± 0.03	96.19 ± 11.26	1417.88 ± 153.72
	Button and Turkovich	Conventional	24.79 ± 0.15	29.13 ± 0.29	13.40 ± 0.06	2.17 ± 0.03	111.38 ± 10.80	2119.02 ± 147.13
		Organic	25.26 ± 0.25	29.41 ± 0.17	13.65 ± 0.13	2.15 ± 0.02	129.56 ± 8.28	2157.20 ± 156.09
	Rominger Brothers Farms	Conventional	24.56 ± 0.24	29.64 ± 0.42	13.42 ± 0.12	2.21 ± 0.03	102.98 ± 10.63	1860.08 ± 128.67
		Organic	25.20 ± 0.29	29.44 ± 0.31	13.65 ± 0.19	2.16 ± 0.04	138.17 ± 16.62	2065.95 ± 167.85
2007	Rominger Brothers Farms	Conventional	24.85 ± 0.41	28.33 ± 0.49	13.19 ± 0.22	2.15 ± 0.02	109.65 ± 9.94	2103.97 ± 170.92
		Organic	25.10 ± 0.16	29.27 ± 0.19	13.28 ± 0.12	2.20 ± 0.02	117.55 ± 14.95	2037.56 ± 206.84
	Joe Rominger	Conventional	25.25 ± 0.16	28.54 ± 0.45	13.39 ± 0.11	2.13 ± 0.04	100.85 ± 5.79	2047.08 ± 168.62
		Organic	25.39 ± 0.44	29.33 ± 1.03	13.53 ± 0.18	2.17 ± 0.05	114.36 ± 9.58	1906.75 ± 187.62
	Joe Muller and Sons	Conventional	24.84 ± 0.18	28.83 ± 0.30	13.04 ± 0.12	2.21 ± 0.03	94.19 ± 6.34	2018.31 ± 131.45
		Organic	24.84 ± 0.21	28.78 ± 0.31	13.20 ± 0.07	2.18 ± 0.02	98.24 ± 8.99	1908.50 ± 91.48
P-values for production system effects			0.070	NS	<0.001	NS	0.063	NS
P-values for year effects			NS	0.016	NS	NS	NS	NS
Year × production system			NS	0.080	0.026	0.088	NS	NS
Estimates for organic production system where conventional = 0			0.24	–	0.17	–	12.75	–

Table 5. Ascorbic acid (AA) and dehydroascorbic acid (DHAA) content in tomatoes and canned tomato sauce (g kg^{-1})

			Fresh weight (FW)				Dry weight (DW)			
			AA	DHAA	AA	DHAA	AA	DHAA	AA	DHAA
			Tomatoes		Sauce		Tomatoes		Sauce	
2006	Terranova Farms	Conventional	0.168 ± 0.024	0.022 ± 0.005	0.076 ± 0.021	0.015 ± 0.007	2.443 ± 0.255	0.322 ± 0.052	1.190 ± 0.284	0.234 ± 0.103
		Organic	0.204 ± 0.041	0.019 ± 0.008	0.126 ± 0.015	0.026 ± 0.007	3.015 ± 0.542	0.284 ± 0.114	1.860 ± 0.140	0.387 ± 0.108
	Button and Turkovich	Conventional	0.193 ± 0.019	0.034 ± 0.006	0.129 ± 0.019	0.011 ± 0.002	3.661 ± 0.520	0.632 ± 0.099	2.479 ± 0.477	0.204 ± 0.046
		Organic	0.169 ± 0.021	0.034 ± 0.011	0.092 ± 0.034	0.020 ± 0.003	2.852 ± 0.473	0.564 ± 0.175	1.522 ± 0.594	0.325 ± 0.029
	Rominger Brothers Farms	Conventional	0.186 ± 0.045	0.051 ± 0.013	0.134 ± 0.027	0.030 ± 0.002	3.332 ± 0.736	0.932 ± 0.251	2.410 ± 0.422	0.548 ± 0.074
		Organic	0.219 ± 0.023	0.031 ± 0.004	0.143 ± 0.055	0.014 ± 0.001	3.527 ± 0.267	0.493 ± 0.079	2.151 ± 0.808	0.208 ± 0.029
2007	Rominger Brothers Farms	Conventional	0.185 ± 0.018	0.018 ± 0.002	0.160 ± 0.031	0.003 ± 0.003	3.367 ± 0.177	0.331 ± 0.057	3.047 ± 0.466	0.062 ± 0.070
		Organic	0.070 ± 0.014	0.012 ± 0.008	0.136 ± 0.028	0.007 ± 0.009	1.172 ± 0.168	0.208 ± 0.126	2.352 ± 0.360	0.120 ± 0.173
	Joe Rominger	Conventional	0.136 ± 0.017	0.030 ± 0.035	0.099 ± 0.016	0.002 ± 0.005	2.547 ± 0.222	0.556 ± 0.624	2.005 ± 0.323	0.042 ± 0.100
		Organic	0.153 ± 0.038	0.007 ± 0.012	0.148 ± 0.043	0.013 ± 0.014	2.309 ± 0.221	0.099 ± 0.174	2.391 ± 0.439	0.221 ± 0.262
	Joe Muller and Sons	Conventional	0.146 ± 0.015	0.018 ± 0.003	0.102 ± 0.022	0.008 ± 0.006	2.827 ± 0.320	0.354 ± 0.069	2.190 ± 0.452	0.167 ± 0.123
		Organic	0.168 ± 0.025	0.020 ± 0.004	0.136 ± 0.023	0.006 ± 0.007	3.129 ± 0.452	0.369 ± 0.074	2.643 ± 0.350	0.110 ± 0.130
P-values for production system effects			NS	NS	NS	NS	NS	0.08	NS	NS
P-values for year effects			0.06	0.08	NS	0.02	NS	NS	NS	0.03
Year × production system			NS	NS	NS	NS	NS	NS	NS	NS
Estimates for organic production system where conventional = 0			–	–	–	–	–	−0.185	–	–

determined on a fresh weight basis, varied significantly by grower.[9] Caris-Veyrat *et al*. found higher levels of vitamin C on both fresh and dry weight bases in organic tomatoes in two out of three cultivars in a study carried out for a single season and growing location.[26] These conflicting reports are not new to the study of vitamin C. In a 1981 review article, Davies and Hobson reported difficulties in drawing conclusions as to the effects of various environmental, nutritional, and genetic factors on the ascorbic acid content of tomatoes.[22]

Flavonols

Preliminary laboratory tests demonstrated that canned tomato sauce enabled the most complete extraction of flavonoids (data not shown). Comparisons with the literature, standard retention times, and absorbance spectra suggested the presence of two flavonoids in the samples, the dominant one being rutin (Table 6). Samples were spiked with a rutin standard for verification. The other flavonoid was likely a quercetin derivative, based on comparison with a report by Simonetti *et al*.[15] Our results showed no significant difference in rutin content between organic and conventional fruit on either a fresh or dry weight basis (Table 6). While certainly there were differences when looking at the paired fields for a single grower, where organic tomatoes were generally higher in rutin, the variance between growers was great enough to negate any significant production system effect. The nearly threefold higher value in rutin content of organically grown tomatoes from Joe Rominger's farm in 2007, for instance, is quite striking; however, in the same year the two other growers had virtually identical levels of rutin in their matched organic and conventional tomatoes. Year-to-year differences were significant, but there was no observed interaction between year and production system. Higher average temperatures and solar radiation levels in 2006 (Fig. 3) may be responsible for the observed higher rutin content in the same year.

As discussed previously, there are discrepancies in the literature regarding the comparisons of phenolic compounds in organic and conventionally grown crops. Häkkinen and Törrönen, for example, found that organic growing systems had no consistent effect on phenolic content of strawberries when multiple geographical locations were studied.[3] Caris-Veyrat *et al*., however, found higher levels of rutin on both the fresh and dry weight bases in organic tomatoes in all three cultivars studied in a one-year comparison.[26] Chassy *et al*. found significantly higher levels of quercetin in the organic production of one out of two fresh tomato varieties studied over 3 years on a fresh weight basis; however, the results were not significant on a dry weight basis.[10] A recent study by Mitchell *et al*. reported 79% and 97% higher levels of quercetin and kaempferol, respectively, in organic tomatoes collected over a 10-year period on a dry weight basis.[11] Again, it is important to note the tomatoes were all grown at a single location. Our results underscore the need for reporting results on a dry weight basis, studying multiple growers, and studying multiple growing seasons.

Amino acids

Nineteen free amino acids were identified in tomatoes each year, i.e., aspartic acid, threonine, serine, glutamic acid, glutamine, glycine, alanine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, γ-aminobutyric acid, tryptophan, lysine, histidine, arginine, and proline. Of these, eight were significantly affected to some degree by year, production system or both (Table 7). No statistically significant interaction between year and production system was observed. Aspartic acid, leucine, γ-aminobutyric acid, and arginine were significantly different by year only (data not shown). Interestingly, glutamic acid, glutamine, tyrosine, phenylalanine, histidine, methionine, lysine, and threonine were all found to be higher in conventionally grown tomatoes. Statistical estimates suggest 4.91, 27.22, and 0.20 g kg^{-1} higher levels of glutamate, glutamine, and tyrosine, respectively, in conventional tomatoes. Glutamic acid, glutamine, and threonine were all negatively correlated with the percent of green tomatoes ($R = -0.79$, -0.78, and -0.78, respectively).

Valle *et al*. found that glutamine content increased significantly during tomato fruit development, corresponding to a decrease in glutamate content.[29] However, Nagata and Saijo reported an increase in glutamate along with decreases in γ-aminobutyric acid and glutamine during ripening of tomato fruits.[30] Boggio *et al*. compared the green, yellow, and red stages of tomato fruit, and found increases during ripening of aspartate and glutamate, and decreases in asparagine, serine, proline, tyrosine and valine.[31] The maturity stages compared in that study would not be relevant to any minor differences between light-red and red stages of maturity evaluated in the present study.

Clearly there is a great deal of disparity amongst reported studies on free amino acid levels in tomatoes during development and ripening, and this issue has been discussed in more classical literature.[22] In this review it was mentioned that there may be an increase in some free amino acids due to fertilization regimes high in nitrogen and low in phosphate. Since there were significant differences in many of the amino acid contents in tomatoes grown in organic and conventional fields in the present study, it may be important to further research the reason. Few studies to date have compared amino acid levels in organic and conventional crops. Gent reported no significant overall effects of fertilization regimes on total amino acid levels in salad greens.[32] This author found that for individual free amino acids significant species and season (time of harvest) effects and interactions existed and were more dominant than fertilization effects. Starratt and Lazarovits reported increases in free amino acids levels, particularly glutamine and asparagine, in immature tomato plants due to application of dinitroaniline herbicides.[33]

Clearly a simple explanation of maturity differences cannot be used at this point. The influence of pesticides on free amino acid composition may be of particular interest for future study. However, it should be noted that the amino acid content may simply be dependent on the amount of available nitrogen, which is generally greater in conventional fruit.

Fruit minerals, petiole and soil analyses

Nitrogen, potassium, and phosphorus content of the tomatoes were strongly influenced by production system (Table 8). Significantly lower levels of nitrogen and higher levels of phosphorus and potassium were found in organic tomatoes. This is similar to the findings of Colla *et al*., who studied elemental composition of processing tomatoes grown under organic and conventional systems for 2 years.[34] Their findings showed significantly lower levels of nitrogen and higher levels of phosphorus in organic tomatoes each year; however, there was no significant difference in potassium between the production systems. Different fertilizer regimes used in organic and conventional production systems in addition to past soil management and geology will affect these macronutrients as well as the micronutrient minerals. Regardless of these influences, organic tomatoes had on average slightly lower levels of calcium, boron, and manganese, and significantly lower levels

Table 6. Rutin content in canned tomato sauce (g kg^{-1})

			FW	DW
2006	Terranova Farms	Conventional	0.011 ± 0.002	0.177 ± 0.019
		Organic	0.015 ± 0.004	0.213 ± 0.050
	Button and Turkovich	Conventional	0.010 ± 0.002	0.191 ± 0.022
		Organic	0.011 ± 0.003	0.181 ± 0.039
	Rominger Brothers Farms	Conventional	0.013 ± 0.011	0.226 ± 0.147
		Organic	0.016 ± 0.006	0.237 ± 0.084
2007	Rominger Brothers Farms	Conventional	0.007 ± 0.004	0.121 ± 0.069
		Organic	0.007 ± 0.001	0.131 ± 0.034
	Joe Rominger	Conventional	0.004 ± 0.001	0.064 ± 0.015
		Organic	0.011 ± 0.008	0.220 ± 0.168
	Joe Muller and Sons	Conventional	0.004 ± 0.000	0.070 ± 0.013
		Organic	0.004 ± 0.001	0.085 ± 0.008
P-values for production system effects			0.081	NS
P-values for year effects			0.014	0.022
Year × production system			NS	NS
Estimates for organic production system where conventional = 0			0.002	–

of extractable ammonium. Extractable nitrate in most of the samples was below the limit of detection (less than 10 ppm), making statistical analysis impossible (data not reported). Extractable ammonium levels were strongly correlated with glutamine ($R = 0.75$) content. This correlation is suggestive of the deamination of glutamine during ripening.[22] Zinc, copper, and iron were the only minerals that did not seem to be affected by year or production system (data not reported). Colla *et al*. reported higher levels of calcium and lower levels of sodium in organic processing tomatoes compared to conventional, while other micronutrients were not significantly different.[34] Given the different native soils and soil applications used in each field, such variance amongst the minerals is not surprising.

As previously mentioned, since petiole and soil samples were only taken on the day of harvest owing to practical limitations, nutritional deficiencies in the soil that may have been present early in the season cannot be identified. Perhaps not surprisingly, then, the macronutrients nitrogen, phosphorus, and potassium were not significantly different between production systems in the petiole samples (Table 9). Interestingly, there is an apparent production system effect on the percentage of sand content in the soil. Obviously, this percentage is determined by soil type and field location. Although we chose these fields based on their supposedly similar soil types, there were some measured differences, suggesting the soil types may not have been as well matched as previously thought. Blocked studies in single fields have an advantage of minimizing the chances of divergent soil types; this type of experimental design, however, is difficult in studying commercial fields.

^{15}N isotope analysis

In addition to soil type, climatic conditions, and agricultural management, fertilization inputs can drastically impact the nitrogen isotope composition of a crop. Due to their production from atmospheric nitrogen, levels of δ^{15}N are usually close to zero in conventional fertilizers. Levels of δ^{15}N in manure fertilizers commonly used in organic systems are reportedly between 10% and 20%. It is as yet uncertain whether this difference could be exploited for market differentiation of organic and conventional crops and/or organic fraud detection. In this study, a significant production system effect on the nitrogen isotope composition of fruit was observed in both years (Table 8). Large differences seen from grower to grower are likely due to fertilization choices such as chicken or turkey manure *versus* synthetic fertilizers which varied both by grower, production system and year (data not shown). A yearly effect was also seen, again likely due to fertilization choices for different fields. Soil type, climactic conditions, and agricultural management may all have an effect on the nitrogen isotope composition. It is important to note that the ranges for δ^{15}N composition in organic and conventional tomatoes overlap: the conventional tomato content ranged from 0.24% to 2.09% and the organic content from 0.9% to 5.46%. These results are consistent with those of Bateman *et al*., who compared nitrogen isotope composition in organic and conventional tomatoes, lettuce, and carrots.[35] These authors reported a mean δ^{15}N value of 8.1% in organic tomatoes *versus* -0.1% for conventional tomatoes from many samples collected over a 2-year period. Since this study was completed in the UK and sourced European and Mediterranean tomatoes, fertilizer differences and thus different ranges δ^{15}N composition are expected. However, our results are consistent in that organic tomatoes do have a higher average value of δ^{15}N as compared to conventional, e.g., 2.4% and 0.9%, respectively. Since the values may overlap with conventional tomatoes, use of nitrogen isotope analysis in organic fraud detection should not be the only means of discriminating the production system.

Principal component analysis

Principal component analysis was used following the analysis of variance, but production system differences could not be simplified or further explained. However, in simplifying the results from all parameters measured, growers, and years into two principal components, the data points were grouped more by grower than by production system (data not shown). In other words, the grower appeared to have a greater effect on fruit quality and nutritional parameters than the production system; this may also be observed in thorough analysis of the data tables presented.

Table 7. Selected free amino acids in tomatoes (g kg^{-1} DW)

			Glutamic acid	Glutamine	Tyrosine	Phenylalanine	Histidine	Methionine	Lysine	Threonine
2006	Terranova Farms	Conventional	20.22 ± 4.26	17.19 ± 4.58	0.40 ± 0.12	1.71 ± 0.42	0.76 ± 0.20	0.17 ± 0.05	0.99 ± 0.24	1.44 ± 0.43
		Organic	14.33 ± 5.67	10.61 ± 4.78	0.31 ± 0.14	1.46 ± 0.34	0.60 ± 0.22	0.15 ± 0.07	0.77 ± 0.23	1.10 ± 0.44
	Button and Turkovich	Conventional	24.89 ± 5.54	18.67 ± 4.78	0.43 ± 0.14	1.88 ± 0.38	0.79 ± 0.16	0.17 ± 0.04	0.99 ± 0.17	1.31 ± 0.28
		Organic	21.21 ± 3.50	17.21 ± 1.84	0.34 ± 0.07	1.86 ± 0.22	0.82 ± 0.16	0.12 ± 0.02	0.92 ± 0.14	1.32 ± 0.21
	Rominger Brothers Farms	Conventional	25.24 ± 3.19	15.99 ± 3.49	0.36 ± 0.08	1.81 ± 0.28	0.78 ± 0.14	0.15 ± 0.03	0.89 ± 0.17	1.15 ± 0.27
		Organic	18.85 ± 2.94	10.40 ± 2.62	0.22 ± 0.07	1.41 ± 0.27	0.56 ± 0.09	0.10 ± 0.02	0.68 ± 0.10	0.76 ± 0.15
2007	Rominger Brothers Farms	Conventional	37.07 ± 4.13	70.23 ± 25.68	0.98 ± 0.23	3.97 ± 0.74	1.49 ± 0.34	0.41 ± 0.09	2.44 ± 0.49	3.24 ± 0.66
		Organic	36.72 ± 4.03	49.78 ± 15.44	0.54 ± 0.15	3.23 ± 0.86	1.08 ± 0.30	0.21 ± 0.04	1.63 ± 0.32	2.30 ± 0.62
	Joe Rominger	Conventional	35.00 ± 5.83	40.19 ± 4.82	0.50 ± 0.09	2.40 ± 0.20	0.99 ± 0.09	0.19 ± 0.02	1.23 ± 0.15	1.75 ± 0.24
		Organic	31.32 ± 5.34	26.20 ± 4.38	0.48 ± 0.08	2.12 ± 0.19	1.00 ± 0.23	0.19 ± 0.06	1.16 ± 0.26	1.72 ± 0.32
	Joe Muller and Sons	Conventional	39.14 ± 6.57	71.07 ± 21.22	0.68 ± 0.19	3.31 ± 0.77	1.17 ± 0.31	0.30 ± 0.08	1.91 ± 0.41	2.69 ± 0.59
		Organic	29.70 ± 5.60	23.88 ± 4.60	0.29 ± 0.04	1.82 ± 0.24	0.70 ± 0.13	0.10 ± 0.01	0.81 ± 0.15	1.14 ± 0.27
P-values for production system effects			0.011	0.037	0.043	0.057	0.064	0.066	0.068	0.079
P-values for year effects			0.003	0.016	0.07	0.055	0.04	0.078	0.064	0.047
Year × production system			NS	0.092	NS	NS	NS	NS	NS	NS
Estimates for organic production system where conventional = 0			−4.91	−27.22	−0.20	−0.53	−0.20	−0.09	−0.41	−0.54

Table 8. Minerals and δ^{15}N composition of tomatoes (DW)

			Percent					mg kg^{-1}				
			N	P	K	Ca	Mg	B	S	Mn	NH4-N	δ^{15}N (%)
2006	Terranova Farms	Conventional	2.80 ± 0.24	0.37 ± 0.03	3.74 ± 0.28	0.12 ± 0.02	0.18 ± 0.01	15 ± 1	2105 ± 135	13 ± 2	97 ± 23	0.92 ± 0.30
		Organic	2.06 ± 0.35	0.52 ± 0.04	3.93 ± 0.25	0.12 ± 0.03	0.16 ± 0.02	15 ± 1	2188 ± 155	10 ± 2	48 ± 8	5.46 ± 0.90
	Button and Turkovich	Conventional	2.54 ± 0.23	0.36 ± 0.02	3.22 ± 0.15	0.18 ± 0.02	0.19 ± 0.01	20 ± 1	1938 ± 40	18 ± 2	187 ± 49	1.34 ± 0.23
		Organic	2.58 ± 0.26	0.44 ± 0.04	3.76 ± 0.23	0.16 ± 0.02	0.22 ± 0.01	16 ± 1	2193 ± 206	12 ± 1	193 ± 80	2.63 ± 0.43
	Rominger Brothers Farms	Conventional	2.40 ± 0.33	0.37 ± 0.04	3.65 ± 0.28	0.15 ± 0.04	0.20 ± 0.02	19 ± 1	2102 ± 210	20 ± 5	145 ± 82	2.09 ± 0.78
		Organic	1.80 ± 0.22	0.43 ± 0.04	3.74 ± 0.36	0.14 ± 0.02	0.19 ± 0.02	15 ± 1	1807 ± 80	11 ± 2	72 ± 30	2.35 ± 0.54
2007	Rominger Brothers Farms	Conventional	3.05 ± 0.26	0.41 ± 0.06	3.40 ± 0.41	0.14 ± 0.03	0.22 ± 0.03	20 ± 2	2340 ± 157	23 ± 3	340 ± 104	0.24 ± 0.04
		Organic	2.47 ± 0.29	0.44 ± 0.06	4.12 ± 0.30	0.12 ± 0.02	0.21 ± 0.02	19 ± 1	2180 ± 181	16 ± 2	133 ± 30	1.28 ± 0.15
	Joe Rominger	Conventional	2.81 ± 0.30	0.36 ± 0.03	3.49 ± 0.28	0.14 ± 0.01	0.22 ± 0.02	18 ± 1	2203 ± 155	25 ± 2	235 ± 41	0.43 ± 0.11
		Organic	2.62 ± 0.17	0.44 ± 0.05	3.89 ± 0.21	0.13 ± 0.04	0.21 ± 0.03	17 ± 1	2253 ± 112	16 ± 2	132 ± 58	1.61 ± 0.18
	Joe Muller and Sons	Conventional	3.00 ± 0.19	0.39 ± 0.03	3.39 ± 0.29	0.14 ± 0.02	0.26 ± 0.01	20 ± 1	2278 ± 140	20 ± 1	253 ± 41	0.32 ± 0.08
		Organic	2.27 ± 0.25	0.43 ± 0.04	4.57 ± 0.27	0.13 ± 0.02	0.22 ± 0.02	20 ± 2	2195 ± 172	14 ± 2	112 ± 21	0.90 ± 0.07
P-values for production system effects			0.015	0.009	0.017	0.043	NS	0.057	NS	<0.001	0.026	0.040
P-values for year effects			0.075	NS	NS	NS	0.080	NS	0.064	0.040	NS	0.036
Year × production system			NS	NS	NS	NS	NS	NS	NS	NS	0.043	NS
Estimates for organic production system where conventional = 0			−0.47	0.07	0.52	−0.01	–	−2	–	−7	−94	1.48

Table 9. Petiole and soil parameters

			Petiole macronutrients			Soil					
			(%)				(%)				
			N	P	K	pH	OM	TKN	Sand	Silt	Clay
2006	Terranova Farms	Conventional	2.22 ± 0.29	0.19 ± 0.01	0.69 ± 0.23	7.2 ± 0.2	0.95 ± 0.09	0.08 ± 0.01	63 ± 6	26 ± 4	12 ± 3
		Organic	2.14 ± 0.32	0.27 ± 0.06	1.13 ± 0.13	8.0 ± 0.1	0.83 ± 0.04	0.06 ± 0.00	51 ± 4	36 ± 2	14 ± 1
	Button and Turkovich	Conventional	2.89 ± 0.35	0.22 ± 0.04	0.97 ± 0.32	6.3 ± 0.1	1.11 ± 0.13	0.09 ± 0.01	39 ± 8	35 ± 5	27 ± 4
		Organic	2.48 ± 0.18	0.24 ± 0.01	0.99 ± 0.29	6.8 ± 0.3	1.26 ± 0.14	0.12 ± 0.02	27 ± 13	34 ± 1	39 ± 13
	Rominger Brothers Farms	Conventional	2.72 ± 0.57	0.25 ± 0.03	1.33 ± 0.41	6.3 ± 0.1	1.24 ± 0.25	0.09 ± 0.01	42 ± 6	32 ± 4	27 ± 3
		Organic	2.67 ± 0.31	0.29 ± 0.02	1.73 ± 0.26	6.7 ± 0.1	0.11 ± 0.01	1.38 ± 0.12	30 ± 5	39 ± 4	31 ± 2
2007	Rominger Brothers Farms	Conventional	3.48 ± 1.00	0.25 ± 0.07	1.42 ± 0.68	6.2 ± 0.2	0.87 ± 0.10	0.09 ± 0.00	25 ± 2	42 ± 2	34 ± 1
		Organic	2.00 ± 0.32	0.23 ± 0.02	0.78 ± 0.42	6.7 ± 0.1	1.41 ± 0.10	0.13 ± 0.00	21 ± 4	48 ± 2	32 ± 2
	Joe Rominger	Conventional	2.62 ± 0.35	0.21 ± 0.03	0.99 ± 0.56	6.3 ± 0.1	1.10 ± 0.10	0.11 ± 0.00	21 ± 9	46 ± 5	33 ± 3
		Organic	2.90 ± 0.85	0.27 ± 0.09	1.32 ± 0.57	6.6 ± 0.1	0.94 ± 0.10	0.10 ± 0.00	23 ± 1	43 ± 2	35 ± 1
	Joe Muller and Sons	Conventional	2.07 ± 0.15	0.20 ± 0.02	0.36 ± 0.05	7.1 ± 0.2	1.45 ± 0.10	0.12 ± 0.00	23 ± 2	49 ± 2	29 ± 1
		Organic	1.95 ± 0.13	0.23 ± 0.04	1.09 ± 0.10	7.5 ± 0.1	2.94 ± 0.40	0.20 ± 0.00	8 ± 1	60 ± 1	32 ± 2
P-values for production system effects			NS	0.059	NS	0.001	NS	NS	0.018	NS	NS
P-values for year effects			NS	NS	NS	NS	NS	NS	0.048	0.015	NS
Year × production system			NS	NS	NS	NS	NS	NS	NS	NS	NS
Estimates for organic production system where conventional = 0			–	0.03	–	0.47	–	–	−8.84	–	–

Table 10. Summary of significant differences between conventional and organic tomato fruit (+ = higher; − = lower)

Parameter	Organic	Conventional
Percentage of red tomatoes	−	+
Percentage of attached stems	+	−
Hunter *b* values	+	−
Yellow-eye disorder	−	+
Soluble solids (°Brix)	+	−
Total solids	+	−
Moisture content	−	+
Consistency	+	−
Glutamate	−	+
Glutamine	−	+
Tyrosine	−	+
Total nitrogen	−	+
Ammonium	−	+
Phosphorus	+	−
Potassium	+	−
Calcium	−	+
Boron	−	+
Manganese	−	+
δ^{15}N	+	−
Soil pH	+	−

Remarks on previous literature

The results of this study suggest that differences in physiological maturity at time of harvest may be responsible for some of the discrepancies seen in the literature. Conventional and organic crops given the same amount of time to grow and develop may not be identical in terms of their physiological maturity. It is important to note that even if fruits or vegetables are 'hand-picked' to obtain similar products by color, size, or another maturity index, the actual age of the fruit or vegetable may differ, and this can have an effect on product quality and nutritional status.[19]

Another reason for the contradictory results reported may be due to reporting parameters solely on a fresh weight basis. Several studies have reported statistically significant differences between organic and conventional products on a fresh weight basis, only to find the significance disappears when results are reported on a dry weight basis.[10,26] Lombardi-Boccia *et al*. reported higher levels of vitamin C, E, and flavonols in organic tomatoes; however, the results were all expressed on a fresh weight basis.[36] Similarly, Amodio *et al*. reported higher levels of ascorbic acid and total phenolics in organic kiwi fruit.[37] Pérez-López *et al*. reported higher vitamin C, phenolic compounds, and carotenoids in sweet pepper fruits.[38] All of these studies reported values only on a fresh weight basis. Moisture content was significantly lower in the organic tomatoes in this study, which is consistent with reports in the literature.[39,40] It is thus crucial when studying the impact of production systems to consider moisture content and report results on a dry weight basis.

Future studies should address issues surrounding potentially different maturation and ripening rates between organic and conventional crops, and may also include measures of vegetative growth and foliage shading. Furthermore, since year-to-year and grower-to-grower variability can be highly significant, it is important that future comparisons of organic and conventional products include multiple growers and years.

CONCLUSIONS

Several quality parameters were significantly different between conventional and organic production systems (Table 10). Percentage of red tomatoes was significantly lower in organic fields, while the percentage of attached stems was significantly higher. Hunter *b* values were significantly higher in organic tomatoes. The yellow-eye disorder was more prevalent in conventional tomatoes. Soluble solids and total solids were significantly higher and moisture content was lower in organic tomatoes. Bostwick consistency values were lower, indicating greater consistency in organic tomatoes. Glutamate, glutamine, and tyrosine levels were significantly higher in conventional tomatoes, as were total nitrogen and ammonium concentration. Phosphorus and potassium levels were higher, while calcium, boron, and manganese were lower in organic fruit. Nitrogen isotope composition was significantly different by production systems, with organic tomatoes having higher values of δ^{15}N. The pH of the soil at time of harvest was also significantly higher in organic fields. The primary nutritional parameters studied, vitamin C, lycopene, and rutin, did not differ significantly by production system.

Significant year-to-year variation was observed in the percentages of red, green, and limited-use tomatoes and in Hunter *a* values. Levels of dehydroascorbic acid and rutin in canned tomato sauce varied significantly by year. Levels of several amino acids, including glutamate and glutamine, and δ^{15}N values were also significantly different by year. The fact that different fields were sampled each year resulted in findings of significant year-to-year differences in soil composition.

The finding that conventional tomatoes appeared to reach full maturity more quickly than organic tomatoes has a significant impact on the study of quality and nutritional parameters in organic and conventional foods. In addition, the higher moisture content in conventional tomatoes provides reason to question previous findings that reported results only on a fresh weight basis. The mechanisms that may explain these significant results are not clear, and may depend on a number of factors. Because maturity and moisture content have a significant effect on actual and/or apparent quality and nutritional content, these fundamental parameters should be considered for any comparison of organic and conventional crops.

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