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The Impact of Organic vs. Conventional Agricultural Practices on Selected Quality Features of Eight Potato Cultivars

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Abstract: An organic agricultural system based on natural methods and means of production is an alternative to intensive agriculture. The available research suggests that organic crops, in comparison to the conventional ones, are richer in phenolics and other antioxidants while containing less undesirable pesticide residues and nitrates. The aim of this study was to determine concentrations of polyphenols, lutein, vitamin C, and nitrates in eight potato cultivars (Mazur, Justa, Lawenda, Lech, Tacja, Laskana, Otolia, Magnolia) grown organically and conventionally in a controlled field experiment in Poland. Significant differences between potato tubers of the tested cultivars coming from organic and conventional production were identified for the majority of parameters. Higher concentrations of nitrates and lutein were found in conventional compared to the organic tubers, while organic potatoes were, on average, richer in phenolic compounds. Among the tested cultivars, Magnolia, Otolia, and Laskara were richest in vitamin C and phenolics. Otolia and Laskara also accumulated the highest levels of nitrates. If further confirmed, these observations might be of importance for the producers and consumers, who increasingly search for foods from sustainable and well-controlled agricultural systems.

Keywords: potato; *Solanum tuberosum*; vitamin C; phenolic compounds; lutein; nitrates; organic farming

1. Introduction

Potatoes, next to wheat, corn, and rice, became one of the top crops contributing to the world's food security [1,2]. Globally, the annual consumption of potatoes reaches around 34 kg per capita, with similar figures in both Americas, and above two times higher consumption (82 kg) in Europe [3]. Potato is a valuable source of many nutrients, minerals, and bioactive compounds, including exogenous amino acids, vitamins B and C, potassium, magnesium, copper, phosphorus, as well as carotenoids and polyphenols. Among the polyphenols, phenolic acids are dominant, such as chlorogenic, p-coumaric, ferulic, gallic, and caffeic acid [4]. The consumption of foods rich in these antioxidants may help restore the balance between the production of reactive oxygen and nitrogen species and endogenous protection when the body undergoes oxidative stress. As reported by Godwill (2018), polyphenols and other antioxidants improve the antioxidant status of the organism and, therefore, may prevent many diseases, such as cancers and cardiovascular diseases [5].

Without any doubt, organic farming products represent the goods highly demanded by a modern consumer [6]. It is confirmed by the significant growth of the organic food market observed in recent years. According to the latest report of the International Federation of Organic Agriculture Movements (IFOAM) and Research Institute of Organic Agriculture FIBL [7], between 2016 and 2017, organic market growth was noted in all regions, and in many cases in double digits. The biggest growth was registered in France (by 18%), Spain (by 16%), and Denmark (by 15%).

Healthy nutrition is essential for the quality of life. Health and convenience are nowadays the most important non-economic factors determining consumers' preferences in relation to food [8]. At the same time, these preferences are directed more and more towards foods produced by methods with minimal negative environmental impact. It causes an increase in demand for food from controlled production systems, including organic farming [6,9]. Regardless of whether or not consumers declare the consumption of organic food, they are of the opinion that organic products are healthier, tastier, and safer for the environment than those produced under conventional farming [9–12]. To confirm consumers' beliefs about the values attributed to organic foods, it is necessary to consider the aspects of food quality and safety that have a direct impact on the nutritional and biological value of food. The latest meta-analysis showed clear significant differences in the chemical composition of organically and conventionally grown plant foods. It was found that the content of many antioxidants is much higher in organic plant products than in their conventional counterparts. At the same time, significantly lower cadmium content and four times lower incidence of pesticide residues was confirmed in organic vs. conventional products. The bioactive compounds often found in higher concentrations in organically cultivated crops, apart from the nutritional and health-promoting value, also contribute to specific taste and flavour; therefore, differences in their profiles may affect sensory characteristics of plant products [13–15].

According to Bloksma et al. (2007) [13], the increased production of certain compounds, for example, polyphenols and vitamin C in plants under organic growing conditions, is largely associated with lower availability of nitrogen in the soil, resulting from organic instead of mineral fertilisers use. However, synthesis and further changes of bioactive compounds profiles may also depend on genetic and environmental factors, as well as interactions between them. Therefore, the aim of our research was to determine and to compare the concentrations of ascorbic acid, phenolic acids, flavonoids, lutein, and nitrates in the tubers of eight potato cultivars (very early, early, and mid-early cultivars, representing various cooking types) grown organically and conventionally in a controlled field trial.

2. Materials and Methods

The study was conducted in 2017 in the experimental farm of the Plant Breeding and Acclimatization Institute, in central Poland, on a light loamy sand soil. Eight potato cultivars (Mazur, Justa, Lawenda, Lech, Tacja, Laskana, Otolia, and Magnolia), representing different maturity classes, were grown in two crop production systems, i.e., organic and conventional. Different crop rotations and production technologies were used in each system. The crop rotation designs were as follows: (a) in the organic system: potatoes → oat + field peas → triticale → rye with undersown serradella → mix of yellow lupine with oat + mustard as catch crop; (b) in the conventional system: potatoes → spring wheat → winter wheat → lupine. The two systems also differed in fertilisation, as well as weed, insect, and diseases control practices (Table 1).

Table 1. Agronomic inputs in organic and conventional systems.

Crop Production Practice	Organic System	Conventional System
Fertilisation	Manure—28 t·ha^{-1} + mustard as a catch crop	4–5 t plowed rye straw + 1 kg mineral nitrogen per 100 kg straw, N: 100 kg·ha^{-1}, P: 53 kg·ha^{-1}, K: 150 kg·ha^{-1}
Weed control	Only mechanical tillage	Mechanical tillage + herbicides: Linurex: 1.8 L·ha^{-1}, Titus + Trend: 60 g·ha^{-1} + 0.5 L·ha^{-1}
Colorado potato beetle control	Biological insecticide Spin Tor 240 SC (Spinosad), 2 times per season, 0.15 L·ha^{-1}	Chemical insecticides: Actara: 2 times per season, 60 g·ha^{-1}, Apacz: 40 g·ha^{-1}
Late blight control	Copper fungicides Miedzian 50: 3 L·ha^{-1}, 2 times per season	Chemical fungicides: Ridomil: 2 L·ha^{-1}, Revus: 0.6 L·ha^{-1}, Ranman: 0.2 L·ha^{-1}, Altima: 0.4 L·ha^{-1}

All cultivars were planted at the same time (23rd of April). Plot size was 84 m^2 for each cultivar, in three replications. Plants were grown with 75 × 33.3 cm spacing. The main characteristics of the potato cultivars under the study are given in Table 2. Weather conditions during the vegetation period are given in Table 3.

Table 2. Seed provenance and main tuber sensory characteristics of the eight potato cultivars under study.

Cultivar	Tuber "seed" Provenance	Maturity Group	Skin Colour	Pulp Colour	Cooking Type	Adaptation to Organic System
Justa	HZ Zamarte PL	very early	yellow	yellow	BC	-
Tacja	HZ Zamarte PL	very early	yellow	yellow	B	+
Lawenada	HZ Zamarte PL	early	pink	yellow	B	+
Magnolia	PMHZ Strzekęcino PL	early	light yellow	yellow	BC	++
Laskara	PMHZ Strzekęcino PL	mid early	yellow	light yellow	BC	-
Lech	HZ Zamare PL	mid early	pink	yellow	BC	++
Mazur	PMHZ Strzekęcino	mid early	red	light yellow	BC	+
Otolia	Europlant DE	mid early	yellow	yellow	AB	++

HZ—Potato Breeding, PMHZ—Pomeranian Potato Breeding, PL—Poland, DE—Germany, according to the E.A.P.R. (European Association for Potato Research) cooking type scale: A—firm texture (suitable for steaming, microwaving and boiling); B—fairly mealy texture (multi-purpose cooking), C—mealy texture (suitable for frying). ++ good adaptation to organic system, + weak adaptation to organic system, - the weakest adaptation to organic system.

Table 3. Total monthly rainfall (R) and mean monthly temperatures (T) during the vegetative growth period in the year 2017 in experimental fields in Jadwisin (study location).

Year	April		May		June		July		August		September	
	R	T	R	T	R	T	R	T	R	T	R	T
	(mm)	(°C)	(mm)	(°C)	(mm)	(°C)	(mm)	(°C)	(mm)	(°C)	(mm)	(°C)
2017	8.9	7.3	10.1	14.1	107.5	18.1	78.7	18.4	57.0	19.4	140.8	13.8

All tubers were harvested at the same time, 135 days after planting, when 80% of the haulms were dry. At harvest time, tuber yield and tuber size distributions (<35 mm, 35–60 mm, and >60 mm) were assessed. Tubers that were either green, misshapen, damaged, or weighing less than 20 g were regarded as unmarketable. A sample of at least 20 marketable tubers per replicate (within cultivation system and cultivar) was used.

Dry matter was determined using a gravimetric method according to the Polish standard (Polish Norm PN-EN 12145 2001) [16]. Samples of potato tubers were dried under the following conditions: temperature of 105 °C, constant pressure, time of 48 h, and using a Dryer KC-65 (Premed, Marki, Poland) with free air circulation. Dried samples were cooled in a desiccator and weighed. Dry matter content was calculated in per cent of fresh material.

The sample preparation procedure included the extraction of phenolic compounds from the freeze-dried potato samples (100 mg) with 80% methanol in plastic tubes, using an ultrasonic bath

(10 min, 30 °C). Then the samples were centrifuged (12 min, 3450× *g*, 2 °C). Aliquots (1 mL) of the supernatant were transferred into HPLC vials. The HPLC system (two LC-20AD pumps, a CMB-20A system controller, an SIL-20AC autosampler, an ultraviolet-visible SPD-20AV detector, a CTD-20AC oven, and a Fusion-RP 80A column: 250 mm × 4.60 mm) was used; all of the components were from Shimadzu. Mixtures of water and acetonitrile (10% in phase A and 55% in phase B) at a flow rate of 1 mL min^{-1} were used as a gradient solvent (1.00–22.99 min phase A 95%, 23.00–27.99 min phase A 50%, 28.00–28.99 min phase A 80%, 29.00–35.99 min phase A 80%, 36.00–38.00 min phase A 95%). The wavelength used for detection was 270–360 nm. External standards of polyphenols with purities of 95.00–99.99% were used. HPLC chromatograms showing profiles of polyphenols (phenolic acids and flavonoids) in the tested potatoes are presented in Figures 1 and 2, respectively. The concentrations of polyphenols were calculated on the base of standard curves and sample dilution coefficients [17].

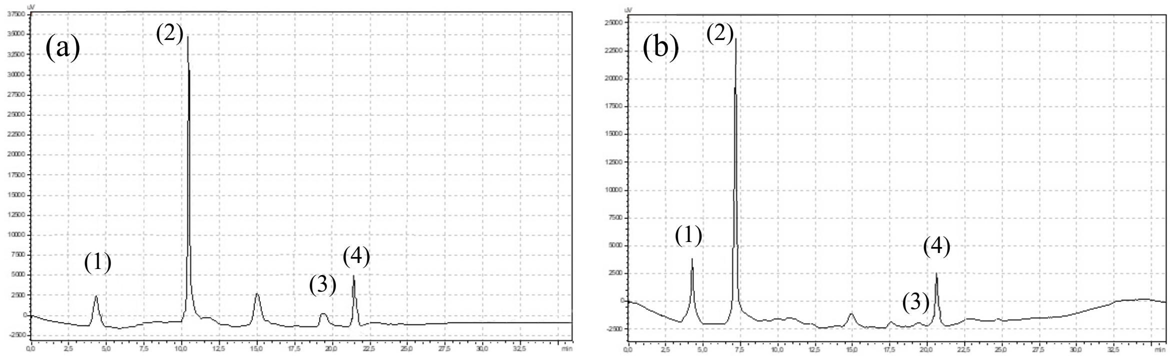

Figure 1. Chromatograms showing retention time for phenolic acids in organic (**a**) and conventional (**b**) potatoes; (1) gallic acid, (2) chlorogenic acid, (3) p-coumaric acid, (4) ferulic acid.

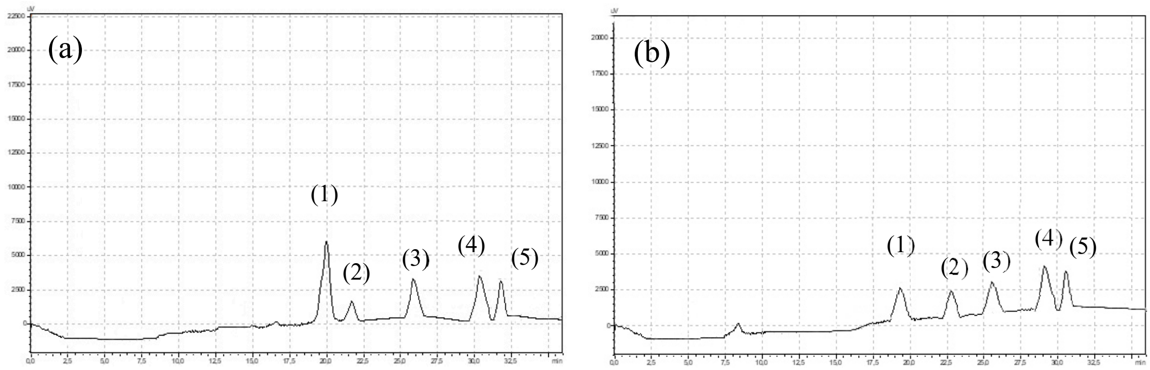

Figure 2. Chromatograms showing retention time for flavonoids in organic (**a**) and conventional (**b**) potatoes; (1) quercetin-3-O-glucoside, (2) kaempferol-3-O-glucoside, (3) myricetin, (4) luteolin, (5) quercetin.

The determination of vitamin C, together with the identification of L-ascorbic acid (L-ASC) and dehydroascorbic acid (DHA), were carried out by the high-performance liquid chromatography method using Shimadzu HPLC. A total of 2 mL of 5% metaphosphoric acid were added to the sample. Samples were mixed on vortex and incubated in an ultrasonic bath for 15 min at 20 °C and then centrifuged (6000 rpm, 0 °C). 1 mL of the supernatant was transferred into HPLC vials. The Phenomenex Fusion 80-A RP column (250 × 4.6 mm), the mobile phase of 50 mM phosphate buffer (pH 4.4), and 0.1 mM sodium acetate were used for analysis. L-ASC and DHA standard solutions were prepared for the standard curves. The result was read from the chromatogram, and compounds were identified based on the retention time of the Fluka and Sigma-Aldrich L-ASC and DHA standards. The wavelength used for detection was 255–260 nm. The analysis time was 18 min [17].

Lutein was determined by HPLC [17]. The examined freeze-dried potato samples were weighed (100 mg) and put into plastic tubes, then MgCO3 was added. The samples were incubated in a cold ultrasonic bath (15 min at 0 °C) with ice. Then hexane was added, and the samples were incubated in the bath again. Next, the samples were centrifuged (2 °C, 10 min). From the test tube, 1 mL of supernatant was collected and recentrifuged (3 °C, 5 min). The supernatant was placed in HPLC vials and analysed. To determine carotenoids, Shimadzu HPLC was used (two LC-20AD pumps, a CMB-20A system controller, SIL-20AC autosampler, UV/vis SPD-215 20AV detector, CTD-20AC controller, and Max-RP 80A column: 250 216 mm × 4.60 mm, with stationary phase: ether-linked phenyl phase with polar end-capping). The gradient solvents (deionized water, acetonitrile, ethyl acetate) were selected, with a flow of 1 mL min^{-1}. The wavelength used was 445−450 nm. To identify the compound, the external standard of lutein (Fluka) with a purity of 99.98% was used. HPLC chromatograms showing retention time for carotenoids in the tested potatoes are presented in Figure 3.

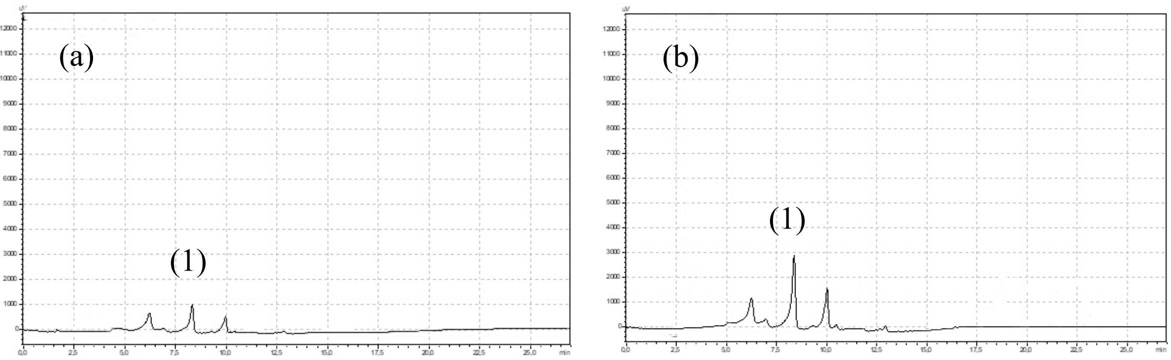

Figure 3. Chromatograms showing retention time for carotenoids in organic (**a**) and conventional (**b**) potatoes; (1) lutein.

The content of nitrites and nitrates was evaluated using the method described in the Polish standard (Polish Norm PN-EN 12014-2:2001) [18]. Proteins were removed from the freeze-dried 50 g samples using two Carrez solutions. Next, the samples were filtrated, and extract (1 mL) was used for the HPLC analysis. The isocratic gradient was applied. The mobile phase was 2.0 mM sodium benzoate (pH 6.5), and a Hamilton column 150 × 4.1 PRP-X100 was used. Oven temperature was set at 21 °C. The wavelength used was 260 nm, and the injection volume was 100 µL. The contents of nitrates and nitrites were calculated based on the standard solution.

For tuber yield and tuber size distribution, data were analysed using one-way ANOVA (analysis of variance), with $\alpha = 0.05$. The data from chemical composition analyses were subjected to one- and two-way analysis of variance, followed by the post-hoc Tukey's test, and differences were considered significant at $p < 0.05$. Pearson's Product-Moment Correlation analysis was performed to assess a possible linear association between the concentrations of polyphenols and nitrates in potato tuber samples. The Statgraphics 5.1. software (StatPoint Technologies, Warrenton, VA, USA) was used for all statistical analyses.

3. Results and Discussion

3.1. Tuber Yield and Tuber Size Distribution

Table 4 shows the total tuber yield of potatoes of the eight cultivars grown in organic and conventional crop production systems. Weather conditions prevailing in the research year were conducive to the accumulation of high yields, but also to the development of late blight, especially on organic plantations. The applied protection in the form of copper preparations allowed to limit the development of the disease and to obtain yields at a relatively high level. Average yields from eight cultivars amounted to 30.1 t ha^{-1} in the organic system and 62.7 t ha^{-1} in the conventional system.

Table 4. Total tuber yields (t ha^{-1}) in relation to the crop production system and cultivar.

Cultivar/Crop Production System	Organic	Conventional	Mean
Justa	30.7 ab	49.2 c	40.0
Tacja	32.2 ab	48.0 c	40.1
Lawenda	28.4 ab	70.4 ef	49.2
Magnolia	32.6 ab	54.4 cd	43.5
Laskara	28.8 ab	73.6 f	51.2
Lech	37.7 b	69.6 ef	53.7
Mazur	25.9 a	75.6 f	50.7
Otolia	24.7 a	61.2 de	42.9
Mean	30.1 A	62.7 B	46.4

Means in the same column followed by different lower case letters are significantly different ($p < 0.05$). Means in the last row followed by different upper case letters are significantly different ($p < 0.05$).

The interaction of cultivars with the production system was found. The cultivar that produced the highest yields in the organic system was Lech, while in the conventional system, Mazur and Laskara. The lowest yields in the organic system were recorded for the Otolia and Mazur cultivars, whereas in the conventional system, in the cultivars Tacja and Justa (Table 4). The Lech cultivar is well adapted to organic production, which was confirmed by its highest yield among the cultivars tested. The low yield of Otolia cultivar in the organic system was unexpected, as this cultivar is generally acknowledged as well-adapted and recommended for organic production (Table 2).

On average, the yield of organic potatoes was significantly lower than the yield of conventional potatoes. Similar results were reported by Brazinskiene et al. (2014) [19]. In their study, potato yield was twice as high in the conventional compared to the organic system and also depended on the cultivar. The growth of potato and, as a consequence, the size of the potato yield is significantly influenced by many factors such as climatic, soil or genetic conditions, and the crop management system [20,21]. The mineral fertilisation and chemical plant protection used probably influenced the acquisition of such high yields in the conventional system [21]. So far, many studies have been carried out comparing the crop yields in organic and conventional agricultural production systems. Most of them show a significant advantage of conventional farming in this respect. A meta-analysis conducted by Ponisio et al. (2015) [22], based on over 115 research papers, indicated that the yields in organic farming are on average 19.2% lower compared to the conventional systems. At the same time, Seufert et al. (2012) [23] showed that organic fruit, soybean, and oilseed production farms achieve yields close to those recorded in conventional farms, while for wheat and vegetables, the yield gap between organic and conventional systems reaches 37% and 33% respectively. In our study, the yield of organic potatoes was on average about 50% (32–65%, depending on a cultivar) lower compared to the conventional ones. Considering the current estimated average organic price premiums of 29–32% at the producer level [24], such a yield gap of 50% would not be directly compensated. Economic performance of the organic farms could, however, be supported by developing strategies to increase overall yielding in the organic systems, but also by promoting the selection of most appropriate, well-adapted, highly yielding cultivars by the organic farmers. At the same time, it should be pointed out that there is an on-going discussion on ecosystem services and other potential environmental and social benefits of organic agricultural systems and, at the same time, on high external costs of intensive industry farming [24–30]. Including these aspects in the cost-benefit analysis of the organic farms could allow further compensation for the current yield gaps between organic and non-organic systems.

As shown in Table 5, there was a significant variation in the yield structure. In the organic system, a significantly higher share of small and medium-sized tubers was found, and a smaller share of large tubers. The biggest differences concerned the share of tubers with a diameter of over 60 mm. In both systems the fraction of tubers with a diameter of 35–60 mm was predominant. The variation of tuber yield structure could have resulted from the uneven distribution of precipitation from May to August [31].

Table 5. Tuber size distribution (%) in relation to the crop production system.

Crop Production System/Tuber Size	<35 mm	35–60 mm	>60 mm
Organic	4.7 b	85.5 b	9.8 a
Conventional	2.1 a	67.3 a	30.6 b

Means in the same column followed by different letters are significantly different ($p < 0.05$).

3.2. Dry Matter Content

In general, a significant relation was found between farming system and dry matter content in tubers. On average, organic potatoes contained significantly more dry matter (Table 6). Comparing individual cultivars from both systems, this was true for most of the cultivars, except for Mazur, Justa, and Magnolia. The results of scientific papers mostly confirm the trend towards higher content of dry matter in plants from organic farming, especially in root and leafy vegetables [32]. This is most probably related to the type and doses of fertilisers used in cultivation [13]. This was also confirmed by the authors of the extensive literature review in which the high-dose mineral fertilisation often used in conventional agriculture was linked to excessive vegetative growth and reduction of dry matter content in agricultural crops [15]. Among the eight cultivars, Laskara (in both systems), Otolia (organic), and Magnolia (in both systems) were characterised by the highest dry matter contents (Table 6).

3.3. Polyphenol Content

Potato tubers are known to contain high levels of polyphenols, including phenolic acids and flavonoids [33,34]. Polyphenols are considered as important pro-healthy compounds, insufficiently represented in a diet of modern and developed societies [35]. In the presented study, potato tubers from organic production were significantly richer in polyphenols (sum), including phenolic acids (Table 7) and flavonoids (Table 8) in comparison to the conventional ones. It was also true for most of the individual phenolic acids as well as flavonoids occurring in the tubers. Among the phenolic acids, chlorogenic acid was a predominant one. The majority of cultivars tested (except for Mazur and Justa) reacted with higher accumulation of this phenolic acid in organic tubers. This was reflected in the content of phenolic acids (sum) and polyphenols (sum) in the tubers (Table 7). We also noticed that the majority of organic potato cultivars were characterised by higher concentrations of flavonoids (sum) compared to their conventional counterparts. This was true for such individual flavonoids such as quercetin-3-O-glucoside and quercetin, but not for myricetin (lack of the system effect) and kaempferol-3-O-glucoside (higher in the conventional system) (Table 8). Our findings were similar to the research outcomes of other authors, who found that organic potatoes were more abundant in polyphenolic compounds [36,37].

According to the theory described by Bloksma et al. (2007) [13], mineral nitrogen fertilisers, especially their high doses, reduce the content of phenolic compounds in vegetables and fruits in conventional farming. In plants from organic production based on natural fertilisers, limiting the availability of nitrogen for plants, a higher synthesis of polyphenolic compounds is usually observed. The differences in the synthesis of polyphenols by plants can also be explained by the way they are protected. The non-use of synthetic pesticides in organic farming increases the exposure of plants to stress factors, which may lead to the intensive production of secondary metabolites as a defence mechanism [34,38].

Table 6. The content of dry matter, vitamin C, lutein, and nitrates in tubers of 8 potato cultivars grown in organic (ORG) and conventional (CONV) system.

Cultivation System	Cultivar	Dry matter	Vitamin C	DHA	L-Asc	Lutein	Nitrate
		%	mg kg^{-1} FW	mg kg^{-1} FW	mg kg^{-1} FW	mg kg^{-1} FW	mg kg^{-1} FW
ORG	Mazur	20.16 ± 1.77 ab	160.0 ± 13.0 ab	13.8 ± 0.4 a	146.2 ± 12.6 ab	4.8 ± 0.5 bc	175.53 ± 13.67 c
	Justa	20.65 ± 0.65 bcd	183.4 ± 3.5 abc	33.6 ± 8.4 cde	149.8 ± 11.1 abc	1.6 ± 0.1 a	175.81 ± 10.87 c
	Lawenda	22.71 ± 0.58 ef	250.0 ± 26.0 de	42.4 ± 6.0 fg	207.6 ± 31.1 bc	9.2 ± 0.2 fg	169.71 ± 9.24 c
	Lech	22.74 ± 0.75 ef	225.0 ± 16.3 cd	46.4 ± 3.7 fg	178.6 ± 19.9 bc	7.4 ± 1.8 def	168.13 ± 11.07 c
	Tacja	21.78 ± 0.55 de	230.7 ± 6.9 cde	69.4 ± 4.1 h	161.3 ± 10.3 abc	5.2 ± 1.2 bcd	97.56 ± 3.10 b
	Laskara	25.34 ± 0.10 g	215.4 ± 10.9 bcd	24.1 ± 1.2 abc	191.4 ± 11.4 bc	3.1 ± 0.3 ab	285.9 ± 12.99 ef
	Otolia	23.80 ± 0.25 f	311.7 ± 22.7 fg	119.2 ± 18.3 j	192.5 ± 13.1 bc	7.8 ± 1.1 ef	258.9 ± 15.11 e
	Magnolia	22.78 ± 0.50 ef	260.7 ± 18.8 def	73.9 ± 12.3 h	186.8 ± 7.0 bc	4.7 ± 0.6 bc	26.57 ± 1.99 a
CONV	Mazur	21.91 ± 0.33 e	256.6 ± 4.5 def	83.1 ± 8.2 hi	173.4 ± 7.1 bc	13.5 ± 0.4 ij	189.34 ± 14.44 cd
	Justa	21.88 ± 0.75 e	239.0 ± 67.4 cde	39.7 ± 16.7 efg	199.3 ± 50.7 bc	15.3 ± 0.3 j	216.01 ± 14.80 d
	Lawenda	20.55 ± 0.35 bc	213.7 ± 59.7 bcd	50.4 ± 2.8 g	163.3 ± 60.4 abc	12.9 ± 0.8 hij	218.01 ± 20.28 d
	Lech	19.70 ± 0.41 ab	131.9 ± 13.8 a	18.3 ± 4.6 ab	113.5 ± 11.0 a	11.0 ± 4.2 gh	222.13 ± 9.61 d
	Tacja	19.28 ± 0.70 a	229.3 ± 81.8 cde	70.5 ± 14.1 h	158.7 ± 94.5 abc	6.4 ± 0.3 cde	192.34 ± 12.37 cd
	Laskara	23.39 ± 0.54 f	289.3 ± 26.6 fg	93.4 ± 8.6 i	195.9 ± 25.2 bc	13.0 ± 2.4 hij	267.73 ± 19.66 e
	Otolia	21.64 ± 0.79 cde	255.2 ± 49.4 def	52.9 ± 10.1 g	202.2 ± 43.9 bc	8.7 ± 1.3 ef	275.01 ± 70.37 ef
	Magnolia	23.37 ± 0.47 f	323.8 ± 24.9 g	138.6 ± 13.9 k	185.3 ± 20.0 bc	12.1 ± 0.6 hi	309.60 ± 3.56 f
Average for production system	ORG	22.49 ± 1.69 B	229.6 ± 45.8 A	52.9 ± 32.4 A	176.8 ± 24.5 A	5.5 ± 2.5 A	169.76 ± 77.33 A
	CONV	21.47 ± 1.51 A	242.3 ± 66.1 A	68.4 ± 35.9 B	174.0 ± 47.7 A	11.6 ± 3.1 B	236.27 ± 46.41 B
Average for cultivar	Mazur	21.03 ± 1.36 a	208.3 ± 48.9 ab	48.5 ± 35.0 ab	159.8 ± 16.0 a	9.1 ± 4.4 bc	182.43 ± 13.40 ab
	Justa	21.26 ± 0.85 a	211.2 ± 47.9 ab	36.7 ± 11.2 a	174.5 ± 38.9 a	8.5 ± 6.8 abc	195.91 ± 22.72 b
	Lawenda	21.63 ± 1.15 ab	231.8 ± 41.7 abc	46.4 ± 5.5 ab	185.5 ± 45.0 a	11.1 ± 1.9 c	193.86 ± 27.36 b
	Lech	21.22 ± 1.60 a	178.5 ± 48.2 a	32.4 ± 14.5 a	146.1 ± 35.1 a	9.2 ± 3.2 bc	195.13 ± 28.30 b
	Tacja	20.53 ± 1.35 a	230.0 ± 47.4 abc	70.0 ± 8.5 cd	160.0 ± 54.9 a	5.8 ± 0.9 a	144.95 ± 47.96 a
	Laskara	24.36 ± 1.03 d	252.4 ± 40.5 bc	58.7 ± 35.0 bc	193.7 ± 16.1 a	8.0 ± 5.1 ab	276.82 ± 16.36 c
	Otolia	22.72 ± 1.18 bc	283.4 ± 42.3 c	86.1 ± 35.2 d	197.4 ± 26.9 a	8.2 ± 1.1 ab	266.96 ± 42.33 c
	Magnolia	23.07 ± 0.49 cd	292.3 ± 36.3 c	106.3 ± 34.0 e	186.0 ± 12.3 a	8.4 ± 3.7 abc	168.09 ± 141.53 ab
p-values	production system	<0.0001	N.S.	<0.0001	N.S.	<0.0001	<0.0001
	cultivar	<0.0001	0.0001	<0.0001	N.S.	0.0001	<0.0001
	interaction	<0.0001	0.0003	<0.0001	N.S.	<0.0001	<0.0001

Data are presented as mean ± SD with ANOVA *p*-value. FW—fresh weight, DHA—dehydroascorbic acid, L-Asc—L-ascorbic acid. Means in the same column followed by the same letter are not significantly different ($p < 0.05$) by Tukey's test. N.S. not significant. ORG—organic, CONV—conventional.

Table 7. The contents of polyphenols in tubers of 8 potato cultivars grown in organic (ORG) and conventional (CONV) system.

Cultivation System	Cultivar	Polyphenols (sum) mg kg^{-1} FW	Phenolic Acids mg kg^{-1} FW	Gallic Acid mg kg^{-1} FW	Chlorogenic Acid mg kg^{-1} FW	P-Coumaric Acid mg kg^{-1} FW	Ferulic Acid mg kg^{-1} FW
ORG	Mazur	265.9 ± 35.9 c	211.1 ± 27.6 cd	11.8 ± 2.8 ab	143.0 ± 20.7 abc	42.9 ± 5.7 c	13.4 ± 1.6 f
	Justa	159.0 ± 13.0 ab	107.0 ± 18.4 ab	13.7 ± 1.2 ab	86.7 ± 17.4 ab	5.1 ± 0.2 a	1.5 ± 0.2 abc
	Lawenda	1230.5 ± 130.9 g	1181.1 ± 133.4 g	14.4 ± 1.6 ab	1158.6 ± 134.4 g	6.6 ± 0.3 ab	1.4 ± 0.3 ab
	Lech	895.7 ± 86.4 f	824.6 ± 85.4 f	44.4 ± 3.3 fg	773.5 ± 83.7 f	5.5 ± 0.5 a	1.3 ± 0.1 ab
	Tacja	717.8 ± 42.8 e	659.9 ± 37.6 e	29.3 ± 7.2 c	623.4 ± 40.5 e	5.8 ± 0.2 a	1.4 ± 1.0 ab
	Laskara	929.1 ± 80.9 f	860.3 ± 78.9 f	44.0 ± 4.9 fg	808.3 ± 79.0 f	6.9 ± 0.3 ab	1.1 ± 0.1 ab
	Otolia	990.7 ± 95.0 f	911.7 ± 98.4 f	43.3 ± 7.6 fg	859.3 ± 91.3 f	6.0 ± 0.6 a	3.1 ± 0.1 e
	Magnolia	957.2 ± 113.4 f	880.6 ± 111.3 f	38.2 ± 1.2 ef	836.1 ± 110.4 f	5.4 ± 0.3 a	0.9 ± 0.1 a
CONV	Mazur	259.3 ± 36.8 bc	234.2 ± 37.1 cd	36.2 ± 1.1 de	191.6 ± 37.2 cd	5.3 ± 0.0 a	1.1 ± 0.1 ab
	Justa	200.4 ± 42.6 abc	174.1 ± 39.1 bc	9.8 ± 1.9 ab	157.1 ± 36.7 bc	5.6 ± 0.5 a	1.6 ± 0.1 abc
	Lawenda	165.6 ± 11.0 abc	135.0 ± 12.6 abc	46.5 ± 1.8 g	79.3 ± 12.9 ab	6.7 ± 0.2 ab	2.6 ± 0.2 de
	Lech	100.3 ± 5.2 a	60.7 ± 6.1 a	11.1 ± 4.4 ab	44.0 ± 4.2 a	4.8 ± 0.2 a	0.9 ± 0.2 a
	Tacja	164.6 ± 7.4 abc	102.8 ± 9.3 ab	31.2 ± 7.9 cd	65.2 ± 1.1 ab	4.7 ± 0.3 a	1.7 ± 0.2 bc
	Laskara	370.3 ± 2.6 d	304.2 ± 7.1 d	25.6 ± 1.9 c	267.8 ± 6.8 d	8.5 ± 0.2 b	2.3 ± 0.3 cd
	Otolia	128.6 ± 4.9 a	69.3 ± 8.2 a	16.0 ± 3.0 b	46.9 ± 5.8 a	5.6 ± 0.4 a	0.9 ± 0.1 a
	Magnolia	130.8 ± 13.4 a	67.4 ± 7.7 a	8.7 ± 1.8 a	51.7 ± 9.5 a	6.1 ± 0.2 ab	1.0 ± 0.1 ab
Average for production system	ORG	768.2 ± 354.4 B	704.5 ± 349.9 B	29.9 ± 14.1 B	661.1 ± 351.4 B	10.5 ± 12.4 B	3.0 ± 0.4 B
	CONV	190.0 ± 83.9 A	143.5 ± 84.5 A	23.1 ± 13.4 A	112.9 ± 79.4 A	5.9 ± 1.2 A	1.5 ± 0.6 A
Average for cultivar	Mazur	262.6 ± 29.9 a	222.7 ± 29.1 a	24.0 ± 12.3 b	167.3 ± 34.6 a	24.1 ± 19.1 b	7.2 ± 6.2 d
	Justa	179.7 ± 33.0 a	140.5 ± 41.8 a	11.7 ± 2.3 a	121.9 ± 42.3 a	5.3 ± 0.4 a	1.6 ± 0.1 ab
	Lawenda	698.1 ± 537.8 e	658.1 ± 528.8 d	30.4 ± 16.1 bc	619.0 ± 545.3 c	6.6 ± 0.2 a	2.0 ± 0.6 c
	Lech	498.0 ± 400.8 bc	442.7 ± 385.1 b	27.7 ± 17.0 bc	408.8 ± 368.0 b	5.2 ± 0.4 a	1.1 ± 0.2 a
	Tacja	441.2 ± 277.7 b	381.4 ± 279.4 b	30.3 ± 6.2 bc	344.3 ± 280.1 b	5.3 ± 0.6 a	1.5 ± 0.6 ab
	Laskara	649.7 ± 283.3 de	582.3 ± 281.8 cd	34.8 ± 9.7 c	538.0 ± 274.1 c	7.7 ± 0.8 a	1.7 ± 0.6 ab
	Otolia	559.6 ± 434.5 cd	490.5 ± 425.0 bc	29.6 ± 14.4 bc	453.1 ± 409.6 bc	5.8 ± 0.5 a	2.0 ± 1.1 c
	Magnolia	544.0 ± 418.4 bcd	474.0 ± 411.7 bc	23.4 ± 14.8 b	443.9 ± 397.4 bc	5.8 ± 0.4 a	0.9 ± 0.1 a
p-values	production system	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	interaction	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Data are presented as mean ± SD with ANOVA *p*-value. FW—fresh weight. Means in the same column followed by the same letter are not significantly different ($p < 0.05$) by Tukey's test. N.S. not significant. ORG—organic, CONV—conventional.

Table 8. The contents of flavonoids (mg kg^{-1} FW) in tubers of 8 potato cultivars grown in organic (ORG) and conventional (CONV) system.

Cultivation System	Cultivar	Flavonoids (sum)	Kaempferol-3-O-Glucoside	Myricetin	Quercetin	Quercetin-3-O-Glucoside
ORG	Mazur	54.8 ± 8.5 cde	1.7 ± 0.1 ij	18.6 ± 2.1 a	4.5 ± 0.4 f	30.0 ± 7.2 bcd
	Justa	52.0 ± 5.4 cd	1.4 ± 0.2 defgh	19.8 ± 2.3 ab	2.0 ± 0.1 a	28.7 ± 3.2 bcd
	Lawenda	49.4 ± 2.6 c	1.0 ± 0.1 abc	19.9 ± 0.9 ab	5.4 ± 0.6 g	23.0 ± 1.0 b
	Lech	71.1 ± 2.0 hi	1.4 ± 0.1 defg	41.3 ± 1.7 i	2.3 ± 0.1 ab	26.1 ± 2.6 bc
	Tacja	57.9 ± 5.6 def	1.3 ± 0.2 bcde	25.0 ± 0.9 def	4.5 ± 0.2 f	27.1 ± 4.8 bcd
	Laskara	68.8 ± 2.1 ghi	1.0 ± 0.1 ab	29.2 ± 2.0 g	5.4 ± 0.1 g	33.2 ± 4.0 cd
	Otolia	79.0 ± 4.0 j	1.5 ± 0.1 efghi	22.1 ± 2.8 abc	5.8 ± 0.1 h	49.7 ± 3.2 e
	Magnolia	76.6 ± 5.1 ij	1.0 ± 0.1 a	22.5 ± 3.2 cde	2.4 ± 0.1 bc	50.7 ± 2.9 e
CONV	Mazur	25.1 ± 0.8 a	1.8 ± 0.1 j	20.3 ± 1.2 ab	2.5 ± 0.1 bc	0.4 ± 0.4 a
	Justa	26.2 ± 3.7 a	2.6 ± 0.1 k	19.3 ± 2.4 ab	2.4 ± 0.1 bc	1.9 ± 1.3 a
	Lawenda	30.6 ± 1.7 a	1.6 ± 0.6 fghij	23.1 ± 2.1 cde	2.6 ± 0.2 bc	3.3 ± 0.6 a
	Lech	39.6 ± 1.1 b	1.4 ± 0.1 defg	34.4 ± 0.8 h	3.3 ± 0.1 d	0.6 ± 0.5 a
	Tacja	61.8 ± 1.9 efgh	1.7 ± 0.2 ghij	29.1 ± 3.1 g	4.1 ± 0.3 e	26.9 ± 5.0 bcd
	Laskara	66.1 ± 9.1 fgh	1.7 ± 0.2 hij	27.3 ± 1.5 fg	3.5 ± 0.3 d	33.6 ± 8.2 d
	Otolia	59.3 ± 5.4 defg	1.1 ± 0.1 abcd	22.9 ± 4.8 cde	2.4 ± 0.1 bc	32.8 ± 7.3 cd
	Magnolia	63.4 ± 5.8 fghi	1.3 ± 0.1 cdef	26.3 ± 1.6 efg	2.7 ± 0.1 c	33.1 ± 5.1 cd
Average for production system	ORG	63.7 ± 11.5 B	1.3 ± 0.3 A	24.8 ± 7.2 A	4.0 ± 1.5 B	33.6 ± 10.5 B
	CONV	46.5 ± 17.1 A	1.7 ± 0.5 B	25.3 ± 5.1 A	2.9 ± 0.6 A	16.6 ± 15.7 A
Average for cultivar	Mazur	39.9 ± 15.7 a	1.8 ± 0.1 bc	19.5 ± 1.6 a	3.5 ± 1.0 c	15.2 ± 15.4 a
	Justa	39.1 ± 13.4 a	2.0 ± 0.6 c	19.6 ± 1.9 a	2.2 ± 0.2 a	15.3 ± 13.6 a
	Lawenda	40.0 ± 9.5 a	1.3 ± 0.5 a	21.5 ± 2.1 ab	4.0 ± 1.4 d	13.2 ± 9.9 a
	Lech	55.3 ± 15.8 b	1.4 ± 0.1 a	37.8 ± 3.6 d	2.8 ± 0.5 b	13.3 ± 12.9 a
	Tacja	59.9 ± 3.9 bc	1.5 ± 0.2 ab	27.0 ± 2.8 c	4.3 ± 0.3 d	27.0 ± 4.0 b
	Laskara	67.4 ± 5.5 cd	1.3 ± 0.4 a	28.3 ± 1.7 c	4.4 ± 1.0 d	33.4 ± 5.3 bc
	Otolia	69.2 ± 10.6 d	1.3 ± 0.2 a	22.5 ± 3.2 ab	4.1 ± 1.7 d	41.2 ± 9.6 bc
	Magnolia	70.0 ± 8.0 d	1.1 ± 0.2 a	24.4 ± 2.8 bc	2.6 ± 0.2 ab	41.9 ± 9.4 c
p-values	production system	<0.0001	<0.0001	N.S.	<0.0001	<0.0001
	cultivar	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	interaction	<0.0001	<0.0001	0.0044	<0.0001	<0.0001

Data are presented as mean ± SD with ANOVA *p*-value. FW—fresh weight. Means in the same column followed by the same letter are not significantly different ($p < 0.05$) by Tukey's test. N.S. not significant. ORG—organic, CONV—conventional.

3.4. Ascorbic Acid

Vitamin C, especially in combination with flavonoids, is considered one of the essential compounds in human diet. Its two forms—L-ascorbic acid (L-ASC) and dehydroascorbic acid (DHA)—are obtained primarily from fruits and vegetables. Interaction with flavonoids promotes increased absorption of vitamin C from the gastrointestinal tract [39]. As estimated by Herencia et al. (2011) [40], 58% of research on the impact of agricultural production methods on the content of vitamin C in vegetables and fruits indicates its higher content in plant materials from organic versus conventional farming. It was also confirmed in the meta-analysis based on 343 carefully selected publications [41]. In our study, vitamin C content, including L-ascorbic acid content, was not influenced by the cultivation system. Only differences between some cultivars from both systems were observed. The results showed that the cultivar was the stronger factor determining vitamin C content in potatoes (Table 6). Our findings did not confirm the hypothesis that plants in organic farming produce more vitamin C as a response to biotic and abiotic stress [34].

3.5. Lutein Content

As reported by Lachman et al. (2016) [42], lutein is a predominant carotenoid compound in potato. In our study, significantly higher concentrations of lutein were noted in conventional compared to the organic potato tubers, which was confirmed for all cultivars. These results are not fully in agreement with previous findings of Baranski et al. (2014) [41], who showed significantly higher contents of carotenoids in organic foods compared to the conventional ones. However, this applied together to the sum of all carotenoids, xanthophylls, and lutein. When the authors of the above study considered separately individual groups of raw materials and processed products and individual carotenoids, significant differences in favour of organic products were found only in the case of fruits, and only for carotenes group (not confirmed for xanthophylls).

According to the findings described by Lachman et al. (2016) [42], the content of carotenoids in potato tubers depends strongly on genetic and environmental factors (cultivar, locality, and year). The impact of cultivar, as well as the strong interaction between the growing system and the cultivar, were clearly confirmed in our study: when comparing individual cultivars, the highest concentrations of lutein were found in tubers of Justa grown in the conventional system, while the lowest in tubers of the same cultivar grown in the organic system.

3.6. Nitrates

According to the available literature, plant crops from conventional farming systems usually contain higher levels of nitrates as compared to the organic ones [41]. This trend was also observed in our study, where organically produced potatoes contained on average significantly lower contents of nitrates than their conventional counterparts (Table 6). The nitrate levels in potatoes were partly dependent on cultivar. On average, the cultivars Laskara and Otolia contained the highest contents of nitrates, whereas Tacja, Mazur, and Magnolia exhibited the lowest levels. When comparing nitrate content in the same cultivars from organic and conventional production, we observed that Justa, Lawenda, Lech, Tacja, and Magnolia showed higher contents in the conventional system, but no similar differences were noticed in case of Mazur, Laskara, and Otolia cultivars (Table 6). Nitrogen fertilisation is a very important factor affecting the accumulation of nitrates in vegetables. At the same time, it is a factor differentiating the organic and conventional agricultural management systems. According to Montemurro et al. (2007) [43], the higher content of nitrates in the soil increases the concentration of nitrates in plants. Therefore, the difference in the content of nitrates between plant tissues and, consequently, organic and conventional products, can be considered as a direct consequence of restrictions on the use of synthetic fertilisers in organic farming. Nitrates in foods are dangerous to consumers due to the conversion of a relatively harmless form of nitrates(V) to a much more toxic form of nitrates(III). This can occur both before eating vegetables (e.g., improper storage conditions) and during their digestion in the body (reduction under the influence of enzymes in the gastrointestinal tract). Exposure to nitrite is considered a risk factor for gastric cancer and methemoglobinemia of newborn babies, small children, and the elderly [12].

It is worth noting that in our study, an inverse relationship between the content of nitrates and polyphenols in potato tubers was identified (Figure 4). Many studies reported that variations in phenolic and nitrate contents in organic and conventional plants reflect the fertilisation procedures [41].

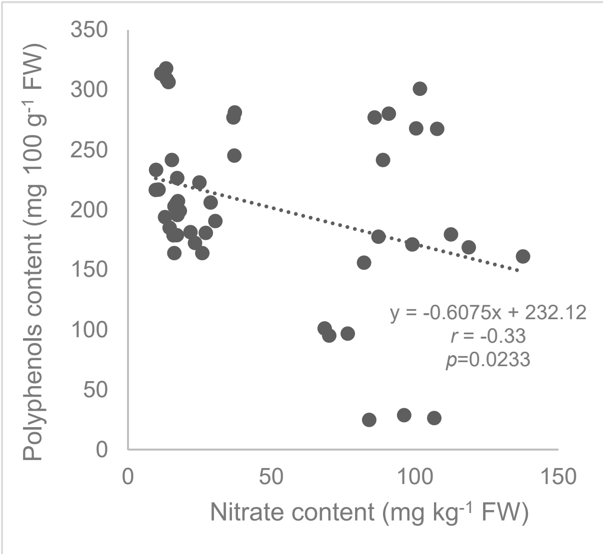

Figure 4. Correlation between the nitrates and polyphenols content in organic and conventional potato tubers (n = 48).

4. Conclusions

It is of great importance for the consumers to have access to high-quality foods, abundant in health-promoting compounds. Therefore, investigating the impact of potentially significant quality-modulating factors, such as agricultural production methods and cultivars, on the compositional parameters of plant products, including potatoes, is of high relevance. Our research showed differences in the content of bioactive compounds and nitrates between potatoes of the tested cultivars coming from organic and conventional production. More nitrates and lutein were found in the tested conventional potato tubers compared to their organic counterparts. At the same time, potatoes from organic production were, on average, richer in polyphenolic compounds (phenolic acids and flavonoids). There was a significant negative correlation between the content of nitrates and polyphenols in the tested potatoes. Among the potato cultivars studied, the cultivars with the highest content of vitamin C, phenolic acids, and flavonoids were Magnolia, Otolia, and Laskara. At the same time, the Otolia and Laskara accumulated the highest contents of nitrates in the tubers.

These findings, showing in most cases a more favourable chemical composition of organic compared to the conventional potatoes of the eight tested genotypes, and giving insights for initial identification of potato cultivars with the highest quality traits, could be of importance for the producers and the consumers, who increasingly search for foods from sustainable and well-controlled production systems. However, the observed trends should be further confirmed, and attention should be especially paid to the potential interactions between the potato genotype, agricultural production system and the year-to-year and location-specific growing conditions, to validate the conclusions.

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