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Organic vs Conventionally Grown Rio Red Whole Grapefruit and Juice: Comparison of Production Inputs, Market Quality, Consumer Acceptance, and Human Health-Bioactive Compounds

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Most claims that organic produce is better tasting and more nutritious than nonorganic (conventional) produce are largely unsubstantiated. This is due mainly to a lack of rigor in research studies matching common production variables of both production systems, such as microclimate, soil type, fertilizer elemental concentration, previous crop, irrigation source and application, plant age, and cultivar. The aforementioned production variables common to both production systems were matched for comparison of Texas commercially grown conventional and certified organic Rio Red red-fruited grapefruit. Whole grapefruits from each production system were harvested between 800 and 1000 h at commercial early (November), mid- (January), and late season (March) harvest periods for three consecutive years. Within each harvest season, conventional and organic whole fruits were compared for marketable qualities (fruit weight, specific gravity, peel thickness, and peel color), and juices were compared for marketable qualities (specific gravity, % juice, and color), human health-bioactive compounds (minerals, ascorbic acid, lycopene, sugars, pectin, phenols, and nitrates), and consumer taste intensity and overall acceptance. Conventional fruit was better colored and higher in lycopene, and the juice was less tart, lower in the bitter principle naringin, and better accepted by the consumer panel than the organic fruit. Organic fruit had a commercially preferred thinner peel, and the juice was higher in ascorbic acid and sugars and lower in nitrate and the drug interactive furanocoumarins.

KEYWORDS: Grapefruit (*Citrus paradisi*); ascorbic acid; citric acid; furanocoumarins; lycopene; naringin; nitrate; sugars; seasonal influence; consumer acceptance

INTRODUCTION

It has been established that "U.S. producers are turning to organic farming systems as a potential way to lower input costs, decrease reliance on nonrenewable resources, capture high-value markets at premium prices, and boost farm income" (*1*). Organic production agriculture is characterized by inputs of biologically (nonsynthetic) based fertilizers and pest management practices that are sustainable (*2*). Much of the U.S. organic farm sector expansion has occurred since the U.S. Department of Agriculture's establishment of uniform organic standards in 2000. Currently, 2% of U.S. fruit crop acreages and 4% of U.S. vegetable crop acreages are certified organic (*1*). Organic fresh fruits and vegetables vs grains, grain byproducts, herbs, nuts, and animal products have been the top-selling category since the retail of organic products started over three decades ago, accounting for 43% of all U.S. organic food sales in 2002. Much of the retail demand for organic produce, which has been increasing 20−25% per annum (*1*), is due to consumer's perceptions of the dangers of pesticide residues (*3*) and that organic produce is better tasting and more nutritious (*4*−*9*).

A review of claims that organic produce tastes better and is more nutritious than nonorganic (conventional) produce found these claims to be largely unfounded (*10*). The review concludes that greater scientific rigor in conventional vs organic produce production studies is needed if quality differences are to be resolved (*10*). Much of the current literature demonstrates a lack of matched "common production/harvest variables" such as soil type, previous crop, irrigation source method and quality, plant

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Table 1. Irrigation Source, Continuous Cropping, and Soil Conditions of Conventionally vs Organically Grown Rio Red Grapefruit Orchards

	soil													
		texture (%)				kg/ha								
production system	depth (cm)	sand	silt	clay	pH	NO_3-N	P	K	Ca	Mg	continuous cropping (years)	previous crop	irrigation source
conventional	0–30	64.4	21.2	14.4	6.9	29 ± 3[a]	20 ± 8	54 ± 15	73 ± 14	32 ± 10	14	grapefruit	Rio Grande
	30–60	66.4	19.2	14.4	7.3	22 ± 4	15 ± 8	61 ± 19	81 ± 10	44 ± 14			
	60–90	64.4	23.2	12.4	7.6	24 ± 3	11 ± 5	58 ± 8	135 ± 46	42 ± 14			
	90–120	62.4	27.2	10.4	7.7	26 ± 2	6 ± 4	55 ± 6	133 ± 36	45 ± 11			
organic	0–30	64.4	21.2	14.4	7.2	30 ± 5	27 ± 6	90 ± 20	53 ± 17	22 ± 5	16	citrus	Rio Grande
	30–60	66.4	19.2	14.4	7.3	21 ± 6	7 ± 6	90 ± 25	65 ± 31	20 ± 10			
	60–90	61.4	24.2	14.4	7.8	24 ± 2	6 ± 2	67 ± 9	99 ± 30	26 ± 12			
	90–120	60.4	27.2	12.4	8.0	24 ± 1	3 ± 1	51 ± 2	114 ± 15	25 ± 11			

[a] Means for each element, within a production system and soil depth, are from three samplings and averaged from three consecutive years ± SD (n = 9).

age, cultivar, fertilizer timing and elemental concentration, harvested product size, harvest time and method, and postharvest handling practices. Moreover, no organic vs conventional production system comparison study has examined the effect of extended harvest season, such as the multiple harvests of tree fruit like citrus, on whole fruit and juice marketability and on juice quality with a focus on human health-bioactive compounds and consumer acceptance.

Grapefruit (*Citrus paradisi* Macf.) juice is known for containing drug interactive compounds, mainly the furanocoumarins (*11*). The concentration of these compounds in grapefruit juice is affected by production inputs (*12*), which is the case for many human health-bioactive compounds in fruits and vegetables (*13*). Eighty percent of all grapefruit produced in the United States is grown in Florida and Texas with 85% of the grapefruit grown as pink or red varieties (*14*). In Texas, currently 2% of the grapefruit production is grown organically with nearly all of the fruit being Rio Red (D. Holbrook, organic grapefruit grower, personal communication). In this study, we utilized Texas commercial conventional and certified organic grown Rio Red grapefruit from orchards that were matched for the aforementioned common production variables. This will provide a rigorous comparison of conventional vs organic production of whole fruit and juice marketability and of juice quality, including the comparative levels of human health-bioactive compounds and consumer acceptance.

MATERIALS AND METHODS

Orchards. Commercial conventional and certified organic Rio Red grapefruit (*C. paradisi* Macf.) production orchards located in South Texas (latitude 26° 27′ N, longitude 98° 19′ W, lat., elevation 60 m) were 76.3 m apart. Soil conditions (percent sand, silt, and clay and major mineral concentrations), cropping history, and irrigation source are defined in **Table 1**. Production systems' fertilizer, weed control, and insecticide usages, rates, and numbers of applications are defined in **Table 2**.

Fruit. Grapefruit, within a production orchard and harvest season, were selected for uniform color, firmness, roundness, and minimal defects and harvested between 800 and 1000 h from inside midcanopy at all cardinal points. Harvests were November 1 (early season), January 2 (midseason), and March 1 (late season) for three consecutive seasons starting in November 2003 and ending in March 2006. A randomly selected set of 10 trees, from each production system, were resampled each harvest. For each harvest season, 40 fruits (four fruits from each tree) from each orchard were immediately transported to the Agricultural Research Service, U.S. Department of Agriculture Research Center in Weslaco, Texas. Ten fruits from within a production system orchard, per harvest season, per year, were reselected for uniform size (96.8−104.8 mm diameter), washed in reverse osmosis H_2O, and immediately processed.

Table 2. Fertilizer, Weed, and Insect Control Inputs of Conventionally vs Organically Grown Rio Red Grapefruit Orchards

production system	input	description	rate	applications
conventional	fertilizer	9 N, 1.8 P, 11 K, 21 S	672 kg ha^{-1}	1
		17 N, 2.2 P, 0 K, 19 S	392 kg ha^{-1}	1
		15 N, 4.4 P, 54.2 K	9.4 L ha^{-1}	2
	insect control	Agrimek	0.7 kg ha^{-1}	1
		citrus oil	46.8 L ha^{-1}	1
		Enable	0.6 kg ha^{-1}	1
		Lorsban	4.7 L ha^{-1}	1
		Vendex	2.2 kg ha^{-1}	1
		R-56	1.8 L ha^{-1}	1
	weed control	Active Plus	9.4 L ha^{-1}	2
		Direx	4.5 kg ha^{-1}	2
		Semazine	3.4 kg ha^{-1}	2
organic	fertilizer			
	compost	2 N, 0.6 P, 1.2 K	3360 kg ha^{-1}	2
	fish emulsion	6 N, 2 P, 0 K	9.4 L ha^{-1}	5
	trace minerals[a]	50 Ca, 0.5 Mg, 50 S, 0.02 B, 0.4 Fe	560 kg ha^{-1}	1
	insect control	flowable sulfur	4.7 L ha^{-1}	5
		compost tea	4.7 L ha^{-1}	5
	weed control	cultivation		2

[a] Minor elements are expressed as kg/kg.

Color Measurements. A CR-200 chromameter from Minolta Corp. (Ramsey, NJ) calibrated using a clean barium sulfate plate (standard white) was used to quantify whole fruit exterior (peel) and cut-fruit interior tissue color characteristics. Color measurements of the whole-fruit peel were taken at three equidistant locations around the fruit equator. Interior fruit measurements were taken at three equidistant locations around the cut equatorial plane. The color was expressed in the lightness, chroma, and hue angle mode: lightness or darkness (+100 = white, −100 = black), chroma (+ = color intensity), and hue° or color (0° = red, 90° = yellow, 180° = green, and 270° = blue).

Juice Extraction. Cut fruits were juiced using a Chef's Juicer from Metrokane (New York, NY).

Consumer Acceptability Determination. Grapefruits were juiced 1 day prior to consumer evaluation, held at 4 °C under aerobic conditions, and allowed to reach room temperature with stirring prior to sampling. Juice tartness, sweetness intensity, and overall acceptability were determined at individual stations by an untrained 75 member panel. Each station displayed 25 mL of juice in red-nontranslucent 300 mL disposable plastic cups following the fruit sensory procedure of Saftner et al. (*15*). Briefly, panelists having a preference for grapefruit juice were randomly selected from the local Agricultural Research Service, U.S. Department of Agriculture, research community. Separate 10 cm unstructured hedonic line scales were used to rate the intensity of tartness and sweetness and the acceptability of overall quality. Panelists were told to cleanse their palates with a drink of room temperature reverse osmosis water before each sample and were then given verbal instructions and paper ballots that had three scales anchored either not tart or not sweet, extremely tart or extremely sweet, or extremely dislike or extremely like.

Mineral Analyses. Soil texture and soil and juice mineral analyses were determined by a local commercial certified plant and soil testing laboratory. The soil texture was determined gravimetrically. Minerals were extracted from 2 g of lyophilized soil or 10 g of evaporated juice by ashing (3 h at 550 °C) in acid-washed porcelain crucibles. The cooled ash was dissolved in 2 mL of 1.0 M HCL, filtered (Whatman #1, Maidstone, United Kingdom), and brought up to 100 mL with double-distilled water. Minerals were calibrated against known standards using atomic absorption spectroscopy.

Peel Thickness. Peel epidermis including adjacent albido tissues were measured for thickness using a sliding caliper from MG Tool Co. (New York, NY)

Juice Phenols. The flavonoids and furanocoumarins representing the predominant phenols in grapefruit were extracted and quantified from 10 mL of juice using the following procedures (*16*−*18*). Furanocoumarins were quantitatively extracted into ethyl acetate. The ethyl acetate was subsequently evaporated, and the dried residue (<40 °C) was then redissolved in 5 mL of tetrhydrofuran. Each extract was analyzed with a Waters Alliance high-pressure liquid chromatograph (HPLC), equipped with a Waters 996 photodiode array (PDA) detector and a Waters/Micromass ZQ single-quadrupole mass spectrometer (MS). Separation was accomplished on a 150 mm × 3.9 mm i.d. Nova-Pak C-18 column (Waters, Milford, MA) with a multistep linear water/acetonitrile/0.05% formic acid gradient at a flow rate of 0.75 mL min^{-1}. The initial elution conditions started at 85:10:5 (v/v/v) water/ acetonitrile/ 0.05% formic acid. This solvent was increased linearly to 55:40:5 (v/v/v) in 15 min and to 25:70:5 (v/v/v) in 25 min, followed by another linear segment to 0:95:5 (v/v/v) in 12 min, and was then held isocratically for 13 min. Furanocoumarins were detected at 310 nm. PDA detection was monitored between 230 and 600 nm. The postcolumn split to the PDA and MS was 10:1. MS parameters were as follows: ionization mode, ES+; capillary voltage, 3.0 kV; extractor voltage, 5 V; source temperature, 100 °C; desolvation temperature, 225 °C; desolvation N_2 flow, 465 L/h; cone N_2 flow, 70 L/h; scan range, m/z 150−900; scan rate, 1 scan/s; and cone voltages, 20, 40, and 60 eV. Single ion monitoring (SIM)−MS was m/z 709 and 727 for furanocoumarin dimers. For bergamottin and similar compounds, the lower limit of detection by SIM-MS was 1.2 ng (signal/noise 10). Furanocoumarins bergoptol, bergamottin, 6′,7′-dihydroxybergamottin (DHB), and DHB dimers 708 plus 728 standards were supplied by J. Manthey (Agricultural Research Service, U.S. Department of Agriculture, Winter Heaven, FL). Naringin and neohesperidin standards were obtained from Sigma Chemical Co. (St. Louis, MO), and narirutin was obtained from ABCR GmbH & Co. (Karlsruhe, Germany).

Juice Quality Determinations. *Ascorbic Acid and Dehydroascorbic Acid.* Total, free, and dehydroascorbic acid were determined from 5 g of frozen juice and detected spectrophotometrically at 525 nm according Hodges et al. (*19*). Juice samples were combined with 15 mL of *m*-phosphoric acid, homogenized, and centrifuged. The supernatant (100 μL) was reacted with KH_2PO_4 and DTT to detect total ascorbic acid or with water to detect free ascorbic acid for 60 min at 22 °C and then was reacted with TCA, orthophosphoric acid, dipyridyl, and $FeCl_3$ for 60 min at 40 °C. Ascrobate concentrations were calculated using a standard curve.

Pectins. Pectins were precipitated from 30 g of frozen juice according to Rouse (*20*).

Soluble Solids Concentration. Soluble solids were determined on juice using a temperature-corrected, digital refractometer from Reichert Scientific Instruments (Buffalo, NY).

Specific Gravity. The specific gravity was determined on fruits of a known weight submerged into a known weight of tap water. Specific gravity = fruit wt/displaced H_2O wt.

Sugars. Sugars were determined on 0.5 mL of juice diluted 20-fold with Milli-Q water (Milli-Q water system, Millipore Corp., Bedford, MA). Sample solutions (1 mL) were filtered through an activated C18 Sep-Pak from Waters Corp. before quantitative determination of fructose, glucose, and sucrose using the HPLC procedure (*21*). Briefly, sugars were quantified by cochromatography with known standards using a Supelcogel Ca (30 cm × 7.8 mm i.d.) column equipped with a Supelcogel Ca guard column (Supelco, Bellefonte, PA) heated to 80 °C and eluted with HPLC grade water at 0.5 mL min^{-1}.

Titratable Acidity. The titratable acidity was determined on 5 mL of juice diluted 10-fold with Milli-Q water and expressed as percent citric acid using a Mettler DL12 autotitrator from Mettler-Toledo, Inc. (Hightstown, NJ).

Lycopene. The total lycopene was extracted according to the procedure of Perkins-Veazie et al. (*22*). Briefly, 20 g of frozen juice was combined with 1:1:1 (v/v/v) hexane/acetone w/ BHT/ethanol, stoppered, placed in the dark, and agitated at 4 °C for 15 min. HPLC water (15 mL) was added, agitated for 5 min, and allowed to stand for 15 min. Lycopene was detected in the hexane layer at 471, 503, and 700 nm.

Experimental Design and Data Analyses. Ten fruits from each production system were assayed each harvest season, each year. Data were subjected to analysis of variance using the PROCMIX procedure of SAS Version 9.1 (SAS, Cary, NC). Treatment means were compared using the least-square means (LSMEANS) procedure of SAS with years as replications. Because of the inability to find several, matching organic and conventional production system orchards, years were used as replicates (S. Duke, Agricultural Research Service, U.S. Department of Agriculture biometrician, personal communication). Statistical means comparisons are within a harvest season, not across harvest seasons ($n = 30$).

RESULTS AND DISCUSSION

Soil analyses, determined on 0−120 cm depth profiles from each orchard 1 month prior to the start of the harvest season (November to March), indicated that the prevailing soil texture for both orchards was a sandy clay loam (**Table 1**). These analyses indicate that both orchards' soils were well-matched having nearly identical pH values, essential mineral contents (NO_3−N, P, K, Ca, and Mg), and textures associated with an increased retention of water and availability of nutrients (*23*). Other important matching criteria included the facts that both orchards were planted to the same cultivar (Rio Red) in the same year (1990); both have been under separate conventional or organic production practices for a near equal number of years, both share a similar microclimate, and both were irrigated with the same water source and method. These closely matching components have provided the necessary commonality required (*10*) to rigorously differentiate production system (conventional vs organic) input effects on whole grapefruit and juice marketable qualities and resulting juice consumer acceptance and human health-bioactive compound contents.

Conventional and organic production systems input were completely different (**Table 2**). The conventional system applied synthetic (chemical) fertilizer and insect and weed control inputs, whereas the organic system, typical of all certified organic production systems, component inputs were completely sustainable (organic). Although fertilizer input sources were different (i.e., chemical vs organic), the relative amounts of total N (130 vs 137 kg/ha), P (22 vs 41 kg/ha), and K (84 vs 81 kg/ha) applied by each input system were very similar. However, even though nutrient levels supplied were similar for each system, N, P, and K availability for plant uptake and mobilization to the leaves and fruit is affected by fertilizer form (chemical vs organic), timing of application (spring vs fall), amount per application, number of applications, degree of fertilizer water solubility, and the soil's texture and pH (*24*). All of these are known to affect orchard product quality attributes (*25*).

The impact of these distinct production systems was compared for whole-fruit quality factors (**Table 3**). Although conventionally and organically grown fruits were matched at harvest for uniform size, shape, and location within the canopy, early season

Table 3. Whole-Fruit Market Quality Attributes of Conventional vs Organic Rio Red Grapefruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and in Ending March 2006[a]

production system	harvest season	fruit fw[c] (g)	fruit specific gravity	peel thickness (mm)	peel color characteristics[b]		
					lightness	chroma	hue°
conventional	early	471 a[d]	0.87 b	66.6 a	60.4 b	38.9 a	90.3 b
organic, $P \leq 0.05$	early	409 b	0.89 a	56.5 b	63.3 a	37.0 b	94.3 a
conventional	mid	466 a	0.88 b	59.3 a	66.7 b	45.1 a	68.7 b
organic, $P \leq 0.05$	mid	457 a	0.92 a	49.5 b	69.0 a	44.4 a	74.3 a
conventional	late	477 a	0.89 b	57.0 a	67.7 a	46.8 a	69.3 b
organic, $P \leq 0.05$	late	477 a	0.93 a	48.5 b	67.2 a	45.7 a	72.9 a

[a] Mean comparisons are within a harvest season. [b] Lightness or darkness (+100 = white, –100 = black), chroma (+ = color intensity), and hue° or color (0° = red, 90° = yellow, 180° = green, and 270° = blue). [c] fw, fresh weight. [d] Means within a column and within a harvest season, pooled from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

Table 4. Internal Fruit Market Quality Attributes of Conventional vs Organic Rio Red Grapefruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and Ending in March 2006[a]

production system	harvest season	juice[c] specific gravity	juice (%)	juice color characteristics[b]		
				lightness	chroma	hue°
conventional	early	1.03 b[d]	40.0 b	36.1 b	15.8 a	28.4 b
organic, $P \leq 0.05$	early	1.05 a	42.1 a	38.8 a	13.0 b	38.0 a
conventional	mid	1.03 b	39.9 b	37.3 b	13.2 a	35.5 b
organic, $P \leq 0.05$	mid	1.05 a	42.6 a	39.7 a	11.5 b	45.8 a
conventional	late	1.04 a	43.0 b	38.0 a	13.1 a	41.4 a
organic, $P \leq 0.05$	late	1.05 a	44.5 a	38.7 a	12.8 a	41.9 a

[a] Mean comparisons are within a harvest season. [b] Lightness or darkness (+100 = white, –100 = black), chroma (+ = color intensity), and hue° or color (0° = red , 90° = yellow, 180° = green, and 270° = blue). [c] On a fresh weight basis. [d] Means within a column and within a harvest season, pooled from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

conventionally grown fruit were significantly heavier, had a thicker peel, and a darker (lower *L* value), more intense (higher *C* value), reddish-yellow color (hue°). As the production season advanced, fruit weights, peel lightness, and color intensity differences from the two systems became nonsignificant. However, some attribute differences were maintained. Organically grown fruits had greater specific gravities and a thinner peel, which is a highly desirable marketing attribute (*26*). Additionally, the peels of the organically grown fruit were more yellow but less reddish-yellow in peel color. According to U.S. Department of Agriculture grapefruit grading standards (*26*), the mid- and late season organic fruits likely would have received the highest grade: U.S. Fancy, for having a thin, smooth peel and yellow color, if no traces of green were apparent. However, organic fruits did have areas of measurable green coloration. All conventionally grown grapefruit likely would have received a lesser grade: U.S. No. 1, due solely to the thicker, less smooth peel. However, conventional grapefruit did have a darker, more uniform, intense reddish-yellow peel color with no traces of green. These observations suggest that grapefruit marketable qualities are greatly affected by production system inputs.

Internal fruit market quality attributes (juice specific gravity, percent juice, and juice color characteristics) at each harvest season were also affected by the production systems (**Table 4**). Early season conventionally grown grapefruit had significantly less percent juice, lower specific gravity, that is, less solids, but had a darker (lower *L* value), more intense (higher *C* value), reddish color (hue°). With the exception of percent juice, which was always greater in organically grown grapefruit, juice specific gravity and color characteristics between the two systems were statistically similar by late season harvest. According to U.S. Department of Agiculture grapefruit juice grading standards (*27*), both conventional and organic juices likely would have received the highest grade: Grade A, due to "good" color characteristics.

Some juice mineral content was influenced by both production system and harvest season (**Table 5**). Conventionally vs organically grown grapefruit were not significantly different for B, Cl, Cu, Fe, Na, P, or Zn. Although the relative amounts of these seven elements changed substantially from harvest season to harvest season, within a harvest, no significant differences between the two production systems were detectable. However, production system differences for juice Ca, K, Mg, Mn, and N (total nitrogen) contents were observed. Conventional grapefruit juice had significantly more total N, K, Mg, and Mn, and midseason juice had significantly more total N and Ca. By late season, there were no significant production system differences for juice mineral contents. In comparison to other crop studies (*28*−*30*), our mineral content differences showed little similarity. Conventionally grown carrot roots (*Dacus carota* L.) and cabbage (*Brassica oleracea* L. var. capitata) were higher in B, Cu, Mn, N, and S, and Mn, N, and Zn, respectively (*24*), whereas conventionally grown potatoes (*Solanum tuberosum* L.) and sweet corn (*Zea mays* L.) were higher in Ca, Cu, Mg, P, and Mg, respectively (*29*), and conventionally grown tomatoes (*Lycopersicon esculentum* Mill.) were higher in Ca, N, Na, and P (*30*). There appears to be no specific concentration of mineral nutrients, which are consistently higher or lower in conventional vs organic produce.

Human health-bioactive compounds ascorbic acid and lycopene, plus sugars, but not pectin, in grapefruit juice were affected by the production systems (**Table 6**). The concentrations of antioxidants ascorbic acid and lycopene were inversely proportional in conventional vs organic juice. Ascorbic acid was always higher, usually significantly higher in organic juice. The opposite was the case with lycopene. Although lycopene declined in both conventional and organic juice from early to late season harvest, the juice from conventionally grown fruit always had significantly higher concentrations. The total sugar content, like ascorbic acid, was also significantly higher in organically grown fruit juice. It is expected that an inverse relationship of higher ascorbic acid and total sugars with lower lycopene would occur in organic fruit as all three compounds are biosynthesized in chloroplasts. Sugars are synthesized during photosynthesis (*31*), ascorbic acid is synthesized from sugars, specifically glucose (*32*), and lycopene is synthesized via desaturation of phytoene during conversion of chloroplasts to chromoplast (*31*). Given that organic fruits were greener (higher hue), that is, indicating a higher level of intact chloroplasts than conventional fruit (**Table 3**), organic juice would have been expected to have higher ascorbic acid/total sugars with lower lycopene concentrations.

There was no difference in juice pectin from conventional vs organic grapefruit throughout the entire harvest season. It is possible these production systems had no effect on grapefruit pectin content, but the likely reason is that pectin levels in cut

Table 5. Juice Mineral Analyses of Conventional vs Organic Rio Red Grapefruit Juice from Fruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and Ending in March 2006[a]

production system	harvest season	total N[b] (%)	Cl (%)	ppm									
				P	K	B	Ca	Cu	Fe	Mg	Mn	Na	Zn
conventional	early	0.065 a[c]	0.10 a	98 a	2160 a	19.2 a	26 a	2.1 a	4.8 a	105 a	2.6 b	83 a	0.7 a
organic, $P \leq 0.05$	early	0.051 b	0.12 a	89 a	1938 b	22.6 a	29 a	2.7 a	5.4 a	88 b	5.9 a	62 a	1.0 a
conventional	mid	0.106 a	0.50 a	132 a	1309 a	15.7 a	102 a	1.4 a	4.1 a	86 a	2.4 a	64 a	0.8 a
organic, $P \leq 0.05$	mid	0.072 b	0.43 a	145 a	1246 a	17.8 a	44 b	1.2 a	7.0 a	85 a	2.5 a	61 a	0.6 a
conventional	late	0.191 a	0.34 a	139 a	1426 a	24 2 a	148 a	3.0 a	8.9 a	67 a	2.5 a	44 a	1.3 a
organic, $P \leq 0.05$	late	0.185 a	0.24 a	144 a	1414 a	24.1 a	132 a	2.3 a	10.4 a	65 a	2.2 a	41 a	1.1 a

[a] Mean comparisons are within a harvest season. [b] On a fresh weight basis. [c] Means within a column and within a harvest season, averaged from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

Table 6. Ascorbic Acid, Lycopene, Sugars, and Pectin in Conventional vs Organic Rio Red Grapefruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and Ending in March 2006[a]

production system	harvest season	juice[b] ascorbic acid (mg/100 g)	juice lycopene (mg/100 g)	juice total sugars (mg/mL)	juice pectin (%)
conventional	early	22.2 b[c]	0.87 a	104.9 b	0.15 a
organic, $P \leq 0.05$	early	31.0 a	0.52 b	108.0 a	0.16 a
conventional	mid	33.6 b	0.52 a	94.2 a	0.09 a
organic, $P \leq 0.05$	mid	41.5 a	0.25 b	95.6 a	0.09 a
conventional	late	33.2 a	0.48 a	107.9 b	0.13 a
organic, $P \leq 0.05$	late	33.7 a	0.30 b	118.2 a	0.12 a

[a] Mean comparisons are within a harvest season. [b] On a fresh weight basis. [c] Means within a column and within a harvest season, pooled from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

Table 7. Acidity, Soluble Solids Concentration, and Consumer Intensity and Acceptance of Conventional vs Organic Rio Red Grapefruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and Ending in March 2006[a]

production system	harvest season	juice[c] titratable acidity (% citric acid)	juice pH	juice soluble solids concentration (%)	juice consumer intensity and acceptance[b]		
					tart	sweet	overall
conventional	early	1.15 b[d]	3.4 a	9.7 b	3.7 b	5.4 a	6.5 a
organic, $P \leq 0.05$	early	1.20 a	3.3 b	10.1 a	5.2 a	4.0 b	6.1 b
conventional	mid	1.07 b	3.3 a	10.3 b	4.2 b	5.0 a	6.5 a
organic, $P \leq 0.05$	mid	1.24 a	3.2 b	10.8 a	5.6 a	3.8 b	5.9 b
conventional	late	1.00 a	3.4 a	10.2 b	4.2 b	5.8 a	6.9 a
organic, $P \leq 0.05$	late	1.04 a	3.3 b	10.8 a	5.2 a	4.6 b	5.6 b

[a] Mean comparisons are within a harvest season. [b] The consumer intensity (tartness and sweetness) or acceptance (overall) rating based on a scale of 1–10 for tart and for sweet: 0–4.0, not tart or not sweet; 7.1–10, extremely tart or extremely sweet; for overall: 0–4.0, extremely dislike; 7.1–10, extremely like ($n = 75$). [c] On a fresh weight basis. [d] Means within a column and within a harvest season, pooled from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

and squeezed grapefruit juices are lower than those of intact grapefruit sections due to pectin's higher concentration in the capillary membranes (*33*), which were excluded by our cutting and extracting (squeezing) process. Thus, our processing of Rio Red grapefruit juice samples may have confounded any difference that production systems may have had on pectin content.

Juice acidity, soluble solids, and consumer taste intensity and overall acceptability ratings were influenced by the production system (**Table 7**). Higher citric acid levels in organic vs conventional juice were reflected in significantly lower pH or more acidic juice. This more acidic organic juice was found to be significantly tarter tasting than conventional juice. Although organic juice had higher sugars (**Table 6**) and higher soluble solids concentrations (**Table 7**), consumer panelists did not perceive organic juice to be sweeter than conventional juice. The panelists perceived organic juice to be significantly less sweet than conventional juice, due likely to interference from the greater tartness, which was reflected in panelist overall acceptance of conventional juice to organic juice.

Another component of taste is bitterness. Naringin, a bitter principle in grapefruit juice detectable by humans at concentrations as little as 19 μg/g (*34*), was always significantly higher in organic grapefruit juice (**Table 8**). The concentrations of naringin, and another bitter compound common in grapefruit juice, neohesperidin (ranges of 13.1, 9.5, and 7.6 μg/g in conventional vs 15.0, 14.3, and 11.4 μg/g in organic), from early, mid and late season harvests, respectively, were significantly ($P \leq 0.05$) lower and likely contributed to consumer panelists finding conventional juice more acceptable (**Table 7**). Although organic grapefruit juice had higher concentrations of flavonoids, which can impart bitterness, these compounds are also known for their unique human wellness properties. Naringin, plus narirutin (ranges of 38.7, 35.4, and 27.8 μg/g in conventional vs 58.4, 52.5, and 38.4 μg/g in organic), from early, mid and

Table 8. Phenols: Flavonoid (Naringin), Furanocoumarins (Bergamottin, DHB, and DHB Dimers 708 and 728), Bergaptol, and Nitrate (NO_3–N) in Conventional vs Organic Rio Red Grapefruit Harvested November 1 (Early Season), January 2 (Midseason), and March 1 (Late Season) for Three Consecutive Years Starting in November 2003 and Ending in March 2005

		juice (μg/g)						
production system	harvest season	naringin[a]	bergamottin	6′,7′-dihydroxy-bergamottin	6′,7′-dihydroxy-bergamottin dimer 708	6′,7′-dihydroxy-bergamottin dimer 728	bergaptol	juice nitrate (ppm)
conventional	early	129.2 b[b]	14.18 a	18.86 a	0.39 a	2.31 a	2.04 b	322 a
organic, $P \le 0.05$	early	170.3 a	8.34 b	12.09 b	0.25 b	1.80 b	3.20 a	290 b
conventional	mid	118.2 b	11.97 a	15.97 a	0.43 a	1.87 a	2.36 b	348 a
organic, $P \le 0.05$	mid	155.3 a	6.46 b	7.25 b	0.18 b	0.36 b	3.46 a	310 b
conventional	late	116.2 b	10.37 a	14.80 a	0.33 a	1.70 a	3.09 b	361 a
organic, $P \le 0.05$	late	132.4 a	9.91 a	11.43 a	0.19 b	0.66 b	3.91 a	336 b

[a] On a fresh weight basis. [b] Means within a column and within a harvest season, pooled from three consecutive years, followed by the same letter are not different by LSMEANS ($n = 30$).

late season harvests, respectively, were significantly ($P \le 0.05$) higher for organic at each harvest. Neohesperidin helps protect against cancers, viral infections, inflammation allergies, fungal infections, and heart disease (*35*, *36*). Naringin, the predominant flavonoid in grapefruit juice, in particular, inhibits COX-2 activity. COX-2 is pivotal in the promotion of colon cancer (*37*).

The furanocoumarin bergamottin along with its derivatives DHB and DHB-dimers 708 and 728 have drug interactive consequences (*12*) and are largely responsible for interacting with cholesterol lowering, calcium channel blocker, antihistamine, and psychiatric medications (*38*). Bergamottin is less drug interactive than DHB, and DHB is less interactive than the DHB dimers (*11*). These furanocoumarins in grapefruit juice were influenced by production system and harvest time (**Table 8**). Bergamottin and its derivatives were significantly higher in conventional juice, increasing from 4 to 419%. As production season (harvest date) advanced, bergamottin concentrations declined in juices from both production systems, but the concentrations were still high enough to be pharmacologically interactive (*11*). Although bergamottin concentrations declined throughout the harvest season, the total furanocoumarin concentration (data not shown) increased as reflected in bergaptol content (**Table 8**), which increased throughout the harvest season. Begaptol, the starting compound from which bergamottins are biosynthesized, was significantly higher in organic than conventional juices, likely due to environmental factors or other cues, for example, production inputs, which are known to affect the bergaptol 5-*O*-methyltransferase activity (*39*). The increase in total furanocoumarin levels occurred with a concomitant increase in juice total N (**Table 5**) and nitrate content (**Table 8**). It is reasonable that increased juice N would be reflected in higher total furanocoumarins, as these compounds are biosynthesized from nitrogen-containing aromatic amino acids (*40*). Our findings of higher total phenols (furanocoumarins) in conventional vs organic, coupled with higher specific flavonoids (e.g., naringin) in organic vs conventional grapefruit juice are corroborated by similar phenolic compound findings in conventionally vs organically grown plums (*Prunus domestica* L.) (*41*).

Another compound in grapefruit juice affecting human health is nitrate, which is associated with methemoglobinemia (blue baby syndrome) in infants and gastric/intestinal cancer in adults (*42*). Nitrate was always significantly higher in conventional grapefruit juice and increased with harvest season in both production systems.

In conclusion, findings from this study have demonstrated inputs specific to conventional vs organic systems can significantly impact Rio Red whole grapefruit and juice marketable qualities and juice antioxidants, consumer taste and acceptance, human drug interactive compounds, secondary plant metabolites, and vitamins. Conventional fruit was better colored and higher in lycopene, and the juice was less tart, lower in the bitter principle naringin, and better accepted by the consumer panel than organic juice, whereas organic fruit had a commercially (marketability) preferred thinner peel, and the juice was higher in ascorbic acid and sugars and lower in the drug interactive bergamottin compounds and the negative health factor nitrate.

The consistency of our findings, repeated over a 5 month harvest season, interacting three consecutive years, is largely due to controlling the common fixed variables. If no input changes are made specific to either conventional or organic production system, these grapefruit quality differences should be assured for many years. However, the practical benefit of this study is that specific product quality differences in conventional and organic fertility inputs are now known (**Table 2**), and with additional research, these quality factors may be improved so that both systems provide great-tasting and highly nutritious grapefruit.

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