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Fruit Quality and Bioactive Compounds with Antioxidant Activity of Tomatoes Grown On-Farm: Comparison of Organic and Conventional Management Systems

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Replicated field trials at three matched farm pairs in southern and central Taiwan were established in October 2004 and 2005 to compare fruit quality and nutritional parameters of tomatoes grown on-farm under organic versus conventional management systems in tropical and subtropical environments. Two processing tomato varieties were evaluated using a randomized complete block design at each of the farms. Aggregation of farms by type (organic vs conventional) across two years resulted in no significant differences between organic and conventional farming systems for all tomato fruit parameters measured, including quality (pH, soluble solids, acidity, and color), content of bioactive compounds with antioxidant activity (β-carotene, lycopene, ascorbic acid, and total phenolics), and antioxidant activity. This study indicated no consistent effect of the farming system on tomato fruit parameters. Farm management skills combined with site-specific effects contributed to high lycopene levels, and the choice of variety significantly influenced the content of bioactive compounds, particularly ascorbic acid and total phenolics.

KEYWORDS: ***Solanum lycopersicum*; variety; pH; soluble solids; acidity; color; β-carotene; lycopene; ascorbic acid; total phenolics; antioxidant activity**

INTRODUCTION

Pesticide residues in fruits and vegetables are of concern to consumers because such foods often are eaten fresh and unprocessed. These concerns have raised the profile of organic fruits and vegetables (*1*). Tomato (*Solanum lycopersicum* L.) is one of the most widely consumed vegetables worldwide. It is an important source of antioxidants including β-carotene, lycopene, ascorbic acid, phenolic acids, and flavonoids (*2*). In recent years, marketing tomatoes as pesticide-free or organic and high in lycopene or antioxidants appears to have been an effective method to increase sales and consumption (*3*).

Expected differences in farming systems would be due mostly to the differences in fertilizer (organic vs mineral fertilizers) and pesticide use (no pesticides or biopesticides vs synthetic pesticides). On the basis of the carbon (C)−nitrogen (N) balance theory, it has been argued that organic fertilizers are not as powerful in promoting plant growth and development as mineral fertilizers; the plant thus allocates more resources to synthesizing carbon-containing compounds such as organic acids and polyphenolics rather than nitrogen-containing compounds such as protein (*4*). However, well-managed organic tomato crops can be as vigorous as well-managed conventionally produced tomato crops (*5*). In addition, it has been argued that by limiting or prohibiting the use of synthetic pesticides, organic production methods cause plants to devote greater resources toward the synthesis of their own chemical defense mechanisms (*4*) such as polyphenolics, higher levels of which have been reported for pak choi after flea beetle attacks (*6*). However, the application of sublethal doses of synthetic herbicides can cause plant stress in conventionally produced crops as well, so one should not automatically assume that plants grown conventionally are subjected to lower levels of stress than organically grown plants (*4*). Therefore, generalizing about growth processes and stress exposure in the two farming systems may not be appropriate. Comparing studies of the two systems and identifying the reasons that contribute to the nutritional composition of produce grown in both remain challenges.

In the literature there is no standard method to express results; comparing different studies thus becomes especially problematic. For example, nutrient content based on fresh weight or dry weight may result in different conclusions. Significant differences in lycopene and naringenin were found in organically grown tomatoes compared to tomatoes produced by conventional

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means when results were expressed as fresh matter, but not if they were expressed as dry matter (*7*). Researchers should compare the quality of tomatoes produced in different farming systems only when the same variety was used. The three-year average showed tomato fruits of variety cv. Burbank had significantly higher total phenolics content under organic management compared to conventional management (*8*). In the same study a second tomato variety, cv. Ropreco, was used, and in contrast to cv. Burbank the total phenolics content of cv. Ropreco was not influenced significantly by the farming system (*8*), suggesting the choice of variety greatly influences the outcome of comparison studies, even if the same variety has been used in both farming systems.

Keeping in mind these difficulties in comparing the results of organic versus conventionally cultivated plant products, review papers suggest that organic fruits and vegetables often have lower protein and carotene content (*9*), lower pesticide residue levels, and lower nitrate content (*4, 10*) than conventionally grown fruits and vegetables. In contrast, organically produced fruits and vegetables often contain higher concentrations of ascorbic acid (*11*, *12*) and higher contents of defense-related secondary metabolites (*13*). However, a recent review paper pointed out contradictory findings related to the levels of secondary metabolites in organic versus conventionally produced crops and stated that it is premature to conclude one production system is superior to the other with respect to nutritional composition (*4*).

There was no consistent effect of the organic farming system on the levels of phenolic compounds in strawberries. Differences in varieties and production locations were more evident (*14*). The total phenolics content was lower in organic compared to conventionally produced plums (*15*). In contrast, significantly higher levels of some individual phenolic acids and total polyphenols were found in organic compared to conventionally cultivated peaches and pears (*16*). Organically grown cabbage had higher total phenolics content than conventionally managed cabbage. The authors suggested that the interference of mineral fertilizers and/or pesticides used in the conventional system could explain the lower amounts of total phenolics in conventional compared to organically managed cabbage (*17*). Different crops usually respond differently to agronomic factors such as nutrient availability, indicating that generalized statements regarding the influence of farming systems on the antioxidant microconstituent composition of fruits and vegetables are not appropriate (*6, 8*).

According to a three-year study, genotype has the greatest influence on the phytochemical composition in tomato. In addition to significant varietal effects, this study found significant year-to-year effects of the farming system on fruit parameters such as quercetin content (*8*). Comparisons of analyses of dried archived tomato samples from conventional and organic production systems have demonstrated significantly higher levels of quercetin and kaempferol in organic tomatoes (*18*). Higher levels of soluble solids, titratable acidity, and consistency were found in organic tomatoes, whereas conventionally produced tomatoes were redder in color and their microwaved juice was higher in ascorbic acid and total phenolics (*19*). The latter finding suggests there is a tradeoff rather than a win−win situation when consumers or processors buy organic tomatoes in terms of their quality and nutritional value.

The annual variability in levels of flavonoids, total phenolics, and ascorbic acid in tomatoes points out the importance of making multiple-year comparisons (*8*). Here, we report results from a two-year study. Our results are particularly valuable in that they are derived from the tropics and subtropics, where few comparisons of farming systems have been made (*20*). The aim of our study was to compare fruit quality (pH, soluble solids, acidity, and color), bioactive compounds with antioxidant activity (β-carotene, lycopene, ascorbic acid, and total phenolics), and antioxidant activity in two processing tomatoes grown on-farm under organic and conventional production conditions over the two-year period.

Table 1. Location of Organic and Conventional Farms, Soil Characteristics in 0−20 cm Soil Depth, Fertilizer Amount Applied, and Previous Crops Grown, Year 2005/2006

farm pair/type[a]	location[b]	pH	OM (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	previous crop
SH-O	S	6.6	1.2	167	22	42	fallow
SH-C	S	6.1	1.1	268	84	102	paddy rice
MA-O	S	8.1	2.2	402	89	170	fallow
MA-C	S	7.9	1.3	425	102	256	sesbania
SI-O	C	8.0	2.6	175	33	432	cauliflower
SI-C	C	8.0	3.0	542	100	242	fallow

[a] SH, Shinhua; MA, Madou; SI, Sihu; O, organic; C, conventional; OM, organic matter; N, nitrogen; P, phosphate (P_2O_5); K, potassium (K_2O). [b] Location along the west coast of Taiwan: S, south (tropical part of Taiwan); C, central (subtropical part of Taiwan); data for year 2004/2005 are provided in ref *21*.

MATERIALS AND METHODS

Study Area. In October 2004 and 2005, replicated field trials were established in three matched farm pairs in Shinhua (SH), Madou (MA), and Sihu (SI), Taiwan. The conventional farmer in SH was replaced in the second project year. All farms were located in the lowlands along the western coast of Taiwan. Monthly mean temperature at SH and MA during the hot-wet season from May to September ranges from 27.0 to 29.0 °C and during the cool-dry season from October to April, from 17.4 to 25.9 °C. Mean annual precipitation is about 1670 mm, distributed bimodally. The mean precipitation during the hot-wet season from May to September is about 1450 mm and during the cool-dry season from October to April, about 220 mm (Central Weather Bureau, Station Tainan, 1971−2000). Thus, it was necessary to irrigate the tomato crops in this study. The location SI is slightly cooler (16.2−24.9 °C cool-dry season, 25.7−28.5 °C hot-wet season), and there is slightly less mean annual rainfall of about 1640 mm (Central Weather Bureau, Station Taichung, 1971−2000).

Organic and conventional farms were selected on the basis of their close proximity to each other, about 100 m (SH in 2005/2006) to 800 m (MA, SI, and SH in 2004/2005 and 2005/2006) to ensure more or less similar environmental conditions in terms of air temperature, precipitation, slope, and soil type. However, field history and management of tomato crops were different among farmers, even within the same group of farm type (**Table 1**).

The organic farms were certified by an accredited Taiwanese certifying agency. All three farmers started organic farming about 10 years ago; thus, they were quite familiar with growing organic crops including tomatoes. The three conventional counterparts were also quite familiar with growing tomatoes.

Variety Selection and Trial Design. Two determinate tomato varieties with geminivirus resistance, PT 4769 (V1) and PT 4762 (V2), were selected in both years. The varieties are used for industrial processing. Both varieties had similar maturity and cultural requirements and were identified to develop high lycopene content in fruits. To enclose the experimental plot and provide separation between V1 and V2, a third tomato variety, FMTT 848 was used, with the same virus resistance and cultural habits.

Seedlings were transplanted on matched farms on the same day, at SH on October 18, 2004 (October 19, 2005); at MA on October 18, 2004 (October 24, 2005); and at SI on October 19, 2004 (October 20. 2005). Raised beds had been prepared in advance by each cooperating farmer. The experimental design was randomized complete blocks, with three replications in 2004 (four replications in 2005) on each farm. The treatment was the variety grown (V1 and V2). Plants (18 per plot) were planted 40 cm apart in single rows in the middle of the raised beds. The bed top was 1.0 m wide × 7.2 m long. Furrow space between beds was 50 cm. Furrow irrigation was used at each site. In 2004/2005 the plants were not staked; in 2005/2006 the tomato plants were staked at each farm in the same way at 23−28 days after transplanting (DAT).

Tomato Fruit Sampling. In both experimental years, fruits at the full-red stage were harvested from each plot once when one or more clusters on most plants within plots had ripe fruits. In general, fully red ripe fruits with bright red color and marketable appearance without pest impact symptoms were used in the laboratory analyses described below. These tomato fruits were delivered to the laboratory on the same day right after picking. However, the sampling patterns of fruits in the experimental years was different. In 2004/2005 about 36 fruits of six randomly selected plants per plot were harvested around 104 DAT (*21*) and were delivered in 2005 to the laboratory. In 2005/2006 total and marketable fruit yields were assessed, and the fruit sampling method was modified; all marketable fruits from 10 of 18 tomato plants in the center of each row were harvested and weighed (*5*). From these fruits about 40 fully red ripe fruits (see above) were delivered at 113 DAT (MA), at 119 DAT (SH), and at 126 DAT (SI) in 2006 to the laboratory. Tomato fruit parameters measured were related to fruit quality (pH, soluble solids, acidity, and color), bioactive compounds with antioxidant activity (β-carotene, lycopene, ascorbic acid, and total phenolics), and antioxidant activity. The analyses were carried out in duplicates, except for the HPLC analyses of β-carotene and lycopene.

Sample Preparation. Fruits per plot were cut, blended with a homogenizer, and filtered through gauze to remove seeds. Fruit slurry was used the same day to measure fruit quality parameters. Several 20.0 g samples of tomato slurry were taken, weighed in a plastic bag with seal, and immediately stored at −70 °C for subsequent analyses for carotenoids, ascorbic acid, total phenolics, and antioxidant activity (AOA).

Chemicals Used. 2,2-Azinobis(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS), horseradish peroxidase (HRP), type VI-A, 1000 (units/mg solid), linoleic acid, β-carotene, and lycopene were purchased from Sigma Chemical Co., St. Louis, MO. 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was purchased from Aldrich Co., St. Louis, MO. Other reagents used in this study were all of analytical reagent grade.

Fruit Quality. The detailed methods for quality evaluation were described in ref *2*. Tomato fruit pH value was measured using a pH-meter for the supernatant. Soluble solids concentration was measured with a digital refractometer (PR-101, Atago, Tokyo, Japan). Acidity was determined by titration with 0.05 N NaOH to reach pH 8.1 of supernatants and represented as citric acid equivalent (%, w/v). Color was measured by a colorimeter (Nippon Denshoku Kogyo Co., Ltd. Osaka, Japan) on three scales represented as *a*, *b*, and *L*. Color values of fresh tomato slurry were calculated as *a*/*b*.

Bioactive Compound Analyses. Methods used for analysis of β-carotene, lycopene, ascorbic acid, total soluble phenolics, and antioxidant activity were the same as described in ref *2*. Ten grams of frozen tomato slurry was blended with 100 mL of 6 hexane/4 acetone (v/v) and 0.1 g of $MgCO_3$ in a homogenizer. Acetone was then washed out five times with salt-saturated water. The hexane extract was filtered with a 0.45 μm filter. Lycopene and β-carotene were measured with high-performance liquid chromatography (HPLC; Waters, Milford, MA) equipped with a 717 plus autosampler, a 600 controller, and a 2487 detector (read at 436 nm) with a 125 × 4 mm LiChrospher 100 RP-18e column, 5 μm (Merck, Darmstadt, Germany), under isocratic conditions at ambient temperatures. The mobile phase was 75 acetoniltrile/25 methanol (v/v) at a flow rate of 1.5 mL min^{-1}. Commercial β-carotene and lycopene were used as standards (see above). The data of β-carotene and lycopene are related to all-trans isomers. The determination of total ascorbic acid was on the basis of coupling 2,4-dinitrophenylhydrazine (DNPH) with the ketonic groups of dehydroascorbic acid through the oxidation of ascorbic acid by 2,6-dichlorophenolindolphenol (DCPIP) to form a yellow-orange color in acidic conditions (*22*). Total soluble phenolics were extracted from frozen tomato slurry with 80% methanol, determined using Folin−Ciocalteu reagent (*23*), and expressed as chlorogenic acid equivalent. The reaction mixtures included 0.2 mL of methanol extract, 3.2 mL of distilled water, 0.2 mL of 1 N Folin−Ciocalteu reagent, and 0.4 mL of 35% sodium carbonate in water. The absorbance was read at 760 nm after 30 min of incubation at room temperature. Chlorogenic acid was used for quantification. However, in the estimation of total phenolic content in tomato using Folin−Ciocalteu colorimetry, it cannot be excluded that sufficient ascorbic acid may be present to cause an overestimate of total phenolic content. Antioxidant activity was measured using the Trolox equivalent antioxidant capacity (TEAC) method as described in ref *24* with some modifications as in ref *2*.

Table 2. Mean Values of Fruit Quality Parameters by Farm Type across 2004/2005 and 2005/2006[a]

farm type	mean (V1)	mean (V2)	grand mean [(V1 + V2)/2]	varietal effect (V1 − V2)
		pH		
organic (O)	4.26 ± 0.07	4.32 ± 0.06	4.29 ± 0.07	−0.06 *
conventional (C)	4.32 ± 0.08	4.34 ± 0.07	4.33 ± 0.08	−0.02 ns
difference (O − C)	−0.06 ns	−0.02 ns	−0.04 ns	
		Soluble Solids (°Brix)		
O	3.93 ± 0.56	3.91 ± 0.56	3.92 ± 0.56	0.02 ns
C	3.85 ± 0.52	3.86 ± 0.71	3.86 ± 0.61	0.01 ns
O − C	0.08 ns	0.05 ns	0.06 ns	
		Acidity (Percent Citric Acid)		
O	0.37 ± 0.07	0.34 ± 0.06	0.35 ± 0.06	0.03 ns
C	0.36 ± 0.04	0.36 ± 0.04	0.36 ± 0.04	0.00 ns
O − C	0.01 ns	−0.02 ns	−0.01 ns	
		Color (*a*/*b*)		
O	2.01 ± 0.18	1.96 ± 0.17	1.99 ± 0.17	0.05 ns
C	2.05 ± 0.18	1.94 ± 0.16	2.00 ± 0.18	0.11 **
O − C	−0.04 ns	0.02 ns	−0.01 ns	

[a] Differences: ns, not significant; *, significant at $P < 0.05$; and **, significant at $P < 0.01$, according to Tukey's test. Standard deviation is shown. Processing tomato varieties PT 4769 (V1) and PT 4762 (V2).

Statistical Analyses. Combined data across farms and years were statistically analyzed by combined analysis of variance using the PROC MIXED procedure of the Statistical Analysis System (*25*). The mean differences between the organic and conventional farms within each farm pair were compared using Tukey's test.

RESULTS AND DISCUSSION

In the following two sections we will show the results related to the quality and nutritional value of tomato fruits. We will discuss factors that may override the effect of farming system on the results, such as the maturity stage of the fruit at harvest, farmer management skills, the variety used, and the impact of the growing season.

Fruit Quality Parameters across Two Years by Farm Type. Mean values of fruit quality parameters of the two tomato varieties by farm type are presented in **Table 2**. Data calculated across two years showed no significant differences between organic and conventionally produced tomatoes for the fruit quality parameters including pH ($p = 0.33$), soluble solids ($p = 0.80$), acidity ($p = 0.78$), and color ($p = 0.93$). Varietal effects were less pronounced, and only significant for pH values of organically produced tomatoes and color value of conventionally produced tomatoes (**Table 2**).

In general, our data correspond to the range reported previously for the same tomato fruit quality parameters. For example, the tomato fruit pH values ranged from 4.34 to 4.46, the soluble solid contents ranged from 4.77 to 6.45, and the acidity values ranged from 0.32 to 0.40 (*26*). The color values of 42 red-fruited *S. lycopersicum* varieties ranged from 0.99 to 2.16 (*2*).

Presumably, there are factors involved in producing high-quality tomatoes that are more important than the farming system itself; these factors are likely reasons why we have not identified consistent differences between organic and conventionally produced tomato fruits in our study. Such factors may override any measurable effect of the farming system, particularly if they are related to the maturity stage of the fruit and therefore dependent on the harvest date. For example, variation in tomato fruit acidity is attributed to the stage of maturity. Less mature tomatoes produce pastes with greater titratable acidity (*27*). In contrast, the lycopene content of tomato fruits usually increases with increasing maturity (*28*). Therefore, if the maturity stage/harvest date is the overriding factor contributing to a quality parameter such as titratable acidity and lycopene, then it is rather unlikely to observe consistently significant differences caused by the farming system, unless a farming system approach would be to harvest tomato fruits at an earlier or later stage than commonly practiced.

If the maturity stage of fruits is important for achieving high-quality produce, then it is likely that farmers' management skills are of particular importance. In the next section we will show that individual management skills are an important factor contributing to high lycopene values in tomato fruit.

If a fruit parameter such as the pH value is not only related to the maturity stage of the fruit and, therefore, in addition to the harvest date, dependent on other factors, then it may be more difficult to realize a higher quality product. For example, in 2006 the fruit pH value at SH-O (4.32) was significantly lower compared to SH-C (4.43) in V1, but both values are still relatively high for processing requirements (a fruit pH of 4.25 is regarded to be optimal). Tomato variety cv. Cannery Row, which possesses good quality traits in terms of high soluble solids and viscosity, is marginal for pH in New Zealand (4.27−4.39) (*28*). Thus, more knowledge is needed on how to manipulate fruit pH under organic and conventional management methods, as fruit pH value is dependent on the maturity stage of the fruits and also on several other factors including variety, cultural practices, location, and seasonal variation (*27*). If a quality parameter such as fruit pH is influenced by many different factors, then it is quite challenging to provide particular reasons for results observed in our study and other studies that compare organic versus conventionally grown tomatoes.

The impact of growing season on tomato quality attributes is more significant than any other factor (*27*). In two of three years, organic tomatoes had significantly higher soluble solids contents compared to conventionally produced tomatoes, regardless of the variety grown (*8*). However, in the third year no difference between the farming systems was found, and the soluble solids content in the conventionally produced tomatoes was even slightly higher in both varieties (*8*). These significant year-to-year effects of the farming system on fruit quality parameters may be one major reason for discrepancies in results observed in comparison studies between the two systems.

To summarize, results across two years suggest that farm type has no significant effect on tomato fruit pH, soluble solids, acidity, and color (**Table 2**). However, organically produced fruits and vegetables usually have fewer undesirable compounds such as pesticide residues and nitrate (*4*, *10*) that may affect human health, processing quality, and the taste of products. In contrast, in a one-year on-farm study it was found there might be a potential advantage to using organically grown tomatoes in terms of higher levels of soluble solids, titratable acidity, and consistency based on a four farm pair comparisons, indicating that higher flavor and reduced energy requirement for concentration of juice may result from using organically grown tomatoes (*19*). However, the color value of organic compared to conventionally produced tomatoes was lower, and the microwaved juice was lower in ascorbic acid and total phenolics (*19*). The maturity stage of tomato fruits at harvest, significant year-to-year effects of the farming system on fruit quality parameters, different varieties used, different farmers' management technologies, different production locations, climates, weather, and soil characteristics all may have contributed to the fact that our results are not in agreement with those of ref *19*.

Table 3. Mean Comparison of Bioactive Compounds with Antioxidant Activity of Tomato by Farm Type across 2004/2005 and 2005/2006[a]

farm type	mean (V1)	mean (V2)	grand mean [(V1 + V2)/2]	varietal effect (V1 − V2)
	β-Carotene (Milligrams per 100 g of FW)			
organic (O)	0.56 ± 0.10	0.58 ± 0.14	0.57 ± 0.12	−0.02 ns
conventional (C)	0.51 ± 0.11	0.52 ± 0.12	0.52 ± 0.12	−0.01 ns
difference (O − C)	0.05[b]	0.06[b]	0.05[b]	
	Lycopene (Milligrams per 100 g of FW)			
O	9.75 ± 1.65	8.86 ± 1.79	9.31 ± 1.76	0.89 ns
C	10.08 ± 1.81	8.96 ± 1.32	9.52 ± 1.67	1.12 ns
O − C	−0.33 ns	−0.10 ns	−0.21 ns	
	Ascorbic Acid (Milligrams per 100 g of FW)			
O	20.83 ± 2.77	31.13 ± 3.83	25.98 ± 6.16	−10.30 **
C	18.91 ± 3.19	28.31 ± 5.92	23.61 ± 6.64	−9.40 **
O − C	1.92 ns	2.82 ns	2.37 ns	
	Total Phenolics (Milligrams per 100 g of FW)			
O	69.92 ± 19.66	83.49 ± 20.91	76.71 ± 21.19	−13.57 **
C	64.05 ± 24.15	73.01 ± 18.96	68.53 ± 21.92	−8.96 **
O − C	5.87 ns	10.48 ns	8.18 ns	
	Antioxidant Activity (Micromoles per Gram of FW)			
O	257.4 ± 50.2	289.5 ± 49.0	273.4 ± 51.6	−32.1 *
C	277.6 ± 51.2	282.4 ± 43.6	280.0 ± 47.0	−4.8 ns
O − C	−20.2 ns	7.01 ns	−6.6 ns	

[a] Differences: ns, not significant; *, significant at $P < 0.05$, and **, significant at $P < 0.01$, according to Tukey's test. Standard deviation is shown. [b] For β-carotene the interaction of farm type × farm location is significant, which indicates that the effect of farm type is not consistent across locations; thus, significant differences between the means of β-carotene averaged across locations and years (organic versus conventional) are not indicated. Processing tomato varieties PT 4769 (V1) and PT 4762 (V2).

Fruit Bioactive Compounds with Antioxidant Activity across Two Years by Farm Type. Mean values of bioactive compounds with antioxidant activity of fruits of the two varieties by farm type are presented in **Table 3**. Data calculated across two years showed no significant differences between organic and conventionally produced tomatoes for the fruit nutritional parameters including β-carotene (p value cannot be provided due to interactions, see footnote *b* **Table 3**), lycopene ($p = 0.74$), ascorbic acid ($p = 0.12$), total phenolics ($p = 0.31$), and antioxidant activity ($p = 0.64$).

When matched farm pairs were evaluated on the basis of individual-year data, very few significant differences were found between organic and conventionally produced tomatoes in some farm pairs, either in one or both varieties, for β-carotene, ascorbic acid, and total phenolics (not shown). However, for lycopene, consistent effects were found that will be discussed below (see **Table 4**).

In general, our data correspond to the range reported previously for the same tomato fruit parameters of 42 red-fruited *S. lycopersicum* L. varieties grown in Taiwan. The tomato fruit β-carotene values ranged from 0.27 to 1.16 mg/100 g of fresh weight (FW), the lycopene content ranged from 4.15 to 10.64 mg/100 g of FW, the ascorbic acid values ranged from 11.8 to

Table 4. Mean Fruit Lycopene Content (Milligrams per 100 g of FW) by Farm Pairs in 2004/2005 and 2005/2006[a]

	mean 2004/2005		mean 2005/2006	
farm pair/type	V1	V2	V1	V2
SH-O	9.40 ± 0.61	9.17 ± 0.97	12.40 ± 0.44	11.59 ± 0.39
SH-C	9.29 ± 2.44	9.58 ± 2.12	11.26 ± 0.59	9.67 ± 1.01
difference (O − C)	0.11 ns	−0.41 ns	1.14 ns	1.92 **
MA-O	7.58 ± 0.20	6.12 ± 1.07	9.93 ± 1.31	7.99 ± 0.66
MA-C	10.94 ± 0.56	9.10 ± 0.64	11.96 ± 0.59	10.01 ± 0.27
O − C	−3.36 **	−2.98 **	−2.03 **	−2.02 **
SI-O	8.99 ± 0.50	8.94 ± 0.48	10.11 ± 0.95	9.33 ± 0.59
SI-C	8.05 ± 0.98	7.56 ± 0.91	8.93 ± 1.58	7.97 ± 0.94
O − C	0.94 ns	1.38 ns	1.18 ns	1.36 **

[a] Differences: ns, not significant; *, significant at $P < 0.05$, and **, significant at $P < 0.01$, according to Tukey's test. Standard deviation is shown. Processing tomato varieties PT 4769 (V1) and PT 4762 (V2); SH, Shinhua; MA, Madou; SI, Sihu.

28.6 mg/100 g of FW, and the content of total phenolics ranged from 60.0 to 143 mg/100 g of FW (*2*).

In a three-year study varietal effects on several tomato fruit parameters were observed and suggested that genotype has the greatest influence on the phytochemical composition of fruits and vegetables (*8*). The three-year average showed the variety cv. Burbank had significantly higher total phenolics and ascorbic acid content under organic management. However, the higher mean values of total phenolics and ascorbic acid were greatly influenced by a single year result. In contrast, the ascorbic acid and total phenolics content of variety cv. Ropreco were not significantly affected by the farming system. The results of our study are in agreement, particularly for the parameters ascorbic acid and total phenolics. For these parameters, we also found significant differences among tomato varieties that would override the influence of the farming system (**Table 3**).

When looking in detail, the total phenolics and ascorbic acid content appear to be positively related (**Table 3**). However, assessing and discussing correlations among measured parameters are beyond the focus of this paper. The correlations may deserve to be shown and discussed in a separate paper, with a focus on fruit physiological processes including interactions.

All farmers used the same two varieties. However, particularly in 2005/2006 the organic farmer at SH (12.40 mg/100 g of FW) and the conventional farmer at MA (11.96 mg/100 g of FW) produced the highest lycopene content of tomatoes of around 12.0 mg/100 g of FW (**Table 4**). The former may be regarded as a "low-input" organic farmer with respect to organic fertilizer (about 170 kg/ha nitrogen, N) and biopesticide inputs (only a *Bacillus thuringiensis* product applied four times), whereas the latter may be regarded as a "high-input" conventional farmer with regard to mineral fertilizer (about 425 kg/ha N) and synthetic pesticides (11 different fungicides and insecticides, *B. thuringiensis* among them) applied. Nevertheless, both have attained high fruit lycopene contents compared to the other farmers in their group, particularly in 2005/2006. For example, according to field observations at the experimental sites, it is important that farmers maintain fruit health until the fully red ripe stage and maximum lycopene content is reached in tomato fruits. Therefore, the individual farmer's management practice appears to be more important in realizing high lycopene content compared to the effect of the farming system. To summarize, two years of results from our study did not show significant differences for tomato fruit lycopene content between organic and conventional farming systems. This is in agreement with the results of another on-farm study in tomato conducted in California (*19*).

However, the genetic background of the variety (*2*) and the production site, such as weather and soil characteristics, must also be favorable for tomatoes to ripen and reach maximum lycopene levels (*29*). In the presented study, the farm location may have interacted with climate and soil characteristics. The farm pair SI was located in central Taiwan under subtropical climatic conditions with slightly lower mean annual maximum and minimum air temperature compared to the farm pairs located further south at SH and MA in tropical Taiwan (see **Table 1**). Mean annual air temperature ranges from October to April from 17.4 to 25.9 °C at SH and MA, whereas the SI location is slightly cooler (at SI temperature ranges from October to April from 16.2 to 24.9 °C). It may be that the farm pair at SI had slightly less favorable weather conditions during the cool-dry season in Taiwan for fruit ripening, and thus mean lycopene levels at SI were on average slightly lower compared to the farm pair located at SH, particularly in 2005/2006 when tomato lycopene levels were relatively high at SH. On the other hand, tomatoes with above-average lycopene levels were grown on soils with organic matter contents between 1.1 and 1.3% (see **Table 1**). If this is not just a random effect due to small sample size, these soils compared to heavier soils with higher organic matter content might be more favorable during the cool-dry season in Taiwan for tomato crop growth and fruit ripening, presumably due to higher soil temperature development during the day and residual higher temperature at night, improving both below-ground and above-ground crop development. However, data gained in California do not support this hypothesis, because farmers were able to realize relatively high lycopene content in tomatoes grown on a heavy clay soil (*19*). In California farmers harvested tomatoes in summer, but in our study the tomato harvest was conducted during the cool-dry season, which may explain the differences to a certain extent, because during summer when air temperatures are relatively high and suboptimal for tomato crop growth and development, soil temperature (and soil moisture) may be more appropriate for tomato fruit development in heavier soils.

To conclude, on the basis of the two-year results, consistent and uniform effects of farming systems on tomato fruit parameters were not observed. This is in agreement with the statement in a recently published review paper that there is no direct evidence that organic and conventional tomatoes differ in concentrations of various nutrients such as antioxidants (*30*). However, the herein reported results are not in agreement with a recently published comprehensive report, which concluded that, for example, ascorbic acid (in roughly 6 of 10 cases), total phenolics (in roughly 7 of 10 cases), and antioxidant activity (in roughly 9 of 10 cases) are often higher in organic compared to conventionally produced plant products (*31*).

Only when results of individual farm pairs were compared herein a few significant differences for pH, soluble solid, color value, β-carotene, ascorbic acid, and total phenolics were found; however, in general, these were not consistent across farm locations, varieties, or years. Although we did not find consistent effects with respect to the parameters mentioned above, our comparison study might be of benefit by contributing to the identification of weaknesses and strengths in both organic and conventional farming systems that should be addressed to improve tomato fruit quality and nutritional parameters as stated by Lester (*32*). This can be achieved by selecting appropriate varieties and through the use of good agricultural practices to maintain fruit health and quality. For example, according to the review paper by

Dorais et al. (*30*), selection of small and highly colored tomatoes optimizes fruit levels of carotenoids, flavonoids, and vitamin C and, consequently, their nutritional value and health benefits. Cultural practices such as pruning and thinning determine the crop load and fruit size, which can influence the nutritional composition of fruit. In addition, deficit irrigation can constitute a powerful tool to improve the nutritional value of tomato fruit due to a reduced amount of water available to the fruit; thus, dry matter content and concentration of nutrients in the fruit increases. The authors of the review paper concluded that presumably tomatoes of superior nutritional value have to be produced under unique growing conditions that do not necessarily realize the highest yields, but may fetch higher market prices because these can be marketed as a specific health-promoting food (*30*).

The genotype has a great influence on the phytochemical composition of fruits and vegetables (*8*). Results of our study support this statement, particularly for the parameters ascorbic acid and total phenolics. However, our results suggest the individual farmer's management practices such as optimum harvest date and appropriate production techniques to maintain fruit health and overall fruit quality are among the critical factors to realize the maximum lycopene content for tomatoes. Plant defense processes may contribute to increased bioactive compounds with antioxidant activity such as phenolic compounds as well, but plant defense processes are usually associated with lower crop yield and product appearance caused by stress factors such as severe insect pest attacks, usually not desired in any farming system.

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