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EVALUATION OF THE NUTRITIONAL QUALITY OF SELECTED FRUIT AND VEGETABLES DEPENDING ON THE TIME AFTER FARM CONVERSION TO ORGANIC PRODUCTION METHODS

Summary

The quality of the organically produced fruit and vegetables is a frequent subject of research, but very few authors have investigated the differences in the content of biologically active compounds in organic agricultural crops depending on the age of the organic farms. At the same time, many studies have shown that the soil and the whole agroecosystems need time to stabilize after conversion of land to organic production. It suggests that in a mature, stable organic system one could expect higher yields and high quality of the crops. The aim of this study was to verify the following hypotheses: (1) the content of bioactive compounds in agricultural and horticultural crops is higher when they come from the organic production system compared with the conventional crops; (2) the content of bioactive compounds in crops is higher when they come from organic farms applying organic production standards for many years compared to those from the recently converted farms. The research material consisted of potato tubers (Irga variety), carrot roots (Flacoro variety) and apple fruit (varieties Idared and Antonówka) produced in (a) conventional farms, (b) organic farms in the second or third year after conversion, (c) organic farms in the fifth or sixth year after conversion, (d) organic farms over eight years after conversion. The collected fruit and vegetable samples were analyzed for dry matter, vitamin C, polyphenols, phenolic acids, flavonoids, carotenoids and chlorophylls. The results confirm the higher content of bioactive compounds in apples and carrots produced in organic compared to the conventional farms (this applies to most of the tested compounds in apples and total polyphenols & phenolic acids in carrots). At the same time, there was no significant impact of the production system on the content of the tested compounds in potato tubers (with the exception of ferulic acid and rutin, which were found in higher contents in the conventional tubers). In case of potatoes there was also no significant effect of the age of organic farms on the chemical composition of tubers. The exception was again ferulic acid and rutin, which, however, were found in higher contents in tubers from <3-year-old organic farms compared to those converted before 5-6 years. For carrots, the results did not confirm the hypothesis about the effect of time after conversion on the crop quality - the total content of polyphenols was highest in the carrot roots coming from the <3-year-old farms, significantly lower in the 5-6-year-old farms, and the lowest in the oldest (>8-year-old) farms; similar trends were found for phenolic acids and flavonoids (total). For carotenoids, dry matter and vitamin C no statistically significant differences were found between the carrot samples depending on the age of organic farms. In case of apple fruit, only 5-6-year-old and >8-year-old orchards were compared. Similarly to carrots, apple fruit from older (>8-year-old) orchards contained significantly lower contents of many of the tested compounds (flavonoids, carotenoids, chlorophylls) and dry weight compared with fruit from the younger (5-6-year old) orchards. However, the total content of polyphenols in apple fruit did not differ significantly depending on the age of organic farms. In conclusion, the study did not confirm the hypothesis that the content of bioactive compounds in plants is higher when they come from the farms applying organic production standards for many years compared to those just recently converted. In order to assess what other factors (agronomic practices, soil, weather, climate) affected the quality of agricultural products to a greater extent than the period of organic cultivation, the study should be continued on a wider scale.

Key words: *organic agriculture, conventional agriculture, time after conversion, nutritional quality, bioactive compounds, apple, carrot, potato*

OCENA WARTOŚCI ODŻYWCZEJ WYBRANYCH SUROWCÓW ROŚLINNYCH W ZALEŻNOŚCI OD CZASU STOSOWANIA EKOLOGICZNYCH METOD PRODUKCJI

Streszczenie

Jakość produktów rolnictwa ekologicznego jest częstym tematem prac badawczych, jednak bardzo niewiele jest prac pokazujących różnice w zawartości związków biologicznie czynnych w ekologicznych płodach rolnych w zależności od czasu stosowania ekologicznych metod produkcji. Tymczasem wiele badań wskazuje, że gleba i cały system przyrodniczy gospodarstwa ekologicznego potrzebują czasu, aby się ustabilizować. Tylko wtedy można oczekiwać dobrych i trwałych plonów oraz wysokiej jakości otrzymywanych płodów rolnych. Dlatego też celem prezentowanych badań była weryfikacja następujących hipotez badawczych: (1) zawartość związków bioaktywnych w surowcach roślinnych jest wyższa wówczas, gdy pochodzą one z ekologicznego systemu produkcji niż z konwencjonalnego; (2) zawartość związków bioaktywnych w surowcach roślinnych jest wyższa wtedy, gdy pochodzą one z gospodarstw ekologicznych prowadzonych od wielu lat metodami ekologicznymi w porównaniu do surowców z gospodarstw ekologicznych, które od niedawna stosują tę metodę produkcji. Materiał badawczy stanowiły bulwy ziemniaka odmiany Irga, korzenie marchwi odmiany Flacoro oraz owoce jabłoni odmiany Idared i Antonówka pochodzące z gospodarstw (a) konwencjonalnych, (b) ekologicznych w drugim lub trzecim roku od momentu

rozpoczęcia produkcji ekologicznej, (c) w piątym lub szóstym roku od momentu rozpoczęcia produkcji ekologiczne, (d) powyżej 8 lat od momentu rozpoczęcia produkcji ekologicznej. W próbkach owoców i warzyw oznaczono zawartość suchej masy, witaminy C, polifenoli ogółem, kwasów fenolowych, flawonoidów, karotenoidów i chlorofili. Wyniki potwierdzają wyższą zawartość związków bioaktywnych w jabłkach oraz marchwi z gospodarstw ekologicznych w porównaniu do tych z produkcji konwencjonalnej (dotyczy to większości badanych związków w jabłkach oraz polifenoli ogółem i kwasów fenolowych w marchwi). Jednocześnie nie stwierdzono wpływu systemu produkcji na zawartość badanych związków w bulwach ziemniaka (z wyjątkiem kwasu ferulowego i rutyny, których było więcej w bulwach z produkcji konwencjonalnej). W przypadku ziemniaków nie stwierdzono również prawie żadnych istotnych zależności w zakresie wpływu czasu prowadzenia gospodarstwa w sposób ekologiczny na skład chemiczny bulw. Wyjątkiem były kwas ferulowy oraz rutyna, których jednak było więcej w bulwach ziemniaka z gospodarstw <3-letnich niż 5-6-letnich. W przypadku marchwi stwierdzono zależności odwrotne do założonych w hipotezie – zawartość polifenoli ogółem była najwyższa w korzeniach marchwi uprawianych w <3-letnich gospodarstwach, mniejsza w 5-6-letnich, i najmniejsza w ponad 8-letnich; podobne tendencje stwierdzono dla kwasów fenolowych ogółem i flawonoidów ogółem. Dla karotenoidów, suchej masy i witaminy C nie stwierdzono statystycznie istotnych różnic pomiędzy próbkami w zależności od czasu prowadzenia gospodarstwa ekologicznego. W przypadku jabłek badano tylko sady 5-6-letnie i ponad 8-letnie, nie badano sadów młodych, <3-letnich. Podobnie jak w przypadku marchwi, stwierdzono istotnie mniejszą zawartość wielu badanych związków (flawonoidów, karotenoidów, chlorofili), a także suchej masy w jabłkach z sadów > 8-letnich w porównaniu z sadami 5-6-letnimi, natomiast poziom polifenoli ogółem w owocach nie różnił się istotnie w zależności od wieku gospodarstw ekologicznych. Podsumowując, w badaniach nie potwierdzono hipotezy mówiącej, że zawartość związków bioaktywnych w surowcach roślinnych jest wyższa wtedy, gdy pochodzą one z gospodarstw ekologicznych prowadzonych od wielu lat metodą ekologiczną w porównaniu do tych od niedawna stosujących tę metodę produkcji. W celu oceny, jakie inne czynniki (agrotechniczne, glebowe, pogodowe, klimatyczne) wpłynęły na jakość płodów rolnych w większym stopniu niż czas stosowania ekologicznych metod produkcji, badania powinny być kontynuowane na szerszym materiale doświadczalnym.
Słowa kluczowe: *rolnictwo ekologiczne, rolnictwo konwencjonalne, czas gospodarowania, wartość odżywcza, związki bioaktywne, jabłka, marchew, ziemniaki*

1. Introduction

As shown in recently published international meta-analysis based on nearly 350 original comparison studies [1], vegetables, fruit and grains from organic production are characterized by significantly higher contents of many groups of antioxidant compounds and are less frequently contaminated with pesticide residues as compared to conventionally cultivated crops. However, the literature does not always confirm the above [2, 3]. This raises the question about the reasons for discrepancies in the general assessment of the quality of organic vs. conventional food products. As the organic production system is known to be characterized by a gradual process of building homeostasis in the soil [4, 5], age of organic farms (the time of management according to organic farming standards) may be one of the crucial factors for the quality of agricultural products. There are very few studies showing the dynamics of the content of biologically active compounds in organic agricultural crops over years. Nardo et al. (2011) [6] reported no composition differences (in terms of bioactive substances content) between conventional tomatoes and those collected during the conversion period to organic farming. In their 10-year experiment, Mitchell et al. (2007) [7] showed that the content of flavonoids, especially quercetin and kaempferol, in tomato fruits was gradually increasing in the consecutive growing seasons, gaining the highest value in the tenth year of the experiment. However, authors of comparison studies often do not report any information about the age of organic farms included in their research. Therefore, it seems that the investigation of the impact of time of organic management on fruit and vegetables quality would be of interest. Moreover, among the published studies on the quality of organic crops (including the contents of a wide spectrum of bioactive compounds) only a few targeted potatoes, carrots or apples. As the mentioned vegetables and fruit form the basis of the agricultural and horticultural production in many European countries, and are of great economic and nutritional importance, it is of relevance to carry out research evaluating the quality of these crops cultivated in the organic agricultural system.

The aim of the presented study was therefore to evaluate the quality of organic vs. conventional crops, as well as to compare the quality of crops produced in organic farms depending on the age of the farm (time after conversion to organic farming). The following hypotheses have been raised: (1) vegetables and fruit from organic farms have a higher content of bioactive compounds compared with the same species and varieties coming from conventional production; (2) vegetables and fruit from the farms that have been applying organic production standards for many years are characterized by a higher quality (e.g. higher content of bioactive compounds) compared to those that have introduced organic management system recently.

2. Materials and methods

The research was carried out in the years 2014-2015 at the Warsaw of Life Sciences. The research material consisted of apple fruit (Idared and Antonówka variety), potato tubers (*Solanum tuberosum* L., Irga variety) and carrot roots (*Daucus carota* L., Flacoro variety) produced in conventional farms and certified organic farms, divided according to the time after conversion to organic farming standards: (a) in the second or third year after conversion, (b) in the fifth or sixth year after conversion, (c) over eight years after conversion. In case of apple fruit, only 5-6-year-old and >8-year-old orchards were compared. All farms selected for the study were located in Mazovian Voivodeship (central Poland) and were characterized by similar parameters of agricultural environment (i.e. soil and climate conditions). Plant material from each farm was collected in three replicates (size of each sample ≥1kg). The collected fruit and vegetable samples were analyzed in the laboratory of the Division of Organic Foodstuffs, Department of Functional and Organic Food and Commodities (WULS-

SGGW) for dry matter content, vitamin C, polyphenols, phenolic acids, flavonoids, carotenoids and chlorophylls.

Dry matter content of the examined fruit and vegetable samples was determined using gravimetric method, according to the Polish standard [8]. Before the chemical analyses, samples were ground and freeze-dried using a Labconco 2.5 freeze-drier (Labconco Corporation, Kansas City, Missouri, USA) at the temperature of -40 °C and under a pressure of 10 Pa. Freeze-dried samples were kept in plastic containers at -80°C, in order to prevent losses of biologically active compounds until further analyses.

Concentration of vitamin C was determined according to the Polish standard PN-A-04019:1998 [9]. The content of polyphenols (flavonoids and phenolic acids) was determined by HPLC method, with identification of individual phenolic compounds according to the Fluca and Sigma Aldrich standards with a purity of 99.98% (Shimazu equipment, USA Manufacturing Inc, USA: two pump LC-20AD, controller CBM-20A, column oven SIL-20AC, spectrometer UV/Vis SPD-20 AV) [10].

The contents of carotenoids (in all crops) and chlorophylls (in apples) were determined by HPLC method (Shimazu equipment as described above) [11]. Individual carotenoids (lutein, β-carotene and α-carotene) and chlorophylls (a and b) were identified on the basis of the Fluca standards with a purity of 99.98%. Each analysis was done in three technical replications.

The results are presented as mean (g or mg) per 100 g of fresh weight (f.w.) ± standard error (SE). The data were subjected to one-factor analysis of variance ANOVA, followed by the parametric post-hoc Tukey's test (α = 0.05), using Statgraphics Plus 5.1. software (StatPoint Technologies, Inc, Warrenton, Virginia, USA), with (a) production method (organic and conventional) or (b) age of organic farm (0 = conv.; <3y, 5-6y, >8y) as a factor. The p-values are given in the tables. If the result of the analysis was not statistically significant, it was designated as ns.

3. Results and discussion

The samples of potato tubers (Irga variety) were analyzed for dry matter, vitamin C, polyphenols (total), phenolic acids (total, in that: gallic, chlorogenic, caffeic, p-coumaric, ferulic acid), flavonoids (total, in that: rutin, myricetin) and carotenoids (total and individual: lutein, zeaxanthin, β-carotene). The results of the contents of the listed nutritional quality parameters depending on (a) the agricultural production system (organic vs. conventional) and (b) time after farm conversion to organic production methods (<3 years, 5-6 years, >8 years) are presented in Table 1.

No significant impact of the agricultural production system on the content of the tested compounds in potato tubers was identified, with the exception of ferulic acid and rutin, which were found in higher contents in the conventional tubers, $p<0.0001$ and $p=0.0055$ respectively). In case of potatoes there was also no significant effect of the age of organic farms on the chemical composition of tubers. The exceptions were again ferulic acid and rutin, which, however, were found in higher contents in tubers from <3-year-old organic farms compared to those converted before 5-6 years.

Table 1. Selected nutritional quality parameters of potato tubers (*Solanum tuberosum* L., Irga variety) depending on (a) the agricultural production system (organic vs. conventional) and (b) time after farm conversion to organic production methods (<3 years, 5-6 years, >8 years) (mg/100g f.w.)

Composition parameters	Time after conversion (years)				p-value	Production system		p-value
	Conventional (n=3)*	Organic <3y (n=6)	Organic 5-6y (n=9)	Organic >8y (n=18)		Conventional (n=3)	Organic (n=33)	
Dry matter (g/100g f.w.)	18.33±0.15**	19.36±0.40	19.43±0.94	19.71±0.25	ns	18.33±0.15	19.5±0.30	ns
Vitamin C	39.97±1.20	23.00±5.65	37.37±5.38	30.88±3.60	ns	39.97±1.20	30.42±2.79	ns
Polyphenols (total)	4.87±0.13	4.88±0.72	4.30±0.30	4.01±0.26	ns	4.87±0.13	4.40±0.21	ns
Phenolic acids (total)	4.24±0.14	4.25±0.73	3.72±0.32	3.42±0.26	ns	4.24±0.14	3.80±0.21	ns
Gallic acid	0.46±0.21	0.27±0.07	0.46±0.17	0.31±0.10	ns	0.46±0.21	0.35±0.07	ns
Chlorogenic acid	0.41±0.00	1.80±0.61	1.44±0.44	0.98±0.28	ns	0.41±0.00	1.41±0.23	ns
Caffeic acid	0.14±0.02	0.12±0.01	0.19±0.03	0.26±0.04	ns	0.14±0.02	0.19±0.03	ns
p-coumaric acid	0.73±0.05	0.78±0.04	0.83±0.08	0.88±0.04	ns	0.73±0.05	0.83±0.03	ns
Ferulic acid	2.50±0.11c	1.28±0.16b	0.80±0.03a	1.00±0.09ab	<0.0001	2.50±0.11b	1.02±0.06a	<0.0001
Flavonoids (total)	0.63±0.00	0.63±0.01	0.58±0.03	0.59±0.01	ns	0.63±0.00	0.60±0.01	ns
Rutin	0.24±0.01b	0.22±0.01b	0.17±0.01a	0.18±0.01a	<0.0001	0.24±0.01b	0.19±0.01a	0.0055
Myricetin	0.39±0.00	0.41±0.01	0.41±0.02	0.41±0.01	ns	0.39±0.00	0.41±0.01	ns
Carotenoids (total)	1.11±0.02	1.20±0.02	1.20±0.05	1.21±0.02	ns	1.11±0.02	1.21±0.02	ns
Lutein	0.24±0.01	0.25±0.01	0.24±0.01	0.24±0.01	ns	0.24±0.01	0.24±0.00	ns
Zeaxanthin	0.11±0.00	0.12±0.00	0.12±0.01	0.12±0.00	ns	0.11±0.00	0.12±0.00	ns
β-carotene	0.76±0.01	0.83±0.02	0.84±0.04	0.86±0.01	ns	0.76±0.01	0.84±0.01	ns

*n – number of samples; ** average ± standard error; means in a row followed by different letters are significantly different (Tukey's test, p< 0.05); ns, not statistically significant

Source: own work

The results of the chemical analyzes of carrots (Flacoro variety) are presented in Table 2. These include the content of dry matter, vitamin C, polyphenols (total), phenolic acids (total), gallic, chlorogenic, p-hydroxybenzoic, coffee, p-coumaric and ferulic acid, flavonoids (total), rutin, quercetin glycosides, kaempferol, carotenoids (total), lutein, zeaxanthin, α-carotene, β-carotene. The obtained results confirm a tendency towards higher contents of polyphenols (p = 0.0780) and phenolic acids (p = 0.0704), in particular gallic acid (p = 0.0441), in organic compared to conventional carrots (Table 2).

For carrots, the results did not confirm the hypothesis about the effect of time after conversion on the crop quality - the total content of polyphenols was highest in the carrot roots coming from the <3-year-old farms (37.64±3.67 mg/100g f.w.), significantly lower in the 5-6-year-old farms (26.77±2.91 mg/100g f.w.), and the lowest in the oldest (>8-year-old) farms (18.65±1.99 mg/100g f.w.). Similar trends were found for phenolic acids and flavonoids (both total and individual compounds). For carotenoids, dry matter and vitamin C no statistically significant differences were found between the carrot samples depending on the age of organic farms.

Table 3 shows apple composition parameters depending on the production system and the age of the organic farms. In case of apple fruit, only 5-6-year-old and >8-year-old orchards were compared. The measured compounds included dry matter, vitamin C, polyphenols (total), phenolic acids (total, gallic acid, chlorogenic acid, p-coumaric acid), flavonoids (total, epigallocatechin gallate, rutin, kaempferol, kaempferol glucoside, quercetin, quercetin glucoside), carotenoids (total, lutein, zeaxanthin, β-carotene), chlorophylls (total, chlorophyll b, chlorophyll a).

The results confirm a significant effect of the agricultural production system on the content of bioactive compounds in apples. This applies to most of the tested compounds, found in significantly higher concentrations in organic compared to the conventional apples. Organically produced apples contained twice as much polyphenols, vitamin C, flavonoids and phenolic acids (total), 3 times more chlorogenic acid and nearly 20% more carotenoids (total) compared to those produced conventionally (Table 3). However, no statistically significant effect of the agricultural system on the content of dry matter, chlorophylls (total and chlorophyll b), p-coumaric acid, four individual flavonoids and each of the individual tested carotenoids was identified.

Analysis of the effect of the time after conversion to organic farming methods on the quality of apple did not confirm the research hypothesis. Similarly to carrots, apple fruit from older (>8-year-old) orchards contained significantly lower contents of many of the tested compounds (flavonoids, carotenoids, chlorophylls) and dry weight compared with fruit from the younger (5-6-year old) orchards. However, the total content of polyphenols in apple fruit did not differ significantly depending on the age of organic farms (Table 3).

Table 2. Selected nutritional quality parameters of carrot roots (Daucus carota L., Flacoro variety) depending on (a) the agricultural production system (organic vs. conventional) and (b) time after farm conversion to organic production methods (<3 years, 5-6 years, >8 years) (mg/100g f.w.)

Composition parameters	Time after conversion (years)				p-value	Production system		p-value
	Conventional (n=3)*	Organic <3y (n=3)	Organic 5-6y (n=6)	Organic >8y (n=15)		Conventional (n=3)	Organic (n=24)	
Dry matter (g/100g f.w.)	12.96±0.06**	15.09±1.80	13.79±0.29	12.76±0.46	ns	12.96±0.06	13.88±0.40	ns
Vitamin C	17.84±0.30	18.52±1.42	18.78±3.87	18.89±0.86	ns	17.84±0.30	18.75±1.12	ns
Polyphenols (total)	12.18±0.25a	37.64±3.67c	26.77±2.91b	18.65±1.99a	0.0006	12.18±0.25	27.69±2.01	0.0780
Phenolic acids (total)	7.84±0.17a	29.71±3.80b	23.04±2.60b	13.56±1.73a	0.0004	7.84±0.17	22.1±1.82	0.0704
Gallic acid	2.22±0.03a	12.86±1.98b	15.85±1.51b	7.87±1.64ab	0.0079	2.22±0.03a	12.20±1.33b	0.0441
Chlorogenic acid	0.50±0.01	2.05±0.31	1.95±0.63	1.16±0.11	ns	0.50±0.01	1.72±0.19	ns
p-hydroxybenzoic	1.66±0.05a	3.14±0.47b	1.74±0.17a	1.60±0.23a	0.0480	1.66±0.05	2.16±0.19	ns
Caffeic acid	0.32±0.03a	0.62±0.04b	0.28±0.03a	0.30±0.04a	0.0035	0.32±0.03	0.40±0.03	ns
p-coumaric acid	0.92±0.03ab	1.42±0.12b	0.47±0.19a	0.60±0.13a	0.0420	0.92±0.03	0.83±0.11	ns
Ferulic acid	2.22±0.12a	9.61±0.90b	2.75±0.83a	2.03±0.15a	<0.0001	2.22±0.12	4.80±0.56	ns
Flavonoids (total)	4.34±0.08a	7.93±0.12b	3.73±0.39a	5.09±0.50a	0.0110	4.34±0.08	5.58±0.41	ns
Rutin	0.12±0.00	0.20±0.02	0.28±0.01	0.27±0.05	ns	0.12±0.00	0.25±0.03	ns
Quercetin glycoside	0.19±0.00a	1.52±0.16b	0.26±0.03a	0.61±0.12a	0.0007	0.19±0.00	0.80±0.11	ns
Kaempferol	4.03±0.08a	6.21±0.30b	3.19±0.40a	4.22±0.41a	0.0420	4.03±0.08	4.54±0.33	ns
Carotenoids (total)	18.04±0.51	14.64±1.75	21.68±0.70	19.81±1.74	ns	18.04±0.51	18.71±1.20	ns
Lutein	0.07±0.00	0.12±0.01	0.18±0.02	0.17±0.03	ns	0.07±0.00	0.16±0.02	ns
Zeaxanthin	0.04±0.00	0.06±0.01	0.05±0.00	0.05±0.00	ns	0.04±0.00	0.05±0.00	ns
α-carotene	7.18±0.40	8.17±1.00	9.88±0.32	8.91±0.83	ns	7.18±0.40	8.99±0.55	ns
β-carotene	10.75±0.22	6.29±0.73	11.56±0.37	10.68±0.90	ns	10.75±0.22	9.51±0.66	ns

*n – number of samples; ** average ± standard error; means in a row followed by different letters are significantly different (Tukey's test, p< 0.05); ns, not statistically significant

Source: own work

Table 3. Selected nutritional quality parameters of apple fruit depending on (a) the agricultural production system (organic vs. conventional) and (b) time after farm conversion to organic production methods (<3 years, 5-6 years, >8 years) (mg/100g f.w.)

Composition parameters	Time after conversion (years)			p-value	Production system		p-value
	Conventional (n=6)*	Organic 5-6y (n=6)	Organic >8y (n=18)		Conventional (n=6)	Organic (n=24)	
Dry matter (g/100g f.w.)	12.02±0.30a**	14.53±0.18b	12.68±0.34a	0.0036	12.02±0.30	13.61±0.31	ns
Vitamin C	6.04±0.48a	13.15±0.54b	10.89±0.73b	0.0002	6.04±0.48a	12.02±0.60b	0.0002
Polyphenols (total)	11.68±0.56a	22.58±0.33b	23.76±1.53b	0.0002	11.68±0.56a	23.17±1.15b	<0.0001
Phenolic acids (total)	5.13±0.34a	9.71±0.34ab	13.89±1.40b	0.0017	5.13±0.34a	11.80±1.12b	0.0021
Gallic acid	1.73±0.05	2.27±0.12	2.27±0.17	ns	1.73±0.05a	2.27±0.13b	0.0020
Chlorogenic acid	2.72±0.27a	6.02±0.45ab	8.79±0.96b	0.0019	2.72±0.27a	7.40±0.78b	0.0020
p-coumaric acid	0.68±0.03	1.42±0.22	2.82±0.63	ns	0.68±0.03	2.12±0.49	ns
Flavonoids (total)	6.54±0.23a	12.87±0.44c	9.87±0.82b	0.0033	6.54±0.23a	11.37±0.68b	0.0093
Epigallocatechin gallate	3.85±0.16a	7.63±0.30b	5.80±0.70ab	0.0430	3.85±0.16	6.72±0.56	ns
Rutin	0.75±0.07a	2.40±0.56b	1.35±0.19a	0.0150	0.75±0.07a	1.88±0.22b	<0.0001
Kaempferol	1.12±0.02b	1.19±0.02b	0.99±0.04a	0.0350	1.12±0.02	1.09±0.03	ns
Kaempferol glucoside	0.18±0.00a	0.29±0.02ab	0.44±0.06b	0.0220	0.18±0.00a	0.37±0.05b	0.0220
Quercetin	0.12±0.00a	0.11±0.01a	0.20±0.02b	0.0110	0.12±0.00	0.15±0.02	ns
Quercetin glu-coside	0.53±0.00a	1.25±0.03b	1.09±0.06b	<0.0001	0.53±0.00	1.17±0.05	ns
Carotenoids (total)	2.07±0.10a	2.61±0.14b	2.31±0.07a	0.0190	2.07±0.10a	2.46±0.07b	0.0440
Lutein	0.06±0.01	0.06±0.00	0.08±0.02	ns	0.06±0.01	0.07±0.01	ns
Zeaxanthin	0.04±0.00a	0.05±0.00b	0.04±0.00a	0.0024	0.04±0.00	0.04±0.00	ns
β-carotene	1.97±0.09a	2.51±0.14b	2.19±0.06a	0.0133	1.97±0.09	2.35±0.07	ns
Chlorophylls (total)	0.48±0.01a	0.59±0.02b	0.52±0.01a	0.0023	0.48±0.01	0.56±0.01	ns
Chlorophyll b	0.23±0.01a	0.28±0.00b	0.24±0.01a	0.0047	0.23±0.01	0.26±0.01	ns
Chlorophyll a	0.26±0.01a	0.32±0.01b	0.28±0.01a	0.0040	0.26±0.01a	0.30±0.01b	0.0280

*n – number of samples; ** average ± standard error; means in a row followed by different letters are significantly different (Tukey's test, $p < 0.05$); ns, not statistically significant

Source: own work

All crops tested in the study were abundant in polyphenols, in that mainly in phenolic acids and flavonoids. Higher concentrations of these compounds were found on average in organically vs. conventionally produced carrot and apple, but no significant differences were identified in case of potato tubers. For vitamin C, higher concentrations were found in organic vs. conventional apple fruit, while potato tubers and carrot roots did not differ with respect to the contents of this vitamin depending on the agricultural production system. The nutritional quality (i.e. content of the mentioned biologically active compounds) of agricultural crops is known to be affected by genetic (species, cultivar) and environmental factors, as well as agronomic conditions, including cultivation system and post-harvest management [12]. Synthesis of such biochemicals as e.g. polyphenols, can be enhanced by providing certain conditions of plant growth. Nitrogen availability is one of the most important factors. It has been well proven that in growing environments poor in easily assimilable nitrogen (e.g. organic farms), plant metabolism changes in the direction of intensive production of carbon-based chemicals (i.e. phenolic acids, flavonoids, vitamin C). In contrast, high levels of mineral nitrogen fertilizers used in conventional production result in a decrease in the phenolic concentrations in fruits and vegetables [12-17]. Numerous studies indicate that organically produced plant foods are richer in polyphenols compared to conventional products [18-21]. This was also confirmed by the recently published meta-analysis based on nearly 350 carefully selected research papers [1] concluding that plants from organic system contain nearly 60 percent more polyphenolic compounds in comparison to conventional ones.

Total carotenoids content was found to be dependent on the way of apple cultivation (higher concentrations in organic vs. conventional apple fruit), while no effects of the production system were identified in case of carotenoids in potato tubers and carrot roots. According to the study of Kazimierczak et al. [22] medicinal plants from conventional production contained significantly more carotenoids, including lutein and β-carotene, than the organically produced ones. Dean et al. [23] investigated the effect of different levels of nitrogen fertilization on the synthesis of carotenoids by watercress and found a positive correlation between the content of nitrogen in the substrate and the concentration of carotenoids in plant tissues. Similarly, Kaack et al. [24] have reported that the more mineral nitrogen was readily available for carrots at the beginning of the growing season, the more β-carotene has been produced in the carrot roots. As already discussed, soil in organic farming contains less assimilable form of nitrogen compared to the conventional system, thus N availability to plants is lower, what should translate into lower contents of carotenoids in organic plants (not confirmed by the presented study). However, it is important to underline that the plant carotenoids synthesis strongly depends not only on the production system (organic or conventional; availability of minerals in the soil), but also on numerous non-agricultural factors faced by plants during vegetation (e.g. intensity of insolation, temperature) [25].

With regard to the impact of time after conversion on the contents of measured compounds, no such effect was identified in case of potatoes, while in case of carrots and apples the results showed higher contents of most of the tested biochemicals in younger compared to older organic farms. As the organic production system is known to be characterized by a gradual process of building homeostasis in the soil [4, 5], the opposite result was expected (with the higher antioxidants concentrations in fruit and veg from the farms that have been applying organic farming standards for many years). As already mentioned, there are just a few studies showing the changes in the content of biologically active compounds in organic agricultural crops over years, e.g. Mitchell et al. (2007) [7] showed that the content of flavonoids, especially quercetin and kaempferol, in tomato fruits was gradually increasing in the consecutive growing seasons, gaining the highest value in the tenth year of the experiment. However, the same have not been confirmed in the presented study.

4. Conclusions

The study confirmed the hypothesis on the higher content of important bioactive compounds in organic vs. conventional apples and carrots - this applied to most of the tested compounds in apple fruit and total polyphenols & phenolic acids in carrot roots. However, no significant impact of the production system on the content of the tested compounds in potato tubers was identified. At the same time, the hypothesis that the content of bioactive compounds in plants is higher when they come from the farms applying organic production standards for many years compared to those just recently converted, has not been confirmed. In order to assess what kind of other factors (agronomic practices, soil, weather, climate) affected the quality of agricultural products to a greater extent than the time (years) of organic cultivation, the study should be continued on a wider scale, including more samples collected from the farms, ideally in a number of consecutive years, as well as including some additional analyses (e.g. soil analyses).

5. References

[1] Baranski M., Średnicka-Tober D., Volakakis N., Seal C., Sanderson R., Stewart G.B., Benbrook C., Biavati B., Markellou E., Giotis C., Gromadzka-Ostrowska J., Rembiałkowska E., Skwarło-Sońta K., Tahvonen R., Janovska D., Niggli U., Nicot P., Leifert C. (2014): Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. British Journal of Nutrition, Vol. 112, 5, 794-811.

[2] Dangour A.D., Dodhia S.K., Hayter A., Allen E., Lock K., Uauy R. (2009): Nutritional quality of organic foods: a systematic review. American Journal of Clinical Nutrition, Vol. 90, 3, 680-685.

[3] Smith-Spangler C., Brandeau M.L., Hunter G.E., Bavinger J.C., Pearson M., Eschbach P.J., Sundaram V., Liu H., Schirmer P., Stave C., Olkin I., Bravata D.M. (2012): Are organic foods safer or healthier than conventional alternatives?: a systematic review. Annals of Internal Medicine, Vol. 157, 5, 348-366.

[4] van Diepeningen A.D., de Vos O.J., Korthals G.W., van Bruggen A.H.C. (2006): Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. Applied Soil Ecology, Vol. 31, 120-135.

[5] Mäder P., Flieβbach A., Dubois D., Gunst L., Fried P., Niggli N. (2002): Soil Fertility and Biodiversity in Organic Farming. Science, Vol. 296, 1694-1697.

[6] Nardo N., Foddai M.S., Azzini E., Baiamonte I., Di Ferdinando S., Paoletti S., Vizioli V., Paoletti F. (2011): Tomato (Lycopersicon esculentum, cv. cxd271bio) yield and quality during conversion from conventional to organic production. In: Pulkrabova J., Tomaniova M., Kahl J., Hajslova J. (EDS.). Proceedings of the First International Conference on Organic Food Quality and Health Research, Prague, 18-20 May 2011, Vol. 29.

[7] Mitchell A.E., Hong Y.J., Koh E., Barrett D.M., Bryant D.E., Denison R.F., Kaffka S. (2007): Ten-year comparison of the influence of organic and conventional crop management practices on the content of flavonoids in tomatoes. Journal of Agricultural and Food Chemistry, Vol. 55, 6154-6159.

[8] Polish Standard (2001): PN-EN 12145:2001. Fruit and vegetable juices. The estimation of dry matter. Gravimetric method.

[9] Polish Standard (1998): PN-A-04019:1998. Food products. Determination of vitamin C content. Polish Committee for Standardization.

[10] Hallmann E. (2012): The influence of organic and conventional cultivation systems on the nutritional value and content of bioactive compounds in selected tomato types. Journal of the Science of Food and Agriculture, Vol. 92, 14, 2840-2848.

[11] Nishiyama I., Fucusa T., Oota T. (2005): Genotypic differences in chlorophyll, lutein and beta-carotene contents in the fruits of Actinidia species. Journal of Agricultural and Food Chemistry, Vol. 53, 6403-6407.

[12] Bloksma J., Northolt M., Huber M., van der Burgt G.J., van de Vijver L. (2007): A new food quality concept based on life processes. [In:] Cooper J., Niggli U, Leifert C. (eds.). Handbook of organic food safety and quality, CRC Press, 53-73.

[13] Heeb A., Lundegårdh B., Savage G., Ericsson T. (2006): Impact of organic and inorganic fertilizers on yield, taste, and nutritional quality of tomatoes. Journal of Plant Nutrition and Soil Science, Vol. 169, 535-541.

[14] Stefanelli D., Goodwin I., Jones R. (2010): Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. Food Research International, Vol. 43, 1833-1843.

[15] Brandt K., Mølgaard J.P. (2001): Organic agriculture: does it enhance or reduce the nutritional value of plant foods? Journal of the Science of Food and Agriculture, Vol. 81, 924-931.

[16] Heaton S. (2001): Organic farming, food quality and human health (2001): A review of the evidence. Soil Association, http://www.soilassociation.org/Whyorganic/Health/Reports/tabid/388/Default.aspx.

[17] Brandt K., Leifert C., Sanderson L., Seal C.J. (2011): Agroecosystem management and nutritional quality of plant foods: The case of organic fruits and vegetables. Critical Reviews in Plant Sciences, Vol. 30, 177-197.

[18] Hallmann E., Rembiałkowska E. (2012): Characterisation of antioxidant compounds in sweet bell pepper (Capsicum annuum L.) under organic and conventional growing systems. Journal of the Science of Food and Agriculture, Vol. 92, 2409-2415.

[19] Kazimierczak R., Hallmann E., Lipowski J., Drela N., Kowalik A., Püssa T., Matt D., Luik A., Rembiałkowska E.

(2014): Beetroot (Beta vulgaris L.) and naturally fermented beetroot juices from organic and conventional production: metabolomics, antioxidant levels and anticancer activity. Journal of the Science of Food and Agriculture, Vol. 94, 13, 2618-2629.
[20] Bavec M., Turinek M., Grobelnik-Mlakar S., Slatnar A., Bavec F. (2010): 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). Journal of Agricultural and Food Chemistry, Vol. 58, 11825-11831.
[21] Średnicka-Tober D., Barański M., Gromadzka-Ostrowska J., Skwarło-Sońta K., Rembiałkowska E., Hajslova J., Schulzova V., Cakmak I., Ozturk L., Krolikowski T., Wisniewska K., Hallmann E., Baca E., Eyre M., Steinshamn H., Jordon T., Leifert C. (2013): Effect of crop protection and fertilization regimes used in organic and conventional production systems on feed composition and physiological parameters in rats. Journal of Agricultural and Food Chemistry, Vol. 61, 5, 1017-1029.
[22] Kazimierczak R., Hallmann E., Rembiałkowska E. (2014): Effects of organic and conventional production systems on the content of bioactive substances in four species of medicinal plants. Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, Vol. 31, 2, 118-127.
[23] Dean P.R., Hurd C.L. (2007): Seasonal growth, erosion rates, and nitrogen and photosynthetic ecophysiology of Undaria pinnatifida (Heterokontophyta) in southern New Zealand. Journal of Phycology, Vol. 43, 1138-1148.
[24] Kaack K., Nielsen M., Christensen L.P., Thorup-Kristensen K. (2002): Nutritionally Important Chemical Constituents and Yield of Carrot (Daucus carota L.) Roots Grown Organically Using Ten Levels of Green Manure. Acta Agriculturae Scandinavica, Section B - Soil & Plant Science, Vol. 51, 125-136.
[25] Macias-Sanchez M.D., Mantell C., Rodriguez M., Martinez de la Ossa E., Lubian L.M., Montero O. (2009): Comparison of supercritical fluid and ultrasound-assisted extraction of carotenoids and chlorophyll a from Dunaliella salina. Talanta, Vol. 77, 948-952.