Qualitative and Nutritional Differences in Processing Tomatoes Grown under Commercial Organic and Conventional Production Systems

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ABSTRACT: Organically grown products experienced a doubling in percent penetration of organic sales into retail markets during the period from 1997 to 2003; however, there is still a debate over the perceived quality advantage of organically grown fruits and vegetables. In a study focusing on commercial production of processing tomatoes, samples were analyzed from 4 growers with matched organic and conventional fields. For the 4 growers studied, individual analysis of variance results indicated that tomato juice prepared from organically produced tomatoes on some farms was significantly higher in soluble solids (°Brix), higher in consistency, and titratable acidity, but lower in red color, ascorbic acid, and total phenolics content in the microwaved juice. Results were significantly different among specific growers, and this may be attributed to differences in soil type and soil nutrients, tomato cultivar, environmental conditions, or other production-related factors. Higher levels of soluble solids, titratable acidity, and consistency are desirable for the production of tomato paste, in that tomatoes with these attributes may be more flavorful and require less thermal treatment. This has the potential to result both in cost savings from less energy required in paste manufacture and potentially a higher quality product due to less thermal degradation of color, flavor, and nutrients. Future work may involve a larger number of commercial growers and correlation to controlled university research plots.

Keywords: conventional, nutrition, organic, processing, quality, tomatoes

Introduction

In a recent study on factors affecting food choice with respect to fruit and vegetable intake (Pollard and others 2002), it was found that personal ideologies resulted in consumers buying an increasing percentage of organic products, despite rising costs. Of consumers who buy organic produce, a survey commissioned by the Soil Assn. and Baby Organix (The Soil Assn. 1999) found that 43% of people bought organic because of preferred taste, 28% because it is environmentally friendly, and 24% because it is animal welfare friendly. In addition, many consumers perceive that organically grown products are more healthy than conventional, although the research on this aspect is not conclusive.

There is scientific evidence that organically grown crops contain higher mineral and vitamin content (Worthington 1998), higher antioxidant content (Woese and others 1997; Weibel and others 2000; Heaton 2001; Asami and others 2003; Chassy and others 2006), and better flavor (Weibel and others 2000; Reganold and others 2001) than crops produced using conventional production systems. In addition, there is concern by some authors that the antioxidant content of foods grown using conventional production systems is lower than optimal for human health (Woese and others 1997).

Other studies have resulted in conclusions that differences in quality and nutritive value of organically and conventional grown foods are inconsistent or unsubstantiated (Woese and others 1997; Worthington 1998; Bourn and Prescott 2002). In recent reviews of quality comparison studies between organic and conventional foods, Woese and others (1997), Worthington (1998), Brandt and Molgaard (2001), Heaton (2001), and Bourn and Prescott (2002) suggest that interpretation of the results of these investigations is difficult because of methodological differences related to cultivar selection, growing conditions, and sampling and analytical methods. In a recently published Scientific Status Summary by the Inst. of Food Technologists (Winter 2006), the author concludes that it is premature to say that either organic or conventional food systems are superior with respect to safety or nutritional composition.

Although the quality and potential nutritional benefits of organically grown foods are still being studied, the Organic Trade Assn. has reported that recent growth in sales of organic products has been 20% per year (Organic Trade Assn. 2004). The most common point of entry for consumers new to organic products are fruits and vegetables. The Economic Research Service reports that there has been a doubling in the percent penetration of organic sales into retail markets in the most recently documented 6-y period, for example, from 2% in 1997 to 4% in 2003 (Economic Research Service 2005a).

According to the California Dept. of Food and Agriculture (Klonsky and Richter 2007), tomatoes are 6th in the top 10 organically grown commodities produced in the state, with the combination of fresh and processing tomato varieties representing $11 million in sales in 2003 (Economic Research Service 2005b). Ninety-three percent of the organic tomatoes sold in the United States in 2003 originated from California farms (Economic Research Service 2005a). Acreage of processing tomatoes in California has increased from 2232 to 4108 in the period from 1998 to 2003 (Klonsky and Richter, in press) and the number of organic growers has risen in the same period from 33 to 41. Farm level sales of organically grown

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processing tomatoes have gone from $4.6 million in 1998 to $5.3 million in 2003 (Economic Research Service 2005b).

The objective of this study was to compare the quality and nutritional value of processing tomatoes grown on matched commercial grower fields in California. Several tomato fruit quality components, including °Brix, pH, titratable acidity, color, ascorbic acid content, total phenolic content, consistency, and sensory quality, were compared in processing tomatoes grown by conventional production systems and certified organic production systems. Commercial scale processing tomato growers experienced in growing organic tomatoes were collaborators on these trials, and soil samples were taken prior to planting in order to substantiate that soil types on organic and conventional fields on the same farm were similar. Soil samples were also taken after fruit set in order to determine the correlation between soil characteristics and fruit quality.

Materials and Methods

Grower field statistics and selection of sites

In 2003, tomatoes were grown on 4 pairs of matched fields in the California Central Valley. Each field pair consisted of matched organic and conventional fields. In order to assure that soil type, topography, and other dominant soil characteristics were the same for each field pair, research sites were selected using U.S. Dept. of Agriculture–Natural Resources Conservation Service (USDA–NRCS) soil scientist evaluations prior to planting. The soil profile in each field was examined using soil sample cores to a depth of at least 102 cm (Table 1). This allowed research sites to be selected so that soil type, topography, and other soil characteristics would not likely be significant factors in the comparison of tomato fruit quality components between field pairs. Each matched field pair of organic and conventional tomatoes had the same grower, same soil type, same tomato cultivar, same planting date, same irrigation method, and a very similar harvest date (Table 2). Three growers (Harris, O'Neill, and Terranova) from Fresno County and 1 grower (Rominger) from Yolo County, representing major processing tomato regions in California, participated in this study.

Production inputs. Design of this study attempted to control for grower skill, soil type, tomato cultivar, planting date, irrigation method, and harvest date within each field pair, but the production systems were substantially different between farms (Table 3). All organic fields in this study were farmed in accordance with the USDA

Table 1 — USDA-NRCS evaluation of soil properties in organic and conventional fields at 4 farms in California.[a]

Grower	Location	Production system	Soil type	Horizon	Depth (cm)	Soil texture
Harris Farms	Coalinga	Organic	Kimberlina sandy loam	Ap	0 to 17.8	Sandy loam
				A	17.8 to 50.8	Sandy loam
				C1	50.8 to 63.5	Sandy loam
				C2	63.5 to 76.2	Sandy loam
				C3	76.2 to 88.9	Sandy loam
				C4	88.9 to 101.6	Sandy loam
		Conventional	Kimberlina sandy loam	Ap	0 to 17.8	Sandy loam
				A	17.8 to 50.8	Sandy loam
				C1	50.8 to 71.1	Silt loam
				C2	71.1 to 101.6	Fine sandy loam
O'Neill Farming Co.	Five Points	Organic	Ciervo clay	Ap	0 to 38.1	Clay
				Bw	38.1 to 58.4	Clay
				Bk	58.4 to 83.8	Clay loam
				Bzn	83.8 to 101.6	Clay loam
		Conventional	Ciervo clay	Ap	0 to 30.5	Clay loam
				Bw	30.5 to 45.7	Clay
				Bk1	45.7 to 68.6	Clay
				Bk2	68.6 to 81.3	Clay loam
				Bk3	81.3 to 101.6	Clay loam
Terranova Ranch	Helm	Organic	Pond fine sandy loam	Ap1	0 to 27.9	Loam
				Ap2	27.9 to 50.8	Loam
				Btkn1	50.8 to 76.2	Clay loam
				Btkn2	76.2 to 91.4	Clay loam
				Bk	91.4 to 101.6	Loam
		Conventional	Pond fine sandy loam	Ap1	0 to 27.9	Loam
				Ap2	27.9 to 45.7	Loam
				Btkn	45.7 to 71.1	Clay loam
				Bk1	71.1 to 86.4	Loam
				Bk2	86.4 to 101.6	loam
D.A. Rominger & Sons	Winters	Organic	Brentwood silty clay loam	Ap1	0 to 17.8	Silty clay loam
				Ap2	17.8 to 30.5	Silty clay loam
				B21	30.5 to 45.7	Heavy silty clay loam
				B22	45.7 to 55.9	Silty clay loam
				B3	55.9 to 81.3	Silt loam
				BC	81.3 to 106.7	Silty clay loam
				C	106.7 +	Heavy silty clay loam
		Conventional	Brentwood silty clay loam	Ap	0 to 27.9	Silty clay loam
				B21	27.9 to 50.8	Silty clay loam
				B22	50.8 to 61	Silty clay loam
				B3	>61 to 96.5	Heavy silt loam
				C1	96.5 to 111.8	Silty clay loam/clay loam
				C2	111.8 +	Heavy clay loam

[a]Soil evaluation carried out by USDA-NRCS soil scientists Kerry Arroues and Jim Komar.

Table 2—Organic and conventional tomato production system characteristics for 4 farms in California.

Grower and production system	Location	Tomato cultivar	Planting type	Planting date	Irrigation method	Organic certification	Years farmed	Harvest sample date	% Ripe fruit by weight	Sensory sample date	Yield (kg/ha)
Harris Farms	Coalinga										
Organic		HyPeel 45	Transplants	4/4/2003	Drip	1996	30+	8/5/2003	95	8/5/2003	68.38
Conventional		HyPeel 45	Transplants	4/10/03	Drip	—	30+	8/5/2003	90	8/5/2003	59.64
O'Neill Farming Co.	Five Points										
Organic		Rogers 1570	Seed	1/30/2003 to 1/31/2003	Furrow	1991	50+	7/23/2003	87	7/22/2003	85.42
Conventional		Rogers 1570	Seed	1/31/03 to 2/4/03	Furrow	—	50+	7/22/2003	96	7/22/2003	108.51
Terranova Ranch	Helm										
Organic		Bos 315	Transplants	3/22/2003	Furrow	1997	45+	7/29/2003	89	7/29/2003	77.80
Conventional		Bos 315	Transplants	3/22/2003	Furrow	—	45+	7/22/2003	87	7/29/2003	76.45
D.A. Rominger & Sons	Winters										
Organic		HM 830	Transplants	3/31/2003 to 4/1/2003	Furrow	1996	70+	7/30/2003	94	8/6/2003	96.41
Conventional		HM 830	Transplants	3/31/2003	Furrow	—	70+	6/8/2003	96	8/6/2003	109.86

National Organic Standards. The organic crop production methods included (1) soil building with compost, manure, and/or cover cropping; (2) weed control with mechanical cultivation and hand hoeing; (3) plant disease control with copper and sulfur; and (4) insect pest management with biological control methods. The conventional crop production methods included (1) fertilization with synthetic chemical fertilizers (NPK); (2) weed control with synthetic chemical herbicides; (3) plant disease control with copper, sulfur, and synthetic chemical fungicides; and (4) insect pest management with synthetic chemical insecticides.

Research plot designation. Each research area was 11 beds wide (1.52- to 1.68-m beds) by 91.5 m long, approximately 0.2 ha in size. Research areas were oriented in the same north–south–east–west direction in each field pair. Within each research area, 88 plots were established with each plot being 1 bed wide by 0.12 m long. Eight plots within each field's research area were randomly selected for data collection. The selected plots were matched for each field pair.

Soil sampling. Prior to choosing the organic and conventional fields to be used at each grower location, soil samples were taken from 4 randomly selected research plots within each field's research area to determine whether organic and conventional fields were properly matched by soil type. Tomatoes were planted in closely matched fields, and after fruit set, additional soil samples were taken for comparison to and correlation with fruit quality. In each plot, 12 subsamples were taken with an Oakfield soil sampling tube (1.9-cm diameter) from a depth of 0 to 10.2 cm. Soil subsamples were composited, air dried, and analyzed by the Division of Natural Resources Analytical Laboratory at the Univ. of California, Davis. Methods may be found on-line at http://danranlab.ucanr.org.

Soil salinity and alkalinity measurements included pH, cation exchange capacity, estimated soluble salts, sodium absorption ratio, and exchangeable sodium percentage. A saturated paste extract was prepared and the following were also measured: HCO_3, Ca, Mg, Na, and Cl. Soil fertility measurements included soil nitrate and extractable ammonium, total Kjeldhal nitrogen, and extractable potassium using the Olsen method. The following micronutrients were extracted with diethylenetriaminepentaacetic acid: Zn, Mn, Fe, and Cu. In addition, determination of exchangeable minerals (X-K, X-Ca, X-Mg, X-Na) was carried out. The following physicochemical characteristics were evaluated: organic matter and particle size analysis (sand/silt/clay).

Tomato sample harvesting. At harvest, 4.54 kg of red ripe fruit were hand harvested from each of the 8 research plots in each field (Table 2) and delivered the same day to the Univ. of California, Davis, Food Science and Technology laboratory for analysis of fruit quality components. In addition, approximately 5.44 kg of red ripe tomatoes were collected at a later date from each of 4 randomly selected research plots in each field and delivered for sensory analysis. Sensory samples were collected on the same date for each field pair.

Tomato quality analysis

Moisture content. Moisture content in the raw tomatoes was analyzed according to the Assn. of Official Analytical Chemists (AOAC) vacuum oven method (AOAC Intl. 2000) on organic and conventionally grown tomatoes. Triplicate moisture measurements were made on approximately 3-g samples from each of the 4.54-kg samples harvested.

Microwave hot break process. A microwave hot break method developed in the Dept. of Food Science & Technology at the Univ. of California, Davis (Leonard and others 1980) was used as a rapid means of simulating an industrial hot break, or thermal step that is utilized to inactivate enzymes. Enzyme inactivation serves to stabilize the tomato juice to a certain degree and prevent enzyme-catalyzed changes in viscosity, color, flavor, and nutrient content. Predictive equations were previously developed by Leonard and others (1980) to correlate measurements on microwaved tomato juice to catsup yield. Catsup yield is calculated using the following equations (Leonard and others 1980):

$$\text{Paste yield} = 908\text{ kg} * \text{tomato juice }^\circ\text{Brix} / 28\,^\circ\text{Brix}$$

$$\%\text{ tomato solids} = 7.388 + 1.015(\text{paste Bostwick}) - 0.0138(\text{paste Bostwick})$$

$$\text{Catsup yield} = 908\text{ kg} * \text{tomato juice }^\circ\text{Brix} / \%\text{ tomato solids}$$

Tomatoes were washed, towel dried, and sorted for defects, then cut in half for determination of quality factors on the microwave break juice. One half of each fruit was placed in a Pyrex dish to achieve a net weight of approximately 1300 g. The dish was immediately weighed, covered, and microwaved in a commercial (1400 W) microwave oven for 6 min at 100% power, followed by 6 min at 50% power. After cooking, the dish was placed in ice water to cool. Cooled samples were reweighed, and water was added to compensate for evaporative losses during cooking. Seeds and skins were extracted using a lab pulper with a 0.033-inch screen.

Titratable acidity, pH, °brix, Bostwick, and color measurements. Following the microwave treatment, pulped juice samples were evaluated for titratable acidity using titration with NaOH (AOAC Intl. 2000). The remaining juice was deaerated and the temperature adjusted to 25 ± 0.2 °C, then used for determination of pH and °Brix (soluble sugars). Independent duplicate Bostwick consistency readings were obtained on each sample (Barrett and Anthon 2001). Readings reported are the distance (cm) that a volume of juice of fixed dimension flowed in a trough in 30 s. A smaller reading corresponds to less flow or a product of higher consistency.

Color (HunterLab, Reston, Va., U.S.A.) values were also measured on microwaved deaerated juice. Instrumental color measurements

Table 3—Pesticide and fertilizer use by grower and production system.

Grower	Production system	Soil fertility materials/methods	Fertility materials rate	Pest control materials/methods	Pest control materials rate (a.i.)
Harris Farms	Organic	Cow manure	13452 kg/ha	Copper hydroxide	1.73 kg/ha
		Chicken manure	11210 kg/ha	*Bacillus thurengiensis*	0.064 kg./ha
		Compost	6726 kg/ha	Sulfur	33.6 kg/ha
	Conventional	Urea ammonium nitrate	19.1 kg/ha (N)	Rimsulfuron herbicide	0.0058 kg/ha
		Urea ammonium nitrate	168 kg/ha (N)	Rimsulfuron herbicide	0.0058 kg/ha
		10-34-0 (NPK)	1.26 kg/ha (N); 4.8 kg/ha (P_2O_5)	*Bacillus thurengiensis*	0.01 kg/ha
				Tebufenozide insecticide	0.175 kg/ha
				Bacillus thurengiensis	0.064 kg/ha
				Indoxacarb insecticide	0.074 kg/ha
				Sulfur	38.5 kg/ha
				Indoxacarb insecticide	0.074 kg/ha
				Pyraclostrobin fungicide	0.168 kg/ha
				Esfenvalerate insecticide	0.055 kg/ha
O'Neill Farming Co.	Organic	Winter wheat cover crop		*Bacillus thurengiensis*	0.023 kg/ha
		Compost	11210 kg/ha		
		Bird guano	41.5 kg/ha		
		Chilean nitrate	24.7 kg/ha		
	Conventional	11-52-0 (NPK)	37 kg/ha (N); 175 kg/ha (P_2O_5)	Rimsulfuron herbicide	0.0106 kg.ha
		Aqua ammonia	84 kg/ha (N)	Trifluralin herbicide	0.713 kg/ha
		10-34-0 (NPK)	1.4 kg/ha (N); 4.8 kg/ha (P_2O_5)	Copper hydroxide	1.34 kg/ha
		Urea ammonium nitrate	123.3 kg/ha (N)	Maneb fungicide	1.35 kg/ha
		Calcium ammonium nitrate	23.5 kg/ha (N)	Sulfur	43.9 kg/ha
		Urea ammonium nitrate	97.5 kg/ha (N)	Indoxacarb insecticide	.074 kg/ha
Terranova Ranch	Organic	Chicken manure	15694 kg/ha	Copper hydroxide	1.73 kg/ha
		Chicken compost	38114 kg/ha	Sulfur	43.7 kg/ha
	Conventional	11-52-0 (NPK)	31.4 kg/ha (N); 145.7 kg/ha (P_2O_5)	Rimsulfuron herbicide	.058 kg/ha
		Mg & B micronutrients		Copper hydroxide	1.37 kg/ha
		Urea ammonium nitrate	140 kg/ha (N)	Sulfur	43.7 kg/ha
		Urea ammonium nitrate	134.5 kg/ha (N)		
		Urea ammonium nitrate	67.3 kg/ha lbs./A (N)		
D.A. Rominger & Sons	Organic	Turkey manure	15694 kg/ha	Copper hydroxide	3.45 kg/ha
				Copper hydroxide	3.45 kg/ha
				Sulfur	33.6 kg/ha
	Conventional	11-52-0 (NPK)	12.3 kg/ha (N); 58.3 kg/ha (P_2O_5)	Glyphosate herbicide	0.91 kg/ha
		8-24-5 (NPK)	1.1 kg/ha (N); 3.3 kg/ha (P_2O_5)	Trifluralin herbicide	0.56 kg/ha
		Zinc micronutrient		Maneb fungicide	0.598 kg/ha
		28-0-0-5 (NPKS)	15.7 kg/ha (N)	Copper hydroxide	1.75 kg/ha
		Urea ammonium nitrate	78.5 kg/ha (N)	Esfenvalerate insecticide	0.185 kg/ha
				Rimsulfuron herbicide	0.058 kg/ha
				Maneb fungicide	0.598 kg/ha
				Copper hydroxide	1.75 kg/ha
				Sulfur	33.3 kg/ha

were made on juice samples placed in glass sample cups. L (white to black or light to dark), a (green to red), and b (yellow to blue) measurements were taken with a Hunter colorimeter. The colorimeter was calibrated with a white tile and a standard tile of a color similar to that of the sample. L, a, and b values were determined by averaging the results of 3 independent readings per sample. From the L, a, and b values, USDA tomato scores were calculated. In addition, overall color was measured on microwaved deaerated juice using a light emitting device (LED), a standard colorimeter used by the California tomato (Valero and others 2003).

Lycopene. A modification (Barrett and Anthon 2001) of the method published by the AOAC (2000) was used for lycopene analysis. First, 100 μL of microwaved tomato juice was pipetted into a screw cap tube using a 100-μL Drummond micropipettor. Then 7.0 mL of 4:3 (v/v) ethanol:hexane was added, the tube was capped, vortexed, then incubated, out of bright light, with occasional vortexing. After 1 h, 1.0 mL water was added to each sample and then shaken briefly. Samples were allowed to stand 10 min to afford phase separation and dissipation of air bubbles. A sample of the hexane layer was read at Abs 503 compared with hexane in the spectrophotometer (Shimadzu, Japan). Lycopene levels in the hexane extracts were then calculated according to:

$$\mu\text{g lycopene/g fresh wt.} = (A_{503} \times 537 \times 2.7)/(0.1 \times 172) = A_{503} \times 84.3$$

where 537 g/mole is the molecular weight of lycopene, 2.7 mL is the volume of the hexane layer, 0.1 g is the weight of sample added, and 172 mM^{-1} is the extinction coefficient for lycopene in hexane. Duplicate samples were analyzed.

Ascorbic (reduced) and dehydroascorbic (oxidized) acid. Raw and microwaved tomato juice samples were analyzed for ascorbic acid, dehydroascorbic acid, and total phenolics. Ascorbic acid was determined using a spectrophotometric method (Latapi and Barrett 2006). One gram of sample was homogenized with distilled water using a Polytron (Brinkmann Instruments Inc., Model PCU11, Westbury, N.Y., U.S.A.) until a thick paste was obtained. The paste was centrifuged and the supernatant removed for analysis. In a 3-mL cuvette, 2.5 mL of 0.1M sodium phosphate, pH 6.5, 0.1 mL of sample, 0.4 mL of water, and 0.5 mL of 1.0 mg/mL horseradish peroxidase (Sigma Type II) were mixed. The sample was read at Abs 265 in a spectrophotometer (Shimadzu, Japan) to determine total ascorbic acid, 50 mM hydrogen peroxide was added, and the sample was read again after it reached a stable absorbance value at 265 nm to determine oxidized or dehydroascorbic acid. Ascorbic acid content was expressed as mg/g dry weight. Measurements were performed in triplicate.

Total phenolics. Total phenolics concentrations were measured on raw and microwaved tomato juice using the Folin–Ciocalteu assay. Five milliliters acetone, 0.5 mL sample, and 1.0 mL Folin–Ciocalteau reagent were added to a 25-mL volumetric flask. The contents were mixed and allowed to stand for 5 to 8 min at room temperature. Ten milliliters of 7% sodium carbonate solution was added, followed by the addition of Nanopure water filled to volume. Solutions were mixed and allowed to stand at room temperature for 2 h. Sample aliquots were filtered through a Whatman 0.45-μm polytetrafluoroethylene filter prior to the determination of total phenols concentration using a spectrophotometer (Shimadzu) monitoring Abs 750 nm. Total phenolics content was standardized against gallic acid and expressed as gallic acid equivalents (GAE). The linearity range for this assay was determined as 0.5 to 5.0 mg/μL GAE ($R^2 = 0.9990$) giving an absorbance range of 0.050 to 0.555 AU.

Diced tomato texture. Approximately 10 tomatoes were diced and mixed, and firmness was analyzed (Garcia and Barrett 2006) in triplicate 200-g samples using a Kramer shear cell and a TA.XT2 Texture Analyzer (Texture Technologies, Scarsdale, N.Y., U.S.A.). Average values were calculated.

Sensory evaluation. Fresh, uncooked, diced tomatoes were analyzed for sensory quality using consumer preference tests. Samples were presented at random to over 100 untrained panelists. Samples were evaluated for degree of liking on the 9-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Panelists were asked to comment on liking of color, texture, flavor, and overall quality. Data were analyzed by analysis of variance and the Fisher's least significance difference test was used to compare differences among means at the 0.05 level (Microsoft Excel 2000 for Windows computer software).

Evaluation of tomato peelability and product yield. Six batches of 20 clean, sorted tomatoes were weighed for each lot of fruit and peeled by exposure to live steam (30 psig) for 45 s in a pilot scale Odenberg (Odenberg, West Sacramento, Calif., U.S.A.) steam peeler. Following steam exposure, tomatoes were passed over pilot scale disc and pinch rollers. Peelability was classified using a subjective rating system (Barrett 2001), and those with little or no peel were designated as "peeled." Peeled fruits were weighed and percentage whole peel yield was determined. Values of percentage peeled and percentage whole peel yield for the 6 replicate processing batches were averaged.

Statistical analysis

Data were first analyzed using multivariate analysis of variance (MANOVA) models within SAS (SAS Inst., v. 9.1, 2002, Cary, N.C., U.S.A.) "proc glm." MANOVA models differ from regular ANOVA models in that there is more than 1 outcome. In MANOVA models there is less probability of false claims of statistical significance, and the models are consistent for all outcomes (Johnson and Wichern 1998). Multivariate F values (Wilk's Lambda, Pillai's Trace, Hotelling Lawley Trace, and Roy's Greatest Root) were obtained based on a comparison of the error variance/covariance matrix and the effect variance/covariance matrix. Growers were treated as a "fixed" effect; that is, the results are true for the specific growers that were studied and cannot be generalized to the general population of conventional or organic tomato growers. In order to generalize results to the general population, the growers would need to be treated as a random effect. In this study, the use of growers as a random effect would have provided low statistical power for the effects of interest.

After doing the overall MANOVA to see general trends and eliminating insignificant terms, we looked at individual quality parameters using individual or "protected" ANOVAs to determine whether they contributed to the overall significant difference. Means comparisons were performed using least squares (LS) means tests (SAS 2002, SAS Inst.). This allowed us to compare organic and conventional production systems at individual grower locations. We used unadjusted comparisons to maintain statistical power.

Twenty-two different soil characteristics were analyzed. We provide comparisons among growers for each of these characteristics. It was also of interest to determine whether the soil characteristics could account for any observed differences in tomato quality attributes. However, because soil samples were taken from only 4 field locations, it was only possible to use the same 4 (rather than all 8) location-specific samples taken for quality analysis. Principal component analysis (PCA) was used to reduce the number of soil variables to those that were best able to discriminate the 4 growers and those that discriminated conventional and organic production practices (Johnson and Wichern 1998). When quantitative explanatory variables are added to a MANOVA model, the resulting model is referred to as multivariate analysis of covariance (MANCOVA).

Results and Discussion

The 4 grower fields utilized in this study differed in soil type and texture (Table 1), with sandy loam soil in the Harris and Terranova farms and clay soil in the O'Neill and Rominger farms. There were also differences in the tomato cultivar planted, planting type, and irrigation method (Table 2) among growers. The cultivar was selected by each specific grower, and in this study a different cultivar was planted by each of the grower participants. O'Neill direct seeded while the other 3 growers planted transplants. In addition, there were differences in the irrigation methods utilized, with furrow irrigation predominating, but drip irrigation being used at Harris Farms. In terms of the production systems utilized, there were greater similarities in the production systems (whether organic or conventional) at a particular grower location than within the same production system (either organic or conventional) at different grower sites. This illustrates the challenge with conducting research on commercial farms. While scientists would like to evaluate successful production systems in a realistic environment, it is not practical to control production variables and one must acquire whatever information is possible within the constraints of grower prerogatives. Because there were only 4 growers included in this study, it was not possible to make global statements concerning the differences between quality of organic and conventionally grown tomatoes. Rather, the results discussed below will apply only to the 4 specific growers involved in this study.

Table 3 illustrates that even within commercial organic or conventional production systems, there were differences from grower to grower. For the most part, conventional production systems utilized urea ammonium nitrate as a fertilizer, but there were differences in pest control materials and rate of application. The organic soil fertility materials added differed more, with most growers using compost and chicken manure, 1 grower using turkey manure, and another grower a combination of cow and chicken manure. There were also differences in grower yield (Table 2), but it was not possible based on the data collected to conclude whether organic or conventional production systems yielded more kilograms per hectare. Although we attempted to harvest tomatoes at approximately 90% to 95% field maturity, there were some instances, in particular with Terranova Ranch and O'Neill Farming Co. (Table 2), where we were required to hand harvest before the field was 90% to 95% mature because growers had made a decision to machine harvest.

Most of the quality analyses carried out on the tomato samples were done following a microwave hot break treatment. This treatment simulates a commercial tomato paste hot break treatment, which targets the inactivation of endogenous enzymes that may affect quality, in particular the product consistency. While heating the tomato juice inactivates polygalacturonase, pectin methylesterase, and other quality-related enzymes, it can result in degradation of color and nutrients. For this reason, analysis of ascorbic acid, dehydroascorbic acid, and total phenolics was carried out on both raw and microwaved tomato juice.

The overall focus of this project was to determine if qualitative and nutritional differences existed between organically grown and conventionally grown processing tomatoes. Analysis of the MANOVA *F* values (Table 4) indicated that, for all parameters determined, both grower and production system (organic and conventional) were significant, as well as the interaction term, production system × grower. This means that there were differences between fruit produced by organic and conventional production systems, as well as among the 4 grower participants. Therefore, it was not possible to pool growers when evaluating the effect of production system nor was it possible to conclude that organically grown (or vice versa, conventional grown) tomatoes from 1 grower would have the same quality attributes as those grown by another grower.

Individual ANOVAs carried out using the general linear model on each quality variable (average of 8 field locations for each grower and production system) determined the Type III sum of squares (SAS 2002) values for grower, production system, and the interaction term production system × grower (data not shown). Because some of the data did not conform to the statistical assumption of normality of the errors, statistical transformations (log, rank, squared values) were used and are indicated in parentheses. We used 0.05 as our level of statistical significance. It must be stressed that the conclusions from these individual ANOVAs apply to the organic and conventional production systems in the 4 growers that participated in this study, and may not be extrapolated to the general population of growers.

Table 5 to 7 summarize the quality analyses made on organic and conventionally grown fruit, and the *P* values for grower, production system, and the production system × grower interaction. This interaction was significant ($P < 0.05$) for a number of attributes, including °Brix, pH, titratable acidity, catsup yield, *a* and *b* color values, USDA color, dehydroascorbic acid in raw tomato juice, ascorbic and dehydroascorbic acid in microwaved juice, lycopene, and phenolics levels in both raw and microwaved juice. Other as of yet unknown factors must have caused these differences.

On examination of the grower statistics at the bottom of Table 5 to 7, it is clear that there were significant differences ($P < 0.05$) among growers in °Brix, pH, titratable acidity, catsup yield, LED color, *L*, *a*, and *b* color values, USDA color, ascorbic and dehydroascorbic acid in the raw tomato juice, ascorbic acid and total phenolics in the microwaved tomato juice, and lycopene. Grower-specific differences that may affect tomato quality include microclimate, soil type, soil nutrients, irrigation method, moisture-holding capacity of the soil, number of years in cultivation, tomato cultivar, or other unknown factors. In the cases noted, this study was unable to determine why some quality attributes differed among growers.

There were significant differences ($P < 0.05$) between organic and conventional production systems in °Brix, titratable acidity (expressed as %citric acid), Bostwick consistency, catsup yield, LED color, Hunter *b* value, USDA color, dehydroascorbic acid in raw tomato juice, and ascorbic acid and total phenolics in the microwaved juice. This means that for these quality attributes there was a significant difference between tomatoes grown organically and those grown conventionally. The results from this study of 4 growers indicated that organically grown tomatoes on some farms were significantly higher in °Brix (positive), higher in titratable acidity (positive), lower in Bostwick (positive), higher in catsup yield (positive), lower in LED color (negative), lower in *b* value

Table 4—Multivariate analysis of variance (MANOVA) *F* values for grower, production system, and interaction of grower and production systems.

	Wilk's Lambda	Pillai's trace	Hotelling Lawley trace	Roy's greatest root
Grower	< 0.001	< 0.001	< 0.001	< 0.001
Production system	< 0.001	< 0.001	< 0.001	< 0.001
Grower × production system	< 0.001	< 0.001	< 0.001	< 0.001

(positive), and lower in ascorbic acid (negative) and phenolics (negative) in the microwaved juice.

Four different tomato cultivars were utilized in this study, a different cultivar at each grower location. While this is a good test of the effect of production system on a range of processing tomato varieties, it resulted in a confounding of cultivar and grower, and it may have been better from a statistical point of view to use the same cultivar at all grower locations. Woese and others (1997) stated that, in the case of apples grown under conventional and organic production systems, the differences among cultivars had a far greater influence on the composition of the apples than the different cultivation forms.

Grower specific differences in physicochemical properties of conventionally and organically grown tomatoes. Where overall *F* values were significant, pairwise comparisons between the organic and conventional production system at each grower location were made using least square means. These results are presented in Table 5 to 7. While general trends for the 4 grower participants may be obtained from inspection of the ANOVAs for individual quality attributes, it is necessary to use least significant differences (LSD) values to make specific comparisons between organically and conventionally grown tomatoes at each individual grower location.

There were no significant differences in sensory color, texture, flavor or overall quality, diced tomato texture or tomato peelability, and product yield when organically grown and conventionally grown tomatoes were compared. Diced tomato texture values (Table 5) ranged from 155 to 300 N, with a mean of 210 N, in the organic tomatoes, and from 188 to 412 N, with a mean of 260 N, in the conventionally produced tomatoes. The conventionally produced tomatoes were somewhat firmer at each farm site, and in the cases of Terranova and Rominger, these were statistically significant differences.

In comparing the peelability and whole peeled product yield, there were no significant differences between the 2 production systems (data not shown). Percentage of tomatoes peeled ranged from 20% to 95%, but replicate values from the same grower and production method were similar. Tomatoes grown under either production method at the Terranova farm had the highest percentage peeled (70% to 85%) while those grown at the Harris ranch had the lowest percentage peeled (20 to 30%). Although these locational differences appear important, there was no significant correlation between peelability and soil characteristics or production system at a particular farm.

The effect of the microwave thermal treatment on ascorbic acid, lycopene, and total phenolics, in particular, was determined prior to the initiation of this project on 3 samples of Halley 3155 cultivar tomatoes. The microwave process resulted in a decrease in the concentration of both ascorbic and dehydroascorbic acid, but did

Table 5—Physicochemical properties of conventionally and organically grown tomatoes.

Grower	Moisture (%)		°Brix		pH		T.A. (%)		Bostwick (cm)		Catsup Yield (kg)		Texture (N)*	
Harris Farms														
Conventional	94.57	a**	4.86	de	4.65	a	0.26	c	16.70	ab	370.80	cd	188.4	d
Organic	93.05	cd	5.11	cd	4.64	a	0.27	c	16.18	b	385.28	bc	155.7	d
O'Neill Farming Co,														
Conventional	93.28	c	5.06	d	4.47	c	0.31	b	16.13	b	383.89	bc	202.7	cd
Organic	94.76	a	5.03	d	4.55	b	0.30	b	15.68	b	389.95	bc	200.0	cd
Terranova Ranch														
Conventional	94.30	ab	5.56	b	4.32	d	0.31	b	16.30	b	399.49	b	238.1	c
Organic	92.84	d	5.96	a	4.52	bc	0.37	a	14.13	c	438.36	a	185.4	d
D.A. Rominger & Sons														
Conventional	94.48	a	4.66	e	4.70	a	0.21	d	18.22	a	344.73	d	412.8	a
Organic	94.35	ab	5.39	bc	4.52	bc	0.25	c	15.05	bc	409.06	b	300.3	b
Pr > *F*														
Grower			< 0.001		< 0.001		< 0.001		0.0539		< 0.001			
Production system			< 0.001		< 0.1553		< 0.001		0.0005		< 0.001		0.12	
Production System × Grower			< 0.007		< 0.001		0.0029		0.0844		0.0146			

*Texture is reported in Newtons, which is the amount of force required to accelerate a body with a mass of one kilogram at a rate of one m/s^2. 1 N = 1 kg m/s^2.
**Means in a column followed by the same letter are not significantly different at the 5% level of probability.

Table 6—Color of conventionally and organically grown tomatoes.

Grower	LED		Hunter *L*		Hunter *a*		Hunter *b*		USDA Color	
Harris Farms										
Conventional	22.3	d*	23.14	bc	26.12	bc	15.00	ab	44.4	d
Organic	21.6	ab	23.13	bc	26.35	bc	15.08	ab	44.5	d
O'Neill Farming Co.										
Conventional	21.7	bc	22.36	d	27.53	a	15.08	bc	45.6	b
Organic	21.8	abc	23.09	cd	26.24	bc	14.64	c	45.3	bc
Terranova Ranch										
Conventional	22.1	d	23.17	bc	27.77	a	15.24	a	45.6	b
Organic	21.3	a	23.42	ab	27.26	a	14.40	d	46.7	a
D.A. Rominger & Sons										
Conventional	22.5	d	23.61	a	25.87	c	14.67	c	44.8	cd
Organic	22.1	cd	23.51	a	26.63	b	14.84	bc	45.3	bc
Pr > *F*										
Grower	0.0029		< 0.001		< 0.001		0.0030		< 0.001	
Production system	0.0003		0.1813		0.2786		0.0020		0.0170	
Production system × grower	0.102		0.4024		< 0.001		< 0.001		0.0047	

*Means in a column followed by the same letter are not significantly different at the 5% level of probability.

Table 7 – Nutrient concentration (dry weight) of conventionally and organically grown tomatoes.

Grower	Ascorbic acid* raw* μg/g		Dehydro-ascorbic acid raw μg/g		Total AA+DHA raw μg/g	Ascorbic acid microwaved raw μg/g		Dehydro-Ascorbic acid microwaved μg/g		Total AA+DHA microwaved μg/g	Lycopene microwaved μg/g		Total phenolics raw μg/g		Total phenolics microwaved μg/g	
Harris Farms																
Conventional	1187	ab**	2306	b	3493	2211	ab	1184	abc	3395	1215	c	1803	ab	1943	a
Organic	1133	ab	1928	c	3061	1810	c	1031	bc	2841	1018	d	1483	d	1574	c
O'Neill Farming Co.																
Conventional	1739	d	1756	cd	3495	1155	d	1189	abc	2344	1426	b	1511	d	1530	cd
Organic	158	d	2448	b	2606	1302	d	1265	ab	2567	1641	a	1842	a	1858	ab
Terranova Ranch																
Conventional	863	bc	1918	c	2781	2016	bc	1277	a	3293	1569	a	1763	ab	1777	b
Organic	638	c	1587	d	2225	1319	d	989	c	2308	1254	c	1483	cd	1447	d
D.A. Rominger & Sons																
Conventional	1372	a	3031	a	4403	2455	a	1203	abc	3658	1214	c	1708	bc	1831	b
Organic	1153	ab	2242	b	3395	2258	ab	1236	ab	3494	1345	bc	1837	a	1811	b
Pr > *F*																
Grower	< 0.001		< 0.001			< 0.001		0.5156			< 0.001		0.1368		< 0.001	
Production system	0.15		0.0125			< 0.001		0.1803			0.2888		0.8785		< 0.001	

*Nutrient concentration was determined in raw and microwaved tomato juice.
**Means in a column followed by the same letter are not significantly different at the 5% level of probability.

not significantly affect the concentration of lycopene or total phenolics. Average ascorbic acid and dehydroascorbic acid concentrations in the raw tomatoes were 0.408 and 0.161 mg/100g while in microwaved juice they were 0.333 and 0.102 mg/100g, respectively. Average total phenolics concentrations were 100.5 μg/g and 103.0 μg/g in the raw and microwaved juices, respectively. Although a reduction in ascorbic acid resulted from the microwave process, it was felt that this preparative step was quite desirable for inactivation of enzymes that might cause an even greater reduction in quality; therefore, it was utilized.

Results for the physicochemical properties of conventionally and organically grown tomatoes are presented by individual grower in Table 5. There were significant differences in moisture content between tomatoes produced under conventional or organic production systems at all farms with the exception of Rominger; however, in 2 cases the moisture content of conventional tomatoes was higher and in 1 case the organic tomato moisture content was higher. Therefore, there was no consistent trend determined.

Over all, °Brix (soluble solids) of the tomatoes was higher under organic production systems in the grower group studied (Table 5). However, on inspection of LSD values between individual growers, it appears that °Brix was significantly higher under organic production systems at the Terranova and Rominger farms but not significantly different at the Harris and O'Neill farms. Although there were differences among growers, the interaction of production system × grower was not significant (Table 5).

Soluble solids content is an important tomato quality parameter, from both a sensory flavor standpoint and a tomato-processing standpoint. Tomato flavor is generally determined by the content of soluble solids, acid (measured as titratable acidity and expressed as % citric acid), and presence of various flavor volatiles in the tomatoes. Some of these flavor volatiles are generated through enzyme-catalyzed reactions (Anthon and Barrett 2003). Flavor volatiles were not analyzed in this study. There are differing opinions on the relative importance of these factors which contribute to flavor, but Jones and Scott (1984) found that flavor impact is related to total sugar and acid.

Soluble solids are important not only in terms of their contribution to flavor, but also, as mentioned previously, in terms of their relationship to processing requirements. It is desirable to produce tomatoes higher in soluble solids content because they will require less energy to evaporate water to a target final °Brix content. Tomato juice (approximately 4 to 6 °Brix) is typically concentrated to 27 to 31 °Brix prior to packaging for long-term bulk storage as tomato paste. The higher °Brix levels in tomatoes produced under organic production systems by the 4 growers in this study will result in reduced processing costs.

The individual ANOVA results (Table 5) indicated no significant differences in tomato pH values between production systems, but there were differences among growers. The pH values were higher in organic tomatoes than conventional at 2 grower locations, Terranova and O'Neill, but lower at the Rominger farm and the same at the Harris farm. Titratable acidity levels were higher in organically grown tomatoes, which may combine with the higher °Brix levels to contribute favorably to flavor impact (Jones and Scott 1984). As was the case with °Brix, in comparing the LSD values for specific growers, tomato citric acid content was significantly higher under organic production systems at the Terranova and Rominger farms, but not significantly higher at the Harris or O'Neill farms. Therefore, there was a significant effect associated with grower, but the production system × grower interaction was not.

The ratio of sugars to acids is something that may be used to indicate general flavor quality, and the fact that organically grown tomatoes in this study had higher soluble solids and higher titratable acidity indicates that they may have better flavor quality. The sensory evaluation study carried out with consumer panelists, however, did not find a significant difference in the flavor acceptability of the organic compared with conventionally grown tomatoes (data not shown). Such a difference, if it exists, might be determined by a descriptive sensory panel. The use of such a panel was beyond the scope of the present study, but may be something to consider in future research. There was a significant difference in Bostwick consistency among production systems in the 4 growers evaluated (Table 5), with organic production systems producing tomatoes with significantly lower Bostwick values, indicating a higher level of viscosity. Looking at individual growers, Bostwick values were significantly lower under organic production systems at the Terranova and Rominger farms, but not significantly different from conventional tomatoes at the other 2 farms. Bostwick is another important quality attribute in tomato processing, and it will often dictate what type of product tomatoes are intended for. Generally, higher Bostwick values are undesirable as this indicates a less viscous product. In some processed products, such as paste and sauce, a low Bostwick value is desirable, and breeding programs often target these varieties of tomatoes. Paste and sauce products are typically thick and do not separate on standing. For other products, however, such as whole peeled tomatoes, diced tomatoes, tomato juice, and tomato soup, having a viscous product with a low Bostwick value is not as critical. With these products, the target quality parameters are flavor and color, and the viscosity of the product is not so important. Therefore, from a Bostwick perspective, organically grown tomatoes may be more desirable than conventionally grown tomatoes for paste and sauce products.

Catsup yield differed significantly by both grower and production system, but the interaction of the two was not significant (Table 5). Within the 4 growers in this study, organic production systems produced higher catsup yield than conventional production systems. Inspection of the LSD values from the individual grower locations shows that catsup yield was significantly higher under organic production systems at the Terranova and Rominger farms, but not different at the Harris or O'Neill farms. Catsup yield is a value calculated from juice °Brix and juice Bostwick values. High catsup yield is a desirable processing tomato quality attribute and indicates that organically grown tomatoes may be better suited for producing catsup than conventionally grown tomatoes.

Grower specific differences in color of conventionally and organically grown tomatoes. Tomato color was determined using LED and Hunter tristimulus *L*, *a*, and *b* measurements and USDA tomato paste color value was calculated. There was a significant difference at the $P < 0.05$ level in LED values for tomato color both between the 2 production systems and among the 4 growers (Table 6). Inspection of LSD values of the LED color scores from individual growers revealed that tomatoes were significantly more red when grown under conventional production systems at the Terranova and Harris farms but not significantly different from organically grown tomatoes at the Rominger and O'Neill farms. In the California processing tomato industry, loads of harvested tomatoes are inspected by the Processing Tomato Advisory Board, a 3rd party inspection agency, prior to processing. A determination of whether the load is acceptable or not, and the price the grower is paid, are dictated by the grade given.

A more robust measurement of color is accomplished through use of tristimulus colorimeters. The *a* value is typically the most indicative for the intensity of red color in tomatoes, with higher *a* values more desirable. Table 6 indicates there were significant differences among growers ($P < 0.001$) in *L* and *a* value, and in the calculated USDA color score. The *b* value was significantly different among growers at the $P < 0.05$ level. There were significant differences between production system at the $P < 0.05$ level for both the *b* value and the USDA color score. Inspection of the tomato color differences among individual growers shows that that there were no significant differences in *L* value, but conventionally grown O'Neill tomatoes and organically grown Rominger tomatoes had significantly higher *a* values, or more red color, than their counterparts. The *b* values, which indicate increasing yellowness in the (+) direction, were significantly higher in conventionally grown Terranova tomatoes but were not significantly different at the other 3 farms. USDA color was significantly higher in organically grown Terranova tomatoes; but there were no significant color differences between conventional or organic fruit grown at the other 3 farms.

It may be most important to evaluate the results in terms of either LED value (currently used by the California tomato industry at inspection stations) or the *a* value (most common analytical laboratory parameter). In so doing, the LED result from the individual ANOVA statistics would conclude that conventionally grown fruit are more red, while the *a* value would show mixed results due to a significant interaction of production system and grower.

Grower specific differences in nutrient content of conventionally and organically grown tomatoes. Nutrient levels were also associated with both the production system (organic compared with conventional) and the individual grower (Table 7). Total ascorbic acid content (reduced ascorbic acid or AA and dehdryoascorbic acid or DHA) was generally lower in microwaved tomato juice as compared to raw. In almost all comparisons, the sum of reduced and oxidized forms of ascorbic acid was higher in tomatoes grown on conventional fields than those grown on organic at the same grower location.

On 2 farms, Terranova and Harris, conventional production systems produced higher values of ascorbic acid and lycopene in the microwaved juice. Terranova organically grown tomatoes had significantly lower levels of dehydroascorbic acid in the microwaved juice. Organically grown O'Neill tomatoes had significantly higher levels of lycopene, which is in contradiction to the lycopene results from the Terranova and Harris farms. Lycopene may be one attribute that shows an interaction between production system and grower. Total phenolics levels in the microwaved juice samples were significantly higher in organically grown tomatoes from 1 grower, O'Neill, but on 2 other farms (Terranova and Harris), the conventionally grown fruit had significantly higher levels of total phenolics.

Interestingly, tomatoes grown at the Rominger farm consistently showed no difference in lycopene, ascorbic acid, or total phenolics in the microwaved juice as an effect of production system. On the other hand, these 3 nutrients were always higher in conventional tomatoes grown at Terranova and Harris, and conversely higher (or the same) in organic tomatoes grown at O'Neill farm. If one examines the soil evaluations (Table 1), the Terranova and Harris Farms both had sandy loam soil, while the O'Neill tomatoes were grown on clay. The Rominger tomatoes (which showed no difference in nutrients) had a combination of silty clay and loam. There were also some differences in tomato cultivar and plant type (Table 2), and in fertilizers and pesticides used (Table 3) at these farms. The effect of organic and conventional production systems on nutrient levels requires additional investigation because the results appear to have an interaction with the specific farm studied.

Characterization of soil properties in organic and conventional production systems. The soil analysis was based on the 4 field locations where there were matched soil and quality samples taken; and it was not possible to pool data for "all organic" or "all conventional." Nor was it statistically valid to pool data for growers to determine the effects of these production-related factors.

Three principal components described the soil characteristics of the conventional and organic farms that were studied. These soil samples were taken in each field after fruit set and prior to planting. There was a significant difference between the Terranova farm and others in an ANOVA with PC1 as the outcome. Sodium content was relatively high in both conventional and organic soils at this farm, and Mg was high in organic soils, as compared to the other 3 farms. PC2 separated the 4 different growers, with the Harris farm being lower than others in some soil characteristics. PC3 separated the organic and conventional production systems.

Soils from conventional tomato production fields were generally higher in pH, exchange capacity, Ca, Na, and Cl. Organic production soils were higher in HCO_3, P, Mn, and Fe and moderately higher in K, N, and Cu. Therefore, it was possible to distinguish the 4 organic fields from their conventional counterparts in terms of these specific soil parameters. In a study comparing the major and trace elements in organic and conventional Danish agricultural crops, there were significant differences in element concentration mean values between organically and conventionally grown onions and peas (Gunderson and others 2000). These investigators also used PCA to separate the elements measured into 2 groups according to the cultivation method. In the case of onions, there were differences in some of the same elements evaluated in this study, in particular Ca (calcium). Svec and others (1976) found organically grown tomatoes to be higher in K than conventionally grown. Further research on the effects of these specific components on tomato quality and nutritional value may allow for an understanding of the mechanism by which organic production systems affect these attributes.

The ANCOVA (analysis of covariance) model using the PCs was compared to an ANOVA statistical model, in which all 22 soil characteristics were utilized. In 10 out of 18 outcomes (quality attributes), the models were not significantly different, according to the lack-of-fit test, meaning the 3 PCs were "representative enough" of the farms for those outcomes. These 10 quality attributes included lycopene, dehydroascorbic acid in the microwaved juice, catsup yield, Brix, pH, Bostwick, LED, *a* value, *b* value, and USDA value. The 8 attributes where it was not possible substitute the PCs for model with all of the soil data were T.A., ascorbic acid, dehydroascorbic acid, *L* value, raw and microwaved juice polyphenols. This means that it was possible to represent the differences in organic and conventional production systems by PC3, in particular, for some quality parameters, but not others.

Conclusions

The goal of this study was to compare the quality and nutritional value of processing tomatoes grown on matched organic and conventional farms at 4 commercial grower locations. While we were successful in our evaluation of tomatoes grown under these "real life" conditions, because we were only able to include 4 growers in the study, our conclusions are restricted to this specific group of growers. It was not possible to make statements concerning the differences between quality of organic and conventionally grown tomatoes. In retrospect, our statistical analysis would have been stronger had we selected a larger number (6 to 10) of growers and a smaller number (4) of sampling locations per field.

Within the grower group that we worked with, there were differences even within production system (for example, organic or conventional) in fertilizer and irrigation systems, methods of pest control and tomato cultivar planted. However, these preliminary results on a limited number of commercial growers indicated that there may be potential advantages to the use of organically grown tomatoes because of higher levels of soluble solids, titratable acidity and consistency. This study of 4 growers indicated that both higher flavor impact and reduced energy requirement for concentration of juice may result from use of organically grown tomatoes. Our study showed that conventionally produced tomatoes, on the other hand, were more red in color and the microwaved juice was higher in ascorbic acid and total phenolics.

One important result of this work was the finding that the agricultural production system is a critical factor in determining the quality of fruit produced. The potential exists to affect both positive and negative attributes of fruit quality through a better understanding of the production system, whether it be conventional, organic, or something else. Through this type of study it may be possible to identify major factors that influence quality.

In the future we will attempt to collect data from a larger number of commercial growers in order to improve our ability to make statistically valid conclusions about global differences between organic and conventionally grown tomatoes. In addition, we would like to attempt to correlate our findings in commercial systems with those in university-based research plots, where the production system may be better controlled in terms of fertilizer applications, soil type, irrigation system and methods of pest control. Only when we are able to separate out the influence of grower-specific inputs will it be possible to conclusively state whether there are differences in nutritional quality between organic and conventional systems or not.

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