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Influence of Industrial and Alternative Farming Systems on Contents of Sugars, Organic Acids, Total Phenolic Content, and the Antioxidant Activity of Red Beet (*Beta vulgaris* L. ssp. *vulgaris* Rote Kugel)

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The contents of sugars, organic acids, total phenolic content, and the antioxidant activity were quantified in the flesh of red beet from conventional (CON), integrated (INT), organic (ORG), biodynamic (BD), and control farming systems using established methods. Significant differences were measured for malic acid, total phenolic content (TPC), and total antioxidant activity, where malic acid content ranged from 2.39 g kg^{-1} FW (control) to 1.63 g kg^{-1} FW (CON, ORG, and INT). The highest TPC was measured in BD and control samples (0.677 and 0.672 mg GAE g^{-1}, respectively), and the lowest in CON samples (0.511 mg GAE g^{-1}). Antioxidant activity was positively correlated with TPC (r^2 = 0.6187) and ranged from 0.823 μM TE g^{-1} FW to 1.270 μM TE g^{-1} FW in CON and BD samples, respectively, whereas total sugar content ranged from 21.03 g kg^{-1} FW (CON) to 31.58 g kg^{-1} FW (BD). The importance of sugars, organic acids, phenols, and antioxidants for human health, as well as for plant resilience and health, gained from this explorative study, is discussed and put into perspective.

KEYWORDS: ***Beta vulgaris*; red beet; organic farming; biodynamic farming; quality of food; farming system comparison; chemical composition; sugars; organic acids; total phenolic content; antioxidant activity**

INTRODUCTION

In recent times there has been increased interest in the influence of farming systems on food quality, especially regarding the composition and health promoting effects of food (*1*). The methods of industrial farming are ever more subjected to public pressure for their environmental and health effects (*2*). Alternatives have been sought, and an integrated approach toward agricultural production has been created (*3*). Moreover, demand for organically grown products is steadily growing and has exceeded supply in many countries (*3*). Consumer and research interest in the biodynamic farming system, which is regarded as a part of the organic farming movement, is posing questions regarding its influences and differences (*4*). A number of studies comparing organically and conventionally produced food have been conducted over the past 20 years, the results of which are summarized in various review papers (*5*−*8*). Findings point toward the trend that organically produced foodstuffs in most cases contain greater amounts of health promoting constituents (e.g., vitamins and phenols) and lesser amounts of harmful constituents (e.g., pesticide residues and nitrates). However, the results are not always consistent, as there is a great variety of environmental and production factors influencing the composition of food. Different approaches toward sampling also influence the comparison of food from different farming systems. Often, food is bought in the store or from the market and then the composition is compared (*5*). This presents one of the easiest methods for acquiring samples, and at the same time, it is the food that the consumer would eventually buy in the store or from the market. However, the influence of handling, transport, refrigeration and/or shelf life is not always given and is difficult to account for. Sampling different crop varieties can also strongly bias the results.

Another approach would be to find matching pairs of farms with different production systems in close proximity to each other. In this case, environmental and soil conditions are better matched between the samples, and similar varieties can be grown. One also has a better overview of the production methods and treatments used. However, it is hard to compare more than two different production systems (i.e., four), as so many different farms are often not in close proximity. It is also a challenge to control soil tillage, sowing, and harvesting dates, as practices differ with every farmer.

A controlled field trial is the third option, where most of the above-mentioned factors can be either controlled or at least recorded and where the same varieties and sowing/harvesting dates are applied in all systems under study. The drawback of such trials lies in the cost of establishing and running them. Plots also have to be large enough to gather practice relevant results and at the same time be manageable within a trial.

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Furthermore, the greater number of studies comparing vegetables from organic and conventional production has focused mainly on cabbage, carrots, tomatoes, and potatoes (*9*), whereas other vegetable crops have been examined more sporadically. In the only study found, comparing red beet from organic and conventional production, yields, holistic quality, and some internal quality parameters were investigated (*10*). Red beet is regarded as a good potential source of antioxidants and phenols (*11*−*15*), and it also expresses anticancer and radio-protective properties (*16*, *17*). It has also been shown to contain other health promoting constituents (*18*−*20*) and is therefore regarded as a good enrichment of the human diet (*21*). Furthermore, to date no studies have been published that investigate differences due to the production method in the contents of sugars, organic acids, total phenolic content, and the antioxidative activity in red beet. Thus, there is a need for more studies comparing the amounts of these substances in plant foods under well-defined conditions.

The main objectives of this study were, therefore, to (1) produce red beet in four different production systems (+control plots) in a controlled field trial, (2) collect representative samples of red beet roots, and (3) analyze the chemical composition (sugar, organic acid, total phenolic content, and the antioxidative activity) of red beet from the different farming systems under study.

MATERIAL AND METHODS

Chemicals. The following standards were used for the quantification of sugars and organic acids: sucrose, glucose and fructose; and citric, fumaric, malic, and shikimic acids from Sigma-Aldrich Chemie GmbH (Steinheim, Germany). The chemicals for the mobile phase were HPLC grade. For the total phenolic content, Folin-Ciocalteu phenol reagent (Fluka Chemie GmBH, Buchs, Switzerland), sodium carbonate (Merck, Darmstadt, Germany), gallic acid, and ethanol (Sigma-Aldrich) were used. For the antioxidant activity 1,1-diphenyl-2-picrylhydrazyl (DPPH), ascorbic acid, and methanol were purchased from Sigma-Aldrich.

Plant Material. The plant material was produced in a long-term field trial at the University Agricultural Centre of the University of Maribor in Pivola near Hoče (46°28′N, 15°38′E, 282 m a.s.l). Four production systems + control plots were arranged in a randomized complete block split-plot design with four replications. The size of the experimental field plots was 7 m × 10 m, with 4 m buffer zones between production systems. The farming systems differed mostly in plant protection and fertilization strategies and are defined by the valid legislation and standards: conventional (CON) (*22*), integrated (INT) (*22*−*24*), organic (ORG) (*22*, *25*), biodynamic (BD) (*22*, *25*, *26*) farming system, and control (*22*) plots, where no fertilization/plant protection was used. Basic soil cultivation, sowing, and harvesting dates and methods were identical among experimental plots and were performed on the same dates and in the same manner as that with adjacent fields (**Table 1**). Differences in fertilization and plant protection are presented in detail in **Table 2**. Two different five-course crop rotations were used, where red beet was preceded by 2 years of red clover-grass and spelt, and was succeeded by false flax. Two years prior to the beginning of the trial a red clover-grass mixture was grown on-site, and the whole experimental plot was managed according to organic farming standards for 6 years before the trial started in 2007.

The same varieties of crops were used in all farming systems, although the origin of the seed differed: organically produced seed for the ORG, BD, and control plots vs conventionally produced seed for CON and INT plots. The red beet variety Rote Kugel was chosen, as it is a quality variety for fresh consumption and processing, and its seed was the only one available in both CON and ORG origin.

Samples of red beet were picked on 19th August, 2009 from the center 10 m^2 of the experimental plots, cleaned, and samples from each plot stored separately at optimal conditions (*27*) in a cooling room at 6 °C and 95% relative humidity until the analyses were performed. Sample preparation for analyses was done on 4th November, 2009. For the analyses, 5 representative roots were taken from each stored plot/replication.

Table 1. Farming Systems under Investigation in the Field Trial and the Differences between Them[a]

production system	soil cultivation and basic operations	weed management	pest management	manure application
conventional farming according to the Slovene agriculture act and GAP	plowing, seedbed preparation, sowing, and harvesting	preventive use of herbicides according to GAP, harrowing when needed	preventive use of pesticides according to GAP	NPK and N mineral fertilizers used according to GAP and nutrient removal estimates
integrated farming according to Slovene standards for Integrated farming	plowing, seedbed preparation, sowing, and harvesting	use of herbicides according to the rules of INT management, harrowing at least once	curative use of pesticides according to the rules of INT management	NPK and N mineral fertilizers used on the basis of soil analysis and nutrient removal estimates
organic farming according to the EC Regulation on Organic Farming	plowing, seedbed preparation, sowing, and harvesting	harrowing 2−5 times/season, cover crops after cereals	use of some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1.4 LU of cattle manure/ha
biodynamic farming according to Demeter International Production Standards and EC Regulation on Organic Farming	plowing, seedbed preparation, sowing, and harvesting	harrowing 2−5 times/season, cover crops after cereals	use of BD preparations, some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1.4 LU of composted cattle manure/ha with added BD compost preparations
control plots	plowing, seedbed preparation, sowing, and harvesting	harrowing 1−3 times/season	none	none

[a] GAP, good agricultural practice; INT, integrated farming; EC, European commission; BT, *Bacillus thuringensis*; LU, livestock units; BD, biodynamic.

Table 2. Plant Protection and Fertilizer Applications for Red Beet (*Beta vulgaris* L. ssp. v*ulgaris* Rote Kugel) Production in the Year 2009[a]

			amounts of nutrients applied					
production system	plant protection applied	fertilizers applied (time of application)	N (kg/ha)	N (CON = 100%)	P (kg/ha)	P (CON = 100%)	K (kg/ha)	K (CON = 100%)
conventional farming		350 kg/ha NPK fertilizer 7:20:30 (before sowing)						
	- herbicides: - Goltix (4 kg/ha) - Fusilade forte (1.5 L/ha) - Beetup compact (3 L/ha) - Agil (1 L/ha)	325 kg/ha potassium salt (60% K) (before sowing) 270 kg/ha CAN fertilizer (27% N) (2 rates 1 month apart)	124.5	100	70	100	300	100
	- fungicides: - Amistar Extra (0.8 L/ha)							
	- insecticides: - Bulldock (0.5 L/ha)							
integrated farming		200 kg/ha NPK fertilizer 15:15:15 (before sowing)						
	- herbicides: - Goltix (4 kg/ha) - Fusilade forte (1.5 L/ha) - Beetup compact (3 L/ha) - Agil (1 L/ha)	450 kg/ha potassium salt (60% K) (before sowing) 270 kg/ha CAN fertilizer (27% N) (2 rates 1 month apart)	130	104	30	43	300	100
	- fungicides: - Amistar Extra (0.8 L/ha)							
	- insecticides: - Bulldock (0.5 L/ha)							
organic farming		21,450 kg/ha of cattle manure[b] (before plowing in autumn)	106	85	36	51	162	54
biodynamic farming	BD preparations 500, 501, 507	18,000 kg/ha of composted cattle manure[b] with BD preparations 502−507 added (before plowing in autumn)	112	90	57	81	45	15
control plots			0	0	0	0	0	0

[a] N, nitrogen; P, phosphorus; K, potassium; CON, conventional farming; BD, biodynamic. [b] Cattle manure and composted cattle manure were analyzed for their contents of NPK before application.

Analysis of Individual Carbohydrates and Organic Acids. Red beet samples were analyzed for their content levels of carbohydrates (sucrose, glucose, and fructose) and organic acids (malic, citric, succinic, and fumaric). In the laboratory, roots for each sample were peeled, halved, cut into small pieces, and thoroughly mixed. Thereafter, 5 g of the fresh mass was immersed in 15 mL of twice distilled water and homogenized with a T-25 Ultra-Turrax (Ika-Labortechnik, Stauden, Germany). The vegetable samples were left for extraction for half an hour at room temperature, with frequent stirring, and the extracted samples were centrifuged at 15 550*g* for 7 min at 10 °C (Eppendorf Centrifuge 5810R, Hamburg, Germany). The supernatants were filtered through a 0.45 μm filter (Macherey-Nagel, Düren, Germany), transferred to a vial, and analyzed according to the method described by Sturm, Koron, and Stampar (*28*) using high-performance liquid chromatography (HPLC; Thermo Scientific, Finnigan Spectra System, Waltham, MA, USA). For each analysis, 20 μL of sample was used. Analysis of sugars was carried out using a Rezex-RCM-monosaccharide column (300 × 7.8 mm; Phenomenex, Torrance, CA) and an RI detector with a flow of 0.6 mL min^{-1} and with column temperature maintained at 65 °C. For the mobile phase, twice distilled water was used and an RI detector for identification. Organic acids were analyzed using a Rezex-ROA-organic acid column (300 × 7.8 mm; Phenomenex, Torrance, CA), and the UV detector set at 210 nm with a flow of 0.6 mL min^{-1} maintaining the column temperature at 65 °C. For the mobile phase, 4 mM sulfuric acid (H_2SO_4) was used. The concentrations of carbohydrates and organic acids were calculated with the help of corresponding external standards.

Determination of Total Phenolic Content. In the laboratory, roots for each sample were peeled, halved, cut into small pieces, and thoroughly mixed. Five grams of each sample was extracted with methanol (10 mL) and homogenized with the T-25 Ultra-Turrax, then sonicated with Sonis 4 (Iskra pio, Ljubljana, Slovenia) for 1 h in a cooled water bath. After extraction, the sample extracts were centrifuged for 10 min at 15 550*g* at 4 °C. The supernatant was filtered through a Chromafil AO-45/25 polyamide filter (Macherey-Nagel, Düren, Germany) and transferred to a vial.

The total phenolic content (TPC) of the extracts was assessed using the Folin−Ciocalteu phenol reagent method (*29*). Six milliliters of twice-distilled water and 500 μL of Folin−Ciocalteu reagent were added to 100 μL of the sample extracts, and after waiting for between 8 s and 8 min at room temperature, 1.5 mL of sodium carbonate (20% w/v) and 1.9 mL of twice-distilled water were added. The extracts were mixed and allowed to stand for 30 min at 40 °C before measuring absorbance at 765 nm on a Lambda Bio 20 UV/vis spectrophotometer (Perkin-Elmer, Waltham, MA). A mixture of water and reagents was used as a blank. The total phenolic content was expressed as gallic acid equivalents (GAE) in mg per g FW of red beet. Absorptions were measured in three replicates.

Determination of Antioxidant Activity by the DPPH Radical Scavenging Method. Samples for the determination of antioxidant activity were prepared using the same method as that for TPC. The free radical scavenging activity of the red beet extracts was measured according to the DPPH (1,1-diphenil-2-picrylhydrazyl) method reported by Brand-Williams, Cuvelier, and Berset (*30*), with slight modifications. The extract (50 μL) was placed in 96-well microplates, and 200 μL of 0.1 mM methanolic solution of DPPH was added and allowed to react in the dark at room temperature. The decrease in absorbance of DPPH at 520 nm was measured at 5 min intervals by a spectrophotometer (Perkin-Elmer, Waltham, MA), until the absorbance stabilized (30 min). Methanol was used as a blank and DPPH solution without sample as a control. All samples were prepared in triplicate. Determination of antioxidant activity of the samples at various concentrations was made using the trolox standard curve. The DPPH radical scavenging activity of red beet extracts was expressed as μM trolox equivalents (TE) per g FW of red beet.

Statistical Design and Methods. Data were analyzed by one-way ANOVA with the production system as a factor using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warranton, VA). This was followed by least-squares means comparisons after Duncan's test (*31*). Values given within the article are means ± standard error of the mean (SEM).

RESULTS AND DISCUSSION

Sugars. The same variety of red beet from five different production systems (control, CON, INT, ORG, and BD) was examined in this study and the concentrations of individual sugars were assessed. The most abundant sugar in red beet was found to be sucrose, whereas fructose and glucose were found only in small amounts (**Table 3**). This corresponds with the findings of Rodriguez-Sevilla et al. (*20*), where sucrose was also found to be the most abundant sugar in raw red beet samples. Values for the total sugar content ranged from 21.03 g kg^{-1} (CON) to 31.58 g kg^{-1} (BD), whereas no statistically significant differences were found between the farming systems. Nevertheless, a trend of more total sugar content in organic farming systems is observable. Pfiffner et al. (*10*) compared red beet from different farming systems on the basis of sucrose content and reported no differences between the farming systems. However, also no account is given on the measured values. The importance of sugar content in vegetables is gaining increasing interest, as sugars constitute the main energy source in vegetarian diets (*20*), and information on the content of carbohydrates of food is of relevance also for diabetic patients, as they need to adapt insulin dosage accordingly (*32*). In addition, sugar is being intensively researched for its sensing and signaling functions in plant physiology and development, and it was found to be integrated with signaling pathways in plants (for inorganic nutrients, hormones and various stress factors) (*33*).

Table 3. Concentrations of Individual Sugars in Roots of Red Beet (*B. vulgaris* L. cv. Rote Kugel) Depending on Farming System in g kg^{-1} FW[a]

farming system	sucrose	glucose	fructose	total sugar
control	28.45 ± 7.36	0.28 ± 0.14	1.10 ± 0.21	29.83 ± 7.16
conventional	18.88 ± 4.85	0.65 ± 0.20	1.49 ± 0.19	21.03 ± 4.66
integrated	24.87 ± 2.63	0.80 ± 0.35	1.33 ± 0.19	27.01 ± 2.95
organic	23.70 ± 5.28	0.76 ± 0.17	1.55 ± 0.15	26.01 ± 5.34
biodynamic	29.26 ± 3.66	0.95 ± 0.39	1.37 ± 0.20	31.58 ± 3.49

[a] Average values ± standard errors are presented. No statistically significant differences were detected between the farming systems.

Organic Acids. Four organic acids were identified in red beet, namely, citric, malic, shikimic, and fumaric acid (**Table 4**). Shikimic acid was the most abundant organic acid. Statistically significant differences were found between different farming systems for malic acid content. The significantly highest values were measured in samples from control plots, followed by the BD samples. The CON, INT, and ORG samples contained significantly lower amounts of this organic acid compared to the samples from control plots. Results are partly in line with findings from previous studies, where higher values of malic acid were measured in maize and blueberries from organic production (*34*, *35*). A study of Rudrappa et al. (*36*) hints toward one of the possible reasons for this phenomenon. It was demonstrated that malic acid, selectively excreted through roots, signals beneficial rhizobacteria and encourages their interaction with plants. Beneficial soil bacteria have been found to confer immunity against a wide range of foliar diseases by activating plant defenses. Organic acids (as well as phenolic compounds) have been also found to participate in leveling out P deficiency by being excreted through plant roots (*37*). Levels of P added in our trial were similar for the INT and ORG systems and CON and BD systems (**Table 2**), whereas control plots received no additional P. The aforementioned potential role of organic acids and phenolic compounds in leveling out P deficiency is thus partly reflected in the malic acid concentrations and the TPC in our trial. However, the BD system deviates from this assumption in both cases; despite the relatively high levels of P added, high values for malic acid and TPC were also measured. Reasons for this deviation could be sought in a

Table 4. Concentrations of Organic Acids in Roots of Red Beet (*B. vulgaris* L. cv. Rote Kugel) Depending on the Farming System[a]

	(mg kg^{-1} FW)		(g kg^{-1} FW)		
farming system	citric acid	fumaric acid	malic acid	shikimic acid	total organic acid
control	290.07 ± 65.38	0.21 ± 0.13	2.39 ± 0.36 a	36.75 ± 6.77	39.43 ± 6.47
conventional	304.44 ± 62.16	0.46 ± 0.21	1.63 ± 0.07 b	25.03 ± 8.19	26.96 ± 8.21
integrated	311.71 ± 79.34	0.54 ± 0.07	1.63 ± 0.08 b	13.76 ± 1.00	15.70 ± 1.08
organic	218.41 ± 6.03	0.33 ± 0.10	1.63 ± 0.21 b	24.13 ± 10.74	25.98 ± 10.92
biodynamic	322.01 ± 3.59	0.58 ± 0.28	2.03 ± 0.11 ab	24.81 ± 8.88	27.05 ± 8.98

[a] Average values ± standard errors are presented. Different letters (a−b) in rows mean statistically significant differences between the farming systems at $p < 0.05$ (Duncan test).

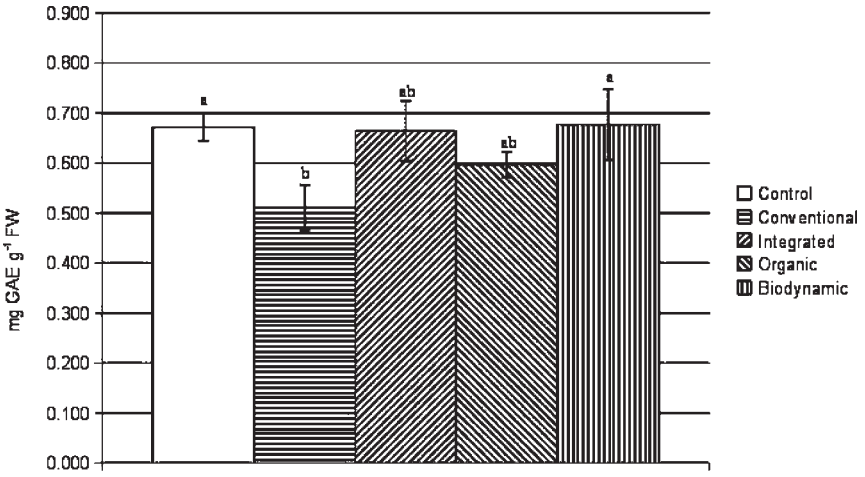

Figure 1. Total phenolic content of red beet depending on the farming system expressed as gallic acid equivalents (GAE) in mg g^{-1} FW of red beet. Average values ± standard errors are depicted. Different letters (a−b) above bars mean statistically significant differences in total phenolic content between the farming systems at $p < 0.05$ (Duncan test).

changed microbial structure, enzyme activity, or amino acid metabolism found in BD systems (*4*). The levels of potassium (K) added correspond better with the measured values of malic acid and TPC, for control and BD plots received substantially less K than CON, INT, and ORG plots (**Table 2**). However, the results are in contrast to the findings of Lobit et al. (*38*), who modeled malic acid accumulation and suggest that there is a strong positive effect of K on malic acid accumulation at the maturity stages of fruits. Levels of N added were similar in all production systems (except control) and are thus a less plausible explanation for the varying organic acid levels. Moreover, according to the carbon: nutrient balance hypothesis (*39*), reasons for a higher content of shikimic acid in some samples could be linked to lower nutrient availability, especially in the control system. However, results for the other systems under investigation are not consistent with this explanation of limited nutrient availability, and perhaps a more complex mechanism would better explain the differences. Plant-microbial interactions and plant−soil interactions are increasingly being researched and seem to play an important role in providing plants with nutrients and activating resilience against pests and diseases, where as a consequence food products can also gain some beneficial constituents/compounds (*37*). Reganold et al. (*1*) found more than 200 different unique strains of microorganisms in organic soils, as compared to only 2 in conventional soils for strawberry production.

Total Phenolic Content. TPC of red beet samples ranged from 0.51 mg g^{-1} FW GAE to 0.68 mg g^{-1} FW GAE in CON and BD beet, respectively. Samples from BD and control plots had significantly higher TPC than samples from CON plots (**Figure 1**). The importance of polyphenols as secondary plant metabolites is still under discussion. Some authors have demonstrated their anticarcinogenic activity (*40*, *41*) others their potential as an atherosclerosis drug (*42*). They have been also shown to play a role in plant defense mechanisms (*43*, *44*) as well as in the antioxidant activity of the plant (*43*). However, the effect of polyphenols strongly depends on the type of polyphenol and its combination with other compounds. It is therefore difficult to draw any definite conclusions on the health effects of total polyphenol content on humans on the basis of TPC. A more detailed composition analysis of TPC would be of assistance; this was, however, not within the scope of this research article.

Kujala et al. (*45*) report that the TPC of red beet samples decreases in the order peel > crown > flesh. Values measured in their studies ranged from 15.5 mg g^{-1} in the peel to 4.2 mg g^{-1} in the flesh (dry weight). When we compare these with regards to the dry matter (DM) content of red beet in our trial, where values of TPC lie between 3.16 mg g^{-1} DM GAE (CON) and 4.94 mg g^{-1} DM GAE (control), results are in a range similar to that in previous findings (*45*) since we determined TPC only in the flesh of the beets. We also have to consider that the quality deterioration of red beet roots in storage, although stored at optimal conditions, can be expressed in significantly lower TPC values over time (*45*). The roots in our trial were in storage for 2 months.

Antioxidant Activity. The antioxidant activity, expressed as Trolox equivalents (TE), ranged from 0.823 μM TE g^{-1} FW to 1.270 μM TE g^{-1} FW in CON and BD samples of red beet, respectively (**Figure 2**) . Kugler et al. (*12*) reported higher values for the antioxidant activity of red beet (11.103 μM TE g^{-1}), where freshly picked red beet roots of the same variety as in our study were extracted and analyzed. Also Pellegrini et al. (*15*) reported

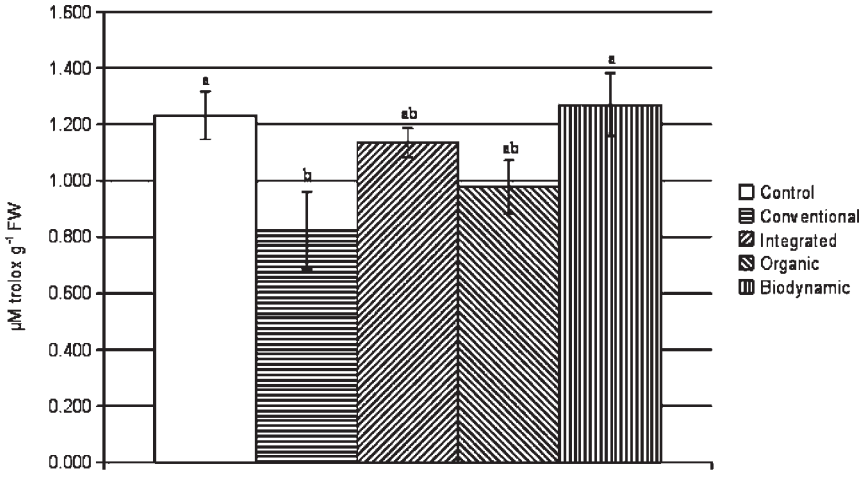

Figure 2. Antioxidative activity of red beet depending on the farming system expressed as μM Trolox equivalents per g FW of red beet. Average values ± standard errors are depicted. Different letters (a−b) above bars mean statistically significant differences in antioxidative activity between the farming systems at $p < 0.05$ (Duncan test).

higher values (5.21 μM TE g^{-1}) for red beet samples purchased at a supermarket. However, differences in attained values could be attributed to the different focus of the studies, as our interest lies in results given on an FW basis, rather than on a DM basis. If we include the DM content in the final results, values lie in a range similar to the findings of aforementioned studies (from 5.09 μM TE g^{-1} in CON to 9.05 μM TE g^{-1} in control samples) .

Samples from BD and control plots had significantly higher TE values than samples from CON plots (**Figure 2**). Furthermore, there is a significantly positive linear correlation between the TPC content and antioxidant activity ($r^2 = 0.6187$). This is in line with findings from other authors (*12*). However, one has to bear in mind that phenolic substances are not the only influence on the antioxidant activity of beet root. Close and McArthur (*46*) suggest, that phenolic content and antioxidant activity increases under conditions with high light or limited fertilization, in order to prevent photodamage to plants. When taking into account nutrients added to the farming systems under investigation (**Table 2**), this theory could partly explain the higher values measured in the alternative farming systems.

In conclusion we can affirm our assumption, that differences between farming systems do exist, even if sometimes only a trend is noticeable. What we could also observe was a variability in the results for some parameters, which may be attributed to the microvariability of soil and/or climatic conditions (as other factors were controlled: fertilization, plant protection, and soil cultivation), since the plots and the whole experimental area amounts to over 1 ha. However, this resembles field conditions in practice, where sometimes neighboring fields may have varying soil/climatic conditions and consequently also varying product quality. Despite this consideration, statistically significant differences were measured for malic acid, TPC, and antioxidant activity values, where red beet from the control production system expressed the significantly highest values, followed by BD, INT, and ORG systems, whereas significantly lower values were measured for red beet from the CON production system. It is also important to keep in mind that sometimes there is a variation within the different organic production systems in the same range as between organic and conventional production systems. This makes it difficult to draw categorical conclusions regarding food quality, and therefore, different production systems from the organic and conventional range have to be compared separately. Measurements done on one variety in one production year may also be regarded as of a more explorative nature; however, long-term trials comparing more varieties and production systems of many different crops are, as discussed already at the beginning of the article, highly time-, work- and resource-intensive, especially when all analyses following the trial and the gap between individual crops within the crop rotation are taken into account. Therefore, we believe that it is important to share and publish results of controlled field trials on a regular basis, in order to update the common base of scientific knowledge in this highly interesting area of production systems comparisons.

Because our interest in the contents of sugars, organic acids, TPC, and the antioxidant activity of red beet roots was focused on the consumer, the removal of the peel may have decreased the content of some constituents, especially when comparing the TPC and antioxidant activity values with those from other studies. However, results are of relevance to practice since few people, if any, eat unpeeled red beet roots. Furthermore, many vegetarians, vegans, and also omnivores consume fresh red beets in salads. Additionally, storage times of 2−3 months used in this study partly take into account quality changes due to storage. Examining the effect of longer storage times and processing procedures on red beet roots from different production systems, however, is seen as a future challenge and would additionally clarify the importance of production systems on the quality of food.

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LITERATURE CITED

(1) Reganold, J. P.; Andrews, P. K.; Reeve, J. R.; Carpenter-Boggs, L.; Schadt, C. W.; Alldredge, J. R.; Ross, C. F.; Davies, N. M.; Zhou, J. Fruit and Soil Quality of Organic and Conventional Strawberry Agroecosystems. *PLoS ONE* **2010**, *5*, e12346.

(2) Wackernagel, M.; Rees, W. *Our Ecological Footprint: Reducing Human Impact on the Earth*; New Society Publishers: British Columbia, Canada, 1995.

(3) Bavec, M.; Mlakar, S.; Rozman, C.; Pazek, K.; Bavec, F. Sustainable agriculture based on integrated and organic guidelines: understanding terms. The case of Slovenian development and strategy. *Outlook Agric*. **2009**, *38*, 89−95.

(4) Turinek, M.; Grobelnik-Mlakar, S.; Bavec, M.; Bavec, F. Biodynamic agriculture research progress and priorities. *Renew. Agric. Food Syst*. **2009**, *24*, 146−154.

(5) Bourn, D.; Prescott, J. A Comparison of the Nutritional Value, Sensory Qualities, and Food Safety of Organically and Conventionally Produced Foods. *CRC Crit. Rev. Food Sci*. **2002**, *42*, 1−34.

(6) Rembialkowska, E. Quality of plant products from organic agriculture. *J. Sci. Food Agric.* **2007**, *87*, 2757−2762.
(7) Velimirov, A.; Huber, M.; Lauridsen, C.; Rembialkowska, E.; Seidel, K.; Bügel, S. Feeding trials in organic food quality and health research. *J. Sci. Food Agric.* **2010**, *90*, 175−182.
(8) Worthington, V. Nutritional quality of organic versus conventional fruits, vegetables, and grains. *J. Altern. Complement Med.* **2001**, *7*, 161−173.
(9) Lairon, D. Nutritional quality and safety of organic food. A review. *Agron. Sustain. Dev.* **2010**, *30*, 9.
(10) Pfiffner, L.; Niggli, U.; Velimirov, A.; Boltzmann, L.; Balzer, U.; Balzer, F.; Besson, J. Effect of three farming systems (Bio-dynamic, bio-organic, conventional) on yield and quality of beetroot (*Beta vulgaris* L. var. *esculenta* L.) in a seven year crop rotation. *Acta Hortuc.* (*ISHS*) **1993**, *339*, 11−32.
(11) Gliszczynska-Swiglo, A.; Szymusiak, H.; Malinowska, P. Betanin, the main pigment of red beet: Molecular origin of its exceptionally high free radical-scavenging activity. *Food Addit. Contam.* **2006**, *23*, 1079−1087.
(12) Kugler, F.; Stintzing, F.; Carle, R. Evaluation of the antioxidant capacity of betalainic fruits and vegetables. *J. Appl. Bot. Food Qual.* **2007**, *81*, 69−76.
(13) Pradhan, S. K.; Holopainen, J. K.; Weisell, J.; Heinonen-Tanski, H. Human urine and wood ash as plant nutrients for red beet (*Beta vulgaris*) cultivation: impacts on yield quality. *J. Agric. Food Chem.* **2010**, *58*, 2034−2039.
(14) Mattila, P.; Hellström, J. Phenolic acids in potatoes, vegetables, and some of their products. *J. Food Compos. Anal.* **2007**, *20*, 152−160.
(15) Pellegrini, N.; Serafini, M.; Colombi, B.; Del Rio, D.; Salvatore, S.; Bianchi, M.; Brighenti, F. Total antioxidant capacity of plant foods, beverages and oils consumed in italy assessed by three different in vitro assays. *J. Nutr.* **2003**, *133*, 2812−2819.
(16) Sembries, S.; Dongowski, G.; Mehrlander, K.; Will, F.; Dietrich, H. Physiological effects of extraction juices from apple, grape, and red beet pomaces in rats. *J. Agric. Food Chem.* **2006**, *54*, 10269−10280.
(17) Lu, X.; Wang, Y.; Zhang, Z. Radioprotective activity of betalains from red beets in mice exposed to gamma irradiation. *Eur. J. Pharmacol.* **2009**, *615*, 223−227.
(18) Hansen, H. Comparison of chemical composition and taste of biodynamically and conventionally grown vegetables. *Plant Food. Hum. Nutr.* **1980**, *30*, 203−211.
(19) Bandyopadhyay, M.; Chakraborty, R.; Raychaudhuri, U. Effect of beet and honey on quality improvement and carotene retention in a carrot fortified milk product. *Innov. Food Sci. Emerg.* **2008**, *9*, 9−17.
(20) Rodríguez-Sevilla, M.; Villanueva-Suárez, M. J.; Redondo-Cuenca, A. Effects of processing conditions on soluble sugars content of carrot, beetroot and turnip. *Food Chem.* **1999**, *66*, 81−85.
(21) Hernandes, N.; Coneglian, R.; Godoy, R.; Vital, H.; Junior, M. Sensory acceptance tests of red beet (*Beta vulgaris* ssp *vulgaris* L.), cv. Early Wonder, minimally processed and irradiated. *Ciencia Tecnol. Alime.* **2007**, *27*, 64−68.
(22) MKGP Zakon o kmetijstvu **2008**.
(23) MKGP Pravilnik o integrirani pridelavi zelenjave **2002**.
(24) MKGP Pravilnik o integrirani pridelavi poljščin **2004**.
(25) EC 834/2007 Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91 **2007**.
(26) Demeter International e.V. Production Standards for the use of Demeter, Biodynamic and related trademarks **2009**.
(27) Henze, J.; Baumann, H. Quality of red beet (*Beta vulgaris* L.) as affected by storage conditions. *Acta Hortic.* **1979**, *93*, 59−66.
(28) Sturm, K.; Koron, D.; Stampar, F. The composition of fruit of different strawberry varieties depending on maturity stage. *Food Chem.* **2003**, *83*, 417−422.
(29) Singleton, V. L.; Rossi, J. A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144−158.
(30) Brand-Williams, W.; Cuvelier, M.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *Food Sci. Technol.-Leb.* **1995**, *28*, 25−30.
(31) Hoshmand, A. R. *Design of Experiments for Agriculture and the Natural Sciences*; 2nd ed.; Chapman & Hall/CRC, Boca Raton, Florida, 2006.
(32) Hecke, K.; Herbinger, K.; Veberic, R.; Trobec, M.; Toplak, H.; Stampar, F.; Keppel, H.; Grill, D. Sugar-, acid- and phenol contents in apple cultivars from organic and integrated fruit cultivation. *Eur. J. Clin. Nutr.* **2006**, *60*, 1136−1140.
(33) Hanson, J.; Smeekens, S. Sugar perception and signaling: an update. *Curr. Opin. Plant Biol.* **2009**, *12*, 562−567.
(34) Wang, S. Y.; Chen, C.; Sciarappa, W.; Wang, C. Y.; Camp, M. J. Fruit quality, antioxidant capacity, and flavonoid content of organically and conventionally grown blueberries. *J. Agric. Food Chem.* **2008**, *56*, 5788−5794.
(35) RÖhlig, R. M.; Engel, K. Influence of the input system (conventional versus organic farming) on metabolite profiles of maize (*Zea mays*) kernels. *J. Agric. Food Chem.* **2010**, *58*, 3022−3030.
(36) Rudrappa, T.; Czymmek, K. J.; Paré, P. W.; Bais, H. P. Root-secreted malic acid recruits beneficial soil bacteria. *Plant Physiol.* **2008**, *148*, 1547−1556.
(37) Badri, D. V.; Vivanco, J. M. Regulation and function of root exudates. *Plant Cell Environ.* **2009**, *32*, 666−681.
(38) Lobit, P.; Genard, M.; Soing, P.; Habib, R. Modelling malic acid accumulation in fruits: relationships with organic acids, potassium, and temperature. *J. Exp. Bot.* **2006**, *57*, 1471−1483.
(39) Lerdau, M.; Coley, P. D. Benefits of the carbon-nutrient balance hypothesis. *Oikos* **2002**, *98*, 534−536.
(40) Owen, R. W.; Giacosa, A.; Hull, W. E.; Haubner, R.; Spiegelhalder, B.; Bartsch, H. The antioxidant/anticancer potential of phenolic compounds isolated from olive oil. *Eur. J. Cancer* **2000**, *36*, 1235−1247.
(41) IUBMB; Fraga, C. G. *Plant Phenolics and Human Health: Biochemistry, Nutrition and Pharmacology*, 1st ed.; Wiley: Hoboken, New Jersey, 2009.
(42) Noguchi, N.; Niki, E. Phenolic antioxidants:: A rationale for design and evaluation of novel antioxidant drug for atherosclerosis. *Free Radical Biol. Med.* **2000**, *28*, 1538−1546.
(43) Veberic, R.; Trobec, M.; Herbinger, K.; Hofer, M.; Grill, D.; Stampar, F. Phenolic compounds in some apple (*Malus domestica* Borkh) cultivars of organic and integrated production. *J. Sci. Food Agric.* **2005**, *85*, 1687−1694.
(44) Mikulic Petkovsek, M.; Stampar, F.; Veberic, R. Accumulation of phenolic compounds in apple in response to infection by the scab pathogen *Venturia inaequalis*. *Physiol. Mol. Plant Pathol.* **2009**, *74*, 60−67.
(45) Kujala, T. S.; Loponen, J. M.; Klika, K. D.; Pihlaja, K. Phenolics and betacyanins in red beetroot (*Beta vulgaris*) root: distribution and effect of cold storage on the content of total phenolics and three individual compounds. *J. Agric. Food Chem.* **2000**, *48*, 5338−5342.
(46) Close, D. C.; McArthur, C. Rethinking the role of many plant phenolics - protection from photodamage not herbivores? *Oikos* **2002**, *99*, 166−172.

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