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ORIGINAL PAPER

Selected nutrients determining the quality of different cuts of organic and conventional pork

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Abstract
Organic meat products are gaining consumer interest worldwide. The aim of this study was to investigate the effect of organic and conventional meat origin on nutritional determinants of the following pork meat cuts: loin, ham, and shoulder. Nutritional value of meat was based on selected indicators such as proximate composition, the concentration of cholesterol, vitamin E content and minerals and trace elements such as calcium, magnesium, potassium, copper, iron, and zinc, and the composition of fatty acids. The results of this study demonstrated that higher contents of protein and selected mineral compounds, as well as lower vitamin E concentration and different fatty acids (i.e., C12:0, C17:0, C17:1 n-7, C18:3 n-6, C24:0 and total n-3 polyunsaturated fatty acids (PUFA)) distinguish organic pork meat cuts from the conventional counterparts. The organically meat parts, especially the shoulder, were identified as a better source of copper, calcium, iron and zinc, while organic ham and loin had more potassium. On the other hand, organic hams were shown to have lower content of vitamin E in comparison to their conventional equivalents present. Also, in organic shoulders showed a higher n-6/n-3 ratio compared to meat of conventional origin.

Keywords Pork meat cuts · Loin · Ham · Shoulder · Fatty acids · Vitamins · Minerals

Introduction

Sustainable production is one of the key concepts within the scope of modern-day food industry. The growing demand for food on a global scale necessitates the continuous improvement of productivity and reduction of agricultural production costs. However, intensive agricultural practices may have an adverse impact on the environment, and thus, on the living conditions of all organisms. This is one of the reasons for an increasing interest in organic food worldwide. This growing trend, especially noticeable in the last 20 years, is also fostered by the economic affluence of the society and a rising consumer awareness regarding the quality and safety of food and its impact on human health seems to be an obvious consequence [1]. Currently, consumers increasingly favor foods that in addition to satisfactory sensory properties are distinguished by high nutritional value and possible health benefits [2, 3]. Our previous research showed that pork origin (conventional vs organic) and carcass element (loin, ham, shoulder) significantly influenced the chelating capacity of iron ions (Fe (II)) and the reducing power of peptides from meat. Thanks to the antioxidant properties of peptides, pork can be recommended for everyday consumption by people who care about their health. In silico analyzes have also shown that this type of meat can be a source of peptides supporting the treatment of non-communicable diseases such as hypertension and diabetes and others [4]. The quality of organic food is a key advantage making it competitive compared to conventional food [5]. It depends on many different factors such as the quality of raw materials and the technologies used for processing, storage, and distribution [6].

Among organic foods, meat and meat products have seen a sharp rise in demand, recapturing consumer interest around the world for numerous reasons. Considering pork, many consumers often think that compared to meat and meat products originating from conventional rearing systems,

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organic ones have higher nutritional value [7, 8]; and hence, they are prepared to pay more for the later [9]. However, it is of particular importance that consumers are provided with adequate information in terms of how the organic rearing system affects the nutritional value of pork. As many consumers still have doubts regarding advantageous properties of organics and considering the fact that research results concerning beneficial effects of eating such foods are not ample enough and in numerous cases inconclusive [10–13], there is a need to conduct further investigation concerning this issue. Moreover, there are only few studies on this topic, indicating there is a need to deepen the research. Most comparative studies have reported about the meat quality and fat composition of pork [14–16], whereas comparative data on the concentration of minerals, vitamins, and cholesterol in pork meat from organic and conventional rearing systems is limited [16, 17]. Moreover, the nutritional value of selected cuts of pork meat from different housing systems has not been compared before.

Considering the abovementioned issues, the aim of the present study was to investigate the effect of meat origin (organic *vs.* conventional) on the nutritional value of pork, with special attention paid to the differences between the selected cuts of pork meat (loin, ham, shoulder). For this purpose, market samples have been collected from slaughterhouses to be sure the cuts examined came for the same carcasses, then analyzed and compared. The procedure allowed to examine meat that is sold to consumers with control of animal features repeatability to ensure that meat characteristics was only influenced by factors related to the way the pigs were reared (organic or conventional).

Materials and methods

Meat samples

The research was conducted on organic and conventional pork meat. The material consisted of three cuts of pork meat: loin (*Musculus longissimus dorsi*), ham (*Musculus biceps femoris*), shoulder (the element consists of muscles: *Musculus supraspinatus, Musculus infraspinatus*, *Musculus subscapularis, Musculus triceps brachii;* the percentage of individual muscles in the element was as follows: 24%, 22%, 8%, 46%). Both variants of samples of meat (organic and conventional), intended for consumer market, were bought in the same, organically certified slaughter house what enabled the cuts to be cut out fresh of the same carcasses. Conventional and organic pigs were slaughtered in the slaughterhouse, but the slaughter took place on different days. Eighteen meat samples (organic and conventional) were selected. In this way the repeatability of meat characteristics was ensured to avoid influence of any factors that are not connect with the used rearing system. At the same time the procedure allowed to analyze meat that consumers normally buy at the butcher's.

The samples were vacuum packed and transported in refrigerated conditions without access of light to the analytical laboratory. The analysis of the samples was carried out 24 h after the slaughter. Before the analysis, the whole muscle samples were purified by removing external fat and membranes. The research aimed at simultaneous verification of all the conditions connected with farming (organic or conventional) on the difference in nutritional composition of meat available for consumers e.g., proximate composition as well as vitamins, mineral and fatty acids content. However, it was ensured that the samples for tests shared the same, following characteristics:

- Group of animals: pigs, species—pig, category fattening pigs – pigs, meat type. The pigs were crossbreed barrows (Polish Large White (wbp) x Polish Landrace (pbz);
- The first sample set came from animals reared in conventional stables, while the other from pigs reared in special stables, arranged according to the Commission Regulation (EC) No. 889/2008 of 5 September 2008 [18] following the detailed rules of Council Regulation (EC) No. 834/2007 [19] on organic production and labeling of organic products with regard to organic production, labeling, and control;
- The conventional rearing system comprised an indoor area of one m^2, whereas the organic rearing system had an indoor area with organic saw dust of one m^2 and an outdoor area with free ranges of one m^2. The conventional stable had climate control and, the organic stable had only gravitation ventilation.
- The organic feed consisted exclusively of raw materials from organic farms and was produced directly on the farm. The second sample set came from animals that were fed with commercial feeds available for conventional producers. The composition and nutritional value of the compound feed were in line with the pig nutrition standards of the *National Research Council, Poland* [20]. Both, conventionally and organically reared animals were given feed and water ad libitum.
- The pigs weighing approximately 110 kg (range 108–112 kg) and Class E according to the classification of pork carcasses depending on the lean meat content according to Reg. (EC) 1234/2007 of October 22, 2007 were analyzed in this study [21]. One day before slaughter, the animals were transported to the abattoir, where they were lairaged overnight with free access to water. The animals were conventionally slaughtered after an electrical stunning.

Proximate composition

The proximate composition (water, protein, fat, collagen, sodium chloride) of the meat samples was determined with near-infrared transmission spectrometry as described in PN-A-82109:2010 using FOSS Food Scan™ Lab (Warszawa, Poland) [22]. The results were expressed as g per 100 g.

Content of copper, iron, magnesium, potassium, zinc, and calcium

The concentration of copper (Cu), iron (Fe), magnesium (Mg), potassium (K), and zinc (Zn) content was determined through atomization in an air/acetylene flame, and that of calcium (Ca) using anacetylene/nitrous oxide flame, all with the deuterium lamp background correction. Samples weighing 0.4–0.5 g were mineralized in a mixture of 65% HNO_3 and 30% H_2O_2 (7:1, V/V) at 200 °C in a Milestone Start D (Sorisole, Italy) microwave. The obtained solutions were quantitatively transferred to volumetric flasks and diluted to 50 mL. The diluted solutions were analyzed by atomic absorption using a Thermo Scientific iCE 3500 (Waltham, MA, USA) apparatus. The results were expressed as mg per kg.

Fatty acid profile

To determine the fatty acid profile, the meat samples were subjected to extraction according to the Soxhlet method with the use of Büchi Extraction System B-811 (Flawil, Switzerland). The extracts (samples 0.2–0.3 g) were esterified according to the ISO 12,966–2:2017 standard [23]. The esterified samples were analyzed in accordance with the ISO 12,966–1:2014 standard [24] on an SRI 8610C (Torrance, CA, USA) gas chromatograph with an Agilent Technologies HP-88 column of 105 m length, 0.25 mmi.D., and 0.2 µm film thickness, with an FID detector, using hydrogen as a carrier gas. The H_2 pressure at the inlet of the column was maintained at 3.8 bar to make the carrier gas flow at a linear speed of 0.5 m s^{-1}. The analyses were performed under a temperature program starting with column heating at 80 °C, followed by an increase of 4 °C min^{-1} to reach 170 °C. Then, the temperature was increased at a rate of 2.5 °C min^{-1} until an end temperature of 240 °C was achieved. The sample analysis time was 55 min. The fatty acid methyl ester (FAME) mix from Restek (Bellefonte, PA, USA) was used as a reference material for the analyses. The results were expressed as % of the total content of fatty acids.

On the basis of the determined profile of fatty acids n-6/n-3 ratio, PUFA/SFA ratio, hypocholesterolemic/hypercholesterolemic (h/H) ratio, the nutritional value (NV), and the indices of atherogenicity (IA) and thrombogenicity (IT) were calculated. For this purpose the following formulas were used: IA = (C12:0 + 4 × C14:0 + C16:0)/(MUFA + n-6 PUFA + n-3 PUFA) [25]; IT = (C14:0 + C16:0 + C18:0)/(0.5 × MUFA + 0.5 × n-6 PUFA + 3 × n-3 PUFA + n-3/n-6) [25]; NV = (C12:0 + C14:0 + C16:0)/(C18:1n-9 + C18:2n-6) [26]; h/H = (C18:1 + C18:2n-6 + C18:3n-3 + C20:3n-6 + C20:4n-6 + C20:5n-3 + C22:5n-3)/(C14:0 + C16:0) [27].

Cholesterol content

Cholesterol was extracted, by direct saponification, according to the method described by Bandeira et al. [28] with some modifications. The digested samples (2 g) were alkaline-saponified with 4 mL of a 50% aqueous solution of potassium hydroxide (KOH), and the unsaponified cholesterol was extracted with 10 mL of petroleum ether. In this study, following the enzymatic digestion, saponification, and extraction procedures, the solvent was distilled off and the residue was dissolved in n-heptane. The analysis was performed with GC-FID. The contents were calculated against a calibration series and an internal standard, taking into account the volumes of petroleum benzine used. The limit of determination was 10 mg kg^{-1}. For the analysis of the samples, gas chromatography (model GC-2010, Shimadzu Europe GmbH, Duisburg, Germany) was used with a flame ionization detector (FID), 0.25 µm analytical column of dimension 30 m × 0.25 mm containing the polyethylene VA-WAX (Varian, CA, USA) as stationary phase. Hydrogen was used as the carrier gas, while nitrogen was employed as the make-up gas. Compressed air was used as the carburant. The ratio of the flow rates of N_2, H_2, and synthetic air was 30:40:400 mL min^{-1}. The gas chromatographic conditions used in this study were set as follows: split injection: 20:1, injection volume: 1.0 µl, and temperature: 250 °C. The FID temperature was 320 °C. The results were expressed as mg per 100 g.

Vitamin E content

The vitamin E concentration in pork samples was determined by HPLC using a method described by Lahučký et al. [29]. A mixture of 1.5 mL sample homogenate (meat and distilled water in proportion 1:10) and 2 mL ethanol, 0.5 mL ascorbic acid was heated at 70 °C for 5 min. After adding 1 mL 10 N KOH, the mixture was again subjected to temperature of 80 °C for 30 min. After cooling, 5 mL n-hexane was added for extraction. The solvent was removed by evaporation under nitrogen, and the residue was immediately resolved in absolute ethanol and HPLC analysis was performed employing methanol/water 97: 3 v/v as mobile phase at a flow rate of 1 mL min^{-1} and a Hypersil WP 300 C4 column with a precolumn (12.5 × 0.4 cm i.d., 5 µm, Thermo Fisher Scientific). Detection was performed by fluorescence at 292 nm excitation and 366 nm emission. Peaks were quantified upon calibration with authentic samples of α-tocopherol SIGMA® (Sigma®, Merck, Germany) standard. The results were expressed as mg per kg.

Statistical analysis

The two-way analysis-of-variance model included the main effects of the meat origin (conventional *vs*. organic) and the kind of pork cuts (loin, ham, shoulder) as well as their interactions was used. The entire experiment was repeated three times. Statistical analyses were conducted with the use of statistical package R, version 3.6.1. The normality of distribution of the variables within groups was verified with the Shapiro–Wilk test. The significance of the differences between mean values was calculated at the level of $p < 0.05$, using Tukey's range *t*-test. The analyses were performed in triplicate.

Results

Proximate composition

The results of this study showed that organic meat in comparison to conventional had a higher content of protein ($p < 0.05$) (Table 1). The average protein concentration in the conventional and organic meat samples was found to be 21.45 g 100 g^{-1} and 22.60 g 100 g^{-1}, respectively.

Moreover, the statistically significant differences in composition between selected meat cuts were noted. The dissimilarities concerned concentrations of protein, fat, collagen and in case of organic meat sodium chloride. Regardless of meat origin, the highest protein content was observed in loin, whereas the lowest content was in shoulder ($p < 0.05$). The fat and collagen content in the samples obtained from pigs reared in both rearing systems decreased significantly ($p < 0.05$) in the following order: shoulder > ham > loin ($p < 0.05$). The average sodium chloride content was equal in both types of meat (organic and conventional) 0.92 g 100 g^{-1} ($p > 0.05$). The significant difference concerned only organic hams (0.96 g 100 g^{-1}) and loins (0.87 g 100 g^{-1}), ($p < 0.05$).

The meat origin had no influence on differences concerning concentration of fat, collagen, and cholesterol. Similarly, no simultaneous impact of the meat cut and meat origin was observed considering proximate composition of the analyzed samples.

Mineral compounds and vitamin E

The results further showed that organic meat in comparison to its conventional equivalent had significantly higher content of the following minerals and trace cuts (Table 2): copper (Cu) (4.13 mg kg^{-1} and 2.67 mg kg^{-1}, respectively), calcium (Ca) (337.63 mg kg^{-1} and 299.66 mg kg^{-1},

Table 1 Proximate composition (g 100 g^{-1}) and cholesterol content (mg 100 g^{-1}) of meat samples

Parameter	Meat sample	Ham	Loin	Shoulder	Interaction		
					Meat cuts [A]	Meat origin [B]	AxB
Fat	C	6.2 ± 2.68^{aA}	4.06 ± 0.76^{bA}	8.91 ± 1.99^{cA}	***	N.S	N.S
	O	6.53 ± 1.73^{aA}	4.5 ± 0.43^{bA}	9.63 ± 1.13^{cA}			
Protein	C	21.33 ± 1.25^{aA}	23.77 ± 0.52^{bA}	19.24 ± 0.64^{cA}	***	***	N.S
	O	22.58 ± 0.61^{aB}	24.43 ± 0.55^{bB}	20.76 ± 0.43^{cB}			
Water	C	70.71 ± 3.63^{aA}	71.33 ± 3.13^{aA}	71.45 ± 3.58^{aA}	N.S	N.S	N.S
	O	68.8 ± 3.16^{aA}	70.76 ± 3.07^{aA}	68.33 ± 3^{aA}			
Collagen	C	1.45 ± 0.28^{aA}	1.01 ± 0.12^{bA}	1.63 ± 0.1^{cA}	***	N.S	N.S
	O	1.44 ± 0.21^{aA}	1.14 ± 0.07^{bA}	1.5 ± 0.11^{aA}			
Sodium chloride	C	0.92 ± 0.06^{aA}	0.9 ± 0.05^{aA}	0.93 ± 0.04^{aA}	*	N.S	N.S
	O	0.96 ± 0.03^{aA}	0.87 ± 0.06^{bA}	0.92 ± 0.08^{abA}			
Cholesterol	C	59.3 ± 11.16^{abA}	51.97 ± 9.27^{aA}	63.47 ± 11.13^{bA}	N.S	N.S	N.S
	O	59.63 ± 11.40^{aA}	63.79 ± 10.55^{aA}	64.9 ± 11.39^{aA}			

[a–c]Means in the same row with different letters differ significantly ($p < 0.05$),

[A, B]Means in the same column with different letters differ significantly ($p < 0.05$),

N.S.—not significant,

*$p < 0.05$,

**$p < 0.01$,

***$p < 0.001$

Table 2 Content of tocopherol and selected mineral compounds (mg kg^{-1}) in meat samples

Parameter	Meat sample	Ham	Loin	Shoulder	Interaction		
					Meat cuts [A]	Meat origin [B]	AxB
Vitamin E expressed as α-Tocopherol	C	7.33 ± 2.64^{aA}	6.08 ± 2.16^{aA}	3.65 ± 1.32^{bA}	***	*	N.S
	O	4.29 ± 2.19^{abB}	6.03 ± 1.72^{aA}	2.93 ± 1.1^{bA}			
Cu	C	3.06 ± 0.59^{aA}	1.81 ± 0.16^{bA}	3.06 ± 0.67^{aA}	***	***	***
	O	4.58 ± 0.31^{aB}	2.34 ± 0.26^{bB}	5.47 ± 0.66^{cB}			
Ca	C	274.66 ± 37^{aA}	313.59 ± 56.62^{aA}	308.74 ± 39.71^{aA}	**	**	N.S
	O	297.42 ± 59.54^{aA}	323.39 ± 97.72^{aA}	392.09 ± 38.75^{bB}			
Mg	C	1022.03 ± 82.01^{aA}	1033.45 ± 85.24^{aA}	840.82 ± 51.16^{bA}	N.S	N.S	***
	O	1063.91 ± 251.57^{aA}	914.88 ± 226.07^{aA}	1121.52 ± 114.43^{aB}			
K	C	$12{,}916.6 \pm 1041.54^{abA}$	$12{,}959.75 \pm 256.14^{aA}$	$11{,}836.68 \pm 1123.84^{bA}$	***	**	N.S
	O	$16{,}213.76 \pm 3894.9^{aB}$	$14{,}301.44 \pm 1741.13^{aB}$	$13{,}402.6 \pm 1280.91^{aB}$			
Fe	C	30.3 ± 3.55^{aA}	22.34 ± 6.33^{bA}	31.73 ± 2.67^{aA}	***	N.S	***
	O	25.99 ± 3.75^{aB}	19.2 ± 5.49^{bA}	43.52 ± 7.21^{cB}			
Zn	C	67.11 ± 6.62^{aA}	53.05 ± 3.13^{bA}	78.89 ± 7.67^{cA}	***	***	***
	O	59.05 ± 5.46^{aB}	60.78 ± 22.35^{aA}	129.25 ± 26.11^{bB}			

[a–c]Means in the same row with different letters differ significantly ($p < 0.05$),

[A, B]Means in the same column with different letters differ significantly ($p < 0.05$),

N.S.—not significant,

[*]$p < 0.05$,

[**]$p < 0.01$,

[***]$p < 0.001$

respectively), potassium (K) (14,722.13 mg kg^{-1} and 12,589.2 mg kg^{-1}, respectively), and zinc (Zn) (85.46 mg kg^{-1} and 66.35 mg kg^{-1}, respectively), ($p < 0.05$).

Significant differences also found for the different cuts of pork meat. A significantly lowest concentration of Cu regardless of meat origin was noted in the case of loin ($p < 0.05$). Considering organic meat, it was also shown that shoulder had the highest Cu content ($p < 0.05$). In the case of Ca, the average concentration in organic shoulder was significantly the highest among all analyzed meat cuts ($p < 0.05$). With reference to K, the significant differences concerned only conventional loins and shoulders, with higher average value noted for loins ($p < 0.05$). The conventional shoulder samples had also the lowest content of Mg among conventional meat cuts ($p < 0.05$). Considering Fe content, loins contained the lowest levels of this cuts among conventional meat cuts, whereas in the shoulders the highest among organic meat cuts ($p < 0.05$). In case of Zn, the significantly highest concentrations were noted for shoulders irrespective of meat origin ($p < 0.05$). Moreover, for conventional meat the statistically significantly lowest concentration of zinc was observed for loin ($p < 0.05$).

The average vitamin E concentration was found to be significantly higher in case of conventional meat samples (5.68 mg kg^{-1}) in comparison to organic equivalents (4.42 mg kg^{-1}) ($p < 0.05$). Moreover, it was found that conventional shoulders contained on average the lowest amounts of this compound ($p < 0.05$). In case of organic meat a significantly ($p < 0.05$) higher content of vitamin E was observed in the loin samples compared to shoulder samples.

The simultaneous influence of the meat origin and meat cuts on the content of selected minerals and vitamins was determined in case of Cu, Mg, Fe, Zn, and tocopherol.

Fatty acid profile

The results of this study showed that in comparison to conventional meat samples organic equivalents had a significantly ($p < 0.05$) lower average concentration of saturated fatty acids (SFA) such as lauric acid (C12:0) (0.12% and 0%, respectively), margaric acid (C17:0) (0.26% and 0.22%, respectively), and lignoceric acid (C24:0) (0.2% and 0.06%, respectively) (Tables 3 and 4). Differences in the content of individual SFA did not significantly affect ($p > 0.05$) their total content. Moreover, it was found that organic meat samples had on average a significantly lower concentration of *cis*-10-Heptadecenoic acid (C17:1n-7) (0.37% and 0.3%, respectively) and α-linoleic acid (C18:3n-6) (0.84% and 0.78%, respectively) compared with conventional meat. Differences in the content of individual monounsaturated fatty

Table 3 Fatty acid profile (%) of meat samples

Parameter	Meat sample	Ham	Loin	Shoulder	Interaction		
					Meat cuts [A]	Meat origin [B]	AxB
C12:0	C	0.12 ± 0.06^{aA}	0.22 ± 0.18^{aA}	n.d.^{bA}	**	***	**
	O	n.d.^{aB}	n.d.^{aB}	n.d.^{aA}			
C14:0	C	1.46 ± 0.16^{aA}	1.69 ± 0.17^{bA}	1.71 ± 0.09^{bA}	**	N.S	N.S
	O	1.52 ± 0.19^{aA}	1.68 ± 0.1^{bA}	1.54 ± 0.25^{abA}			
C16:0	C	24.93 ± 1.35^{aA}	26.37 ± 1.35^{bA}	27.36 ± 1.03^{bA}	***	N.S	*
	O	24.72 ± 1.51^{aA}	27.62 ± 1.21^{bA}	26.08 ± 0.83^{cB}			
C16:1 n-7	C	3.32 ± 0.4^{aA}	3.69 ± 0.25^{bA}	4.21 ± 0.46^{bA}	N.S	N.S	***
	O	3.83 ± 0.39^{aB}	3.82 ± 0.11^{aA}	3.09 ± 0.3^{bB}			
C17:0	C	0.2 ± 0.02^{aA}	0.25 ± 0.04^{bA}	0.31 ± 0.12^{bA}	**	*	N.S
	O	0.19 ± 0.07^{aA}	0.21 ± 0.04^{aA}	0.25 ± 0.04^{bA}			
C17:1 n-7	C	0.32 ± 0.05^{aA}	0.38 ± 0.05^{bA}	0.41 ± 0.16^{bA}	N.S	*	N.S
	O	0.3 ± 0.14^{aA}	0.3 ± 0.05^{aB}	0.31 ± 0.06^{aA}			
C18:0	C	10.32 ± 1.78^{aA}	12.52 ± 0.46^{bA}	13.96 ± 0.27^{cA}	***	N.S	N.S
	O	11.49 ± 2.07^{aA}	12.81 ± 0.65^{aA}	14.53 ± 1.54^{bA}			
C18:1 n-9	C	48.26 ± 2.55^{aA}	46.2 ± 1.41^{bA}	44.02 ± 1.8^{cA}	***	N.S	N.S
	O	48.57 ± 2.33^{aA}	46.07 ± 1.55^{bA}	43.4 ± 1^{cA}			
C18:2 n-6	C	8.16 ± 0.27^{aA}	6.02 ± 0.17^{bA}	5.72 ± 1.29^{bA}	***	N.S	***
	O	6.65 ± 1.39^{aB}	5.46 ± 0.49^{bB}	8.14 ± 0.72^{cB}			
C18:3 n-6	C	0.57 ± 0.04^{aA}	0.41 ± 0.05^{bA}	0.31 ± 0.07^{cA}	***	*	***
	O	0.43 ± 0.11^{aB}	0.39 ± 0.03^{aA}	0.59 ± 0.06^{bB}			
C18:3 n-3	C	0.91 ± 0.09^{aA}	0.85 ± 0.07^{aA}	0.75 ± 0.06^{bA}	***	**	*
	O	0.83 ± 0.1^{aA}	0.74 ± 0.06^{bB}	0.77 ± 0.06^{abA}			
C20:0	C	0.19 ± 0.04^{aA}	0.26 ± 0.01^{bA}	0.21 ± 0.02^{aA}	N.S	N.S	***
	O	0.28 ± 0.09^{aB}	0.22 ± 0.02^{aB}	0.22 ± 0.02^{aA}			
C21:0	C	0.46 ± 0.06^{aA}	0.42 ± 0.11^{aA}	0.26 ± 0.06^{bA}	*	N.S	***
	O	0.35 ± 0.15^{aB}	0.31 ± 0.08^{aB}	0.37 ± 0.06^{aB}			
C22:1 n-9	C	0.58 ± 0.17^{aA}	0.51 ± 0.08^{aA}	0.57 ± 0.11^{aA}	***	N.S	***
	O	0.84 ± 0.22^{aB}	0.39 ± 0.09^{bB}	0.52 ± 0.11^{cA}			
C24:0	C	0.21 ± 0.15^{aA}	0.2 ± 0.08^{aA}	0.18 ± 0.07^{aA}	N.S	***	**
	O	n.d.^{aB}	n.d.^{aB}	0.17 ± 0.03^{bA}			

$^{a–c}$Means in the same row with different letters differ significantly ($p < 0.05$),

$^{A, B}$Means in the same column with different letters differ significantly ($p < 0.05$),

N.S.—not significant,

n.d. – not detected (detection limit 0.05%)

$^{*}p < 0.05$,

$^{**}p < 0.01$,

$^{***}p < 0.001$

acids (MUFA) and polyunsaturated fatty acids (PUFA) did not have significant influence on the discrepancies in their total content ($p > 0.05$). However, a significantly ($p < 0.05$) lower concentration of n-3 fatty acids was noted in organic meat due to the lower content of α-linolenic acid, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) which belong to the family of n-3 fatty acids. This, in turn, resulted in significantly lower average n-6/n-3 ratio of conventional meat. However, no significant differences between average values for organic and conventional pork were noted considering PUFA/SFA, h/H, NV, IA and IT.

Significantly ($p < 0.05$), the highest contents of C18:1n-9, unsaturated fatty acids (UFA), MUFA, and n-9 fatty acids as well as the lowest of C14:0 and C16:0 were observed in ham compared to other meat types regardless of the breeding system. Moreover, conventional ham was characterized by the lowest content of C16:1n-7, C17:0, C17:1n-7, C18:0, as well as the highest n-6/n-3 ratio and the highest concentration of

Table 4 The content (%) of SFA, MUFA, PUFA, UFA, n-6, n-3, and n-9, and relevant fatty acids ratios and indicies of meat samples

Parameter	Meat sample	Ham	Loin	Shoulder	Interaction		
					Meat cuts [A]	Meat origin [B]	AxB
SFA	C	37.9 ± 2.29^{aA}	41.94 ± 1.41^{bA}	43.99 ± 1.33^{cA}	***	N.S	N.S
	O	38.55 ± 2.19^{aA}	42.85 ± 1.74^{bA}	43.17 ± 1.72^{bA}			
MUFA	C	52.48 ± 2.34^{aA}	50.78 ± 1.39^{abA}	49.22 ± 1.93^{bA}	***	N.S	N.S
	O	53.54 ± 2.46^{aA}	50.57 ± 1.53^{bA}	47.31 ± 1.21^{cB}			
PUFA	C	9.64 ± 0.36^{aA}	7.28 ± 0.19^{bA}	6.79 ± 1.38^{bA}	***	N.S	***
	O	7.92 ± 1.53^{aB}	6.59 ± 0.51^{bB}	9.51 ± 0.75^{cB}			
UFA	C	62.12 ± 2.31^{aA}	58.06 ± 1.4^{bA}	56.01 ± 1.34^{cA}	***	N.S	N.S
	O	61.46 ± 2.18^{aA}	57.16 ± 1.73^{bA}	56.81 ± 1.75^{bA}			
n-6	C	8.73 ± 0.3^{aA}	6.43 ± 0.21^{bA}	6.03 ± 1.35^{bA}	***	N.S	***
	O	7.09 ± 1.49^{aB}	5.85 ± 0.52^{bB}	8.73 ± 0.77^{cB}			
n-3	C	0.91 ± 0.09^{aA}	0.85 ± 0.07^{aA}	0.75 ± 0.06^{bA}	***	**	*
	O	0.83 ± 0.1^{aA}	0.74 ± 0.06^{bB}	0.77 ± 0.06^{abA}			
n-9	C	48.84 ± 2.49^{aA}	46.71 ± 1.44^{bA}	44.59 ± 1.8^{cA}	***	N.S	N.S
	O	49.41 ± 2.24^{aA}	46.46 ± 1.56^{bA}	43.91 ± 1.04^{cA}			
n-6/n-3	C	9.64 ± 0.84^{aA}	7.57 ± 0.7^{bA}	7.99 ± 1.62^{bA}	***	*	***
	O	8.57 ± 1.61^{aA}	7.92 ± 1.02^{aA}	11.36 ± 1.59^{bB}			
PUFA/SFA	C	0.26 ± 0.02^{aA}	0.17 ± 0.01^{bA}	0.15 ± 0.03^{bA}	***	N.S	***
	O	0.21 ± 0.04^{aB}	0.15 ± 0.02^{bB}	0.22 ± 0.03^{aB}			
IA	C	0.50 ± 0.04^{aA}	0.58 ± 0.05^{bA}	0.61 ± 0.04^{bA}	***	N.S	*
	O	0.50 ± 0.04^{aA}	0.60 ± 0.04^{bA}	0.57 ± 0.03^{bB}			
IT	C	1.10 ± 0.11^{aA}	1.30 ± 0.08^{bA}	1.44 ± 0.08^{cA}	***	N.S	N.S
	O	1.15 ± 0.11^{aA}	1.38 ± 0.10^{bA}	1.39 ± 0.09^{bA}			
h/H	C	2.20 ± 0.21^{aA}	1.91 ± 0.15^{bA}	1.75 ± 0.12^{bA}	***	N.S	*
	O	2.16 ± 0.18^{aA}	1.80 ± 0.14^{bA}	1.92 ± 0.11^{bB}			
NV	C	0.47 ± 0.04^{aA}	0.54 ± 0.04^{bA}	0.59 ± 0.04^{bA}	***	N.S	*

SFA-saturated fatty acids; MUFA-monounsaturated fatty acids; PUFA-polyunsaturated fatty acids; UFA-unsaturated fatty acids, IA – index of atherogenicity, IT- index of thrombogenicity, h/H—hypocholesterolemic/hypercholesterolemic ratio, NV—nutritional value ratio

[a–c]Means in the same row with different letters differ significantly ($p < 0.05$),

[A, B]Means in the same column with different letters differ significantly ($p < 0.05$),

N.S.—not significant,

*$p < 0.05$,

**$p < 0.01$,

***$p < 0.001$

total n-6 fatty acids among conventional meat cuts. Organic ham, on the other hand, distinguished itself from the other organic meat cuts by the highest concentrations of C18:3n-3 and C22:1n-9 fatty acids. Conventional ham was characterized by significantly the highest PUFA/SFA ratio among the analyzed conventional meat cuts and, at the same time, had significantly higher ratio than its organic equivalent. Both organic and conventional hams had significantly the lowest values of h/H and NV ratios, as well as IA and IT indices.

The analyzed shoulder samples were distinguished by significantly ($p < 0.05$) the highest content of C18:0 and the lowest of C18:1n-9, UFA and n-9 fatty acids among considered meat cuts, regardless of meat origin. Moreover, the organic shoulder was characterized by a significantly the highest ($p < 0.05$) content of C17:0, C18:2n-6, C18:3n-6, PUFA, n-6 fatty acids and n-6/n-3 ratio, as well as the lowest concentration of C16:1n-7 and MUFA compared to other organic meat types. On the other hand, the conventional pork shoulder was characterized significantly the highest concentration of SFA and the lowest of C12:0, C18:3n-6, C18:3n-3, and C21:0 among conventional meat cuts. Moreover, organic shoulder was characterized by significantly higher PUFA/SFA and h/H ratios, whereas lower AI index and NV than its conventional equivalent.

The organic loin had significantly the highest content of C16:0 and the lowest C18:2n-6, C22:1n-9, PUFA, and n-3 fatty acids as well as PUFA/SFA ratio among organic meat types. Conventional loin samples were distinguished from other conventional meat cuts by the highest concentration of C20:0. Moreover, organic loin had significantly lower PUFA/SFA ratio than its conventional equivalent.

The simultaneous influence of meat origin and meat cut was noted in case of C16:0, C16:1n-7, C18:2n-6, C18:3n-6, C18:3n-3, C20:0, C21:0, and C22:1n-9 fatty acids.

Discussion

Proximate composition and content of vitamin E and mineral compounds

The results of the study showed that organic meat had higher content of protein (Table 1). It was found that considerable increases in the quantity of protein in the meat and the reduction of the water/protein index can be achieved by introducing an organic breeding system, which was also observed by other researchers [30, 31]. The findings regarding the highest protein content in loins and the lowest content in shoulders reported in the present study are consistent with the results of previous studies on the protein content of different meat cuts [14, 32]. Similar to the present results, Kim et al. [33] showed that protein content in pork meat was significantly affected by the muscle type with *longissimus dorsi* muscle showing the highest values with 21.79% and *supraspinatus* muscle was lowest with 18.51%.

Moreover, it was found that the highest fat and collagen content was in shoulder and the lowest in loin. These discrepancies could be due to the difference in physical activity in the relation to the anatomic position between cuts. Similar results were also pointed out by other scientists [32–34].

The type of the rearing system was not found to have a significant effect on the cholesterol content in pork. In addition, the cholesterol level obtained in this study is consistent with the data obtained by other researchers. Parunović et al. [35] reported that total cholesterol concentration in pigs reared outdoors was on average of 63.1 mg 100 g^{-1}, while the level of cholesterol in indoor Mangalitsa pigs was on average of 61.7 mg 100 g^{-1}. Tu et al. [36] reported that the content of cholesterol was 62 mg 100 g^{-1} and 65 mg 100 g^{-1} in pork from organically reared animals. Also, in the research of Kim et al. [33], the cholesterol content of twenty-one pork muscles which are included loin, ham and shoulder cuts did not differ significantly. In this study, organic meat cuts contained less alpha-tocopherol compared with conventional meat. Therefore, it can be hypothesized that organic farming not necessarily influences the concentrations of these compounds in plants, and consequently, in animal organisms. This hypothesis seems to be confirmed by the literature. Högberg et al. [16] showed lack of difference in alpha-tocopherol concentration in meat from organically and conventionally fed pigs. Also, Walshe et al. [37] noted the lack of detectable differences in concentrations of vitamin E in organic and conventional bull meat, and Ellis et al. [38] in milk fat, while Govasmark et al. [39] advised vitamin E supplementation to organically reared ruminants.

At present, only the rudimentary information on the content of mineral compounds in organic pork is available. Literature data generally show the levels of different cuts in intensively reared pigs, without specifying the type of muscle or meat cut. In this study it was noticed that an organic breeding system contributes to higher contents of mineral components, such as calcium, copper, zinc, and potassium, which is in line with other reports [14, 30, 31]. Shorthose and Harris [40] stated that there seems to be a correlation between higher content of iron and a greater level of myoglobin, which is observed in animals that are raised in such conditions, which give them plenty of opportunities for recreational activities. However, as in the case of the present study, also Zhao et al. [16] did not notice significant differences in iron content in pork between organically and conventionally reared animals. Similar findings have been observed for magnesium. On the other hand, contrary to our results, the authors also observed a lack of significant differences in the content of calcium, potassium, and zinc. Moreover, they did not detect differences for cuts that were not analyzed in the present study, such as sodium, nickel, or strontium. The concentrations of several trace cuts in organic pork were significantly higher ($p < 0.05$) compared to conventional pork (Cr: 808 and 500 μg kg^{-1}, respectively; Mn: 695 and 473 μg kg^{-1}, respectively), while the levels of some cuts were in agreement with our study (Cu: 1.80 and 1.49 mg kg^{-1}). Dervilly-Pinel et al. [41] also noticed significantly higher concentrations of Cu and Zn, as well as arsenic (As) in organic pork. Copper supplement levels, which exceed the actual physiological requirements, are generally added to animal feed in the conventional rearing system [42]. Zhao et al. [17] stated that when mineral supplements containing too much copper are given to pigs as a growth promoter, it could lead to environmental problems. Copper greatly enhances growth and the antioxidant system (as a cofactor of superoxide dismutase). Consequently, when pigs are reared in an organic system, they probably utilize copper through their outdoor activities [17]. Skobràk-Bodnàr and Bodnàr [43] stated in a review that the copper content of pork can range from 0.92 to 2.1 mg kg^{-1}. Similar results were presented by Nicolic et al. [44]. Moreover, correspondingly to the results obtained in the present study for organic meat samples, Nicolic et al. [44] noted the highest levels of Cu in pig shoulder compared to the significantly lower levels present in loin. Also Tomovic et al. [45], who analyzed the content of copper in *semimembranosus* muscle (hind leg) from ten different genetic pig lines, determined the Cu content at a similar level 3.5 mg kg^{-1}. Our results also showed a two-fold higher Zn concentration in organic meat compared to that reported by Nikolic et al. [46]. A significantly higher content of Zn was observed in shoulder compared to ham and loin regardless of the breeding system. Similar results were presented by Nicolic et al. [44]. Those authors noted the highest levels of Zn in pig shoulder compared to the significantly lower levels present in loin. Based on these results, it could be concluded that organic pork, especially shoulder, is a rich source of Zn. Średnicka-Tober et al. [47] carried out a meta-analysis based on 67 published studies, comparing the composition of organic and nonorganic meat products. It was found that the evidence base was too weak to carry out meaningful meta-analyses of biologically active compounds such as minerals, antioxidants, and vitamins. This suggests the need for additional research on the content of biologically active peptides in organic and conventional pork.

In the present study, considering meat cuts, the levels of four essential cuts (Cu, Ca, Fe, Zn) were found higher in organic shoulder, than in organic loin. This finding was in accordance with the results reported by Nikolic et al. [46], who characterized three Mangalica pork cuts from Serbia. Among the possible reasons for the higher iron levels in the shoulder and ham compared to the loin, may be the higher metabolic activity of these muscles during the lifetime of the animal. This suggests that pork, especially organic shoulder, may be relevant in a healthy balanced diet and can prevent iron deficiency. Similar results were obtained by Kim et al. [33] and Nicolic et al. [44]. Those authors pointed out the highest iron content in *m. vastus intermedius* and *infraspinatus*, while the lowest was found in *m. longissimus dorsi*.

Fatty acid profile

In the present study, palmitic acid (C16:0) was found to be the amplest SFA, oleic acid (C18:1n-9) was the most abundant example of MUFA, and linoleic acid (C18:2n-6) was the amplest PUFA in the organic and conventional pork samples. The fatty acid composition of meat plays an important role in the human diet and nutritional status. Yet, a reduced intake of total fat and cholesterol is strongly recommended by nutritionists (especially SFA and trans-fatty acids, which are associated with an increased risk of certain cancers and cardiovascular diseases) [48]. The research results showed the preponderance of organic pork over conventional meat in terms of selected fatty acid profile, which corresponds to other literature data [15, 49]. In this study it was also found that organic meat had a significantly ($p < 0.05$) lower concentration of some of the SFA such as lauric acid (C12:0), margaric acid (C17:0), and lignoceric acids (C24:0). Yet, similarly to the meat-analysis results of Średnicka-Tober et al. [47], no difference regarding average total SFA content in organic and conventional pork was detected. On the other hand, some literature sources provide information that organic meat contains more PUFA and less SFA. The finding of lower SFA concentration in organic pork has also been reported by Kim et al. [14] in a study on native Korean black pigs. The SFA, MUFA, UFA, PUFA, n-6, n-3 contents also showed significant differences with their levels ranging between cuts. Similar results were described by Kim et al. [33], where the total contents of PUFA were the highest for *adductor* and *rectus femoris*, while the lowest for *longissimus dorsi*. In addition, Leseigneur-Meynier and Gandemer [50] found that fatty acid composition of triglycerides from *longissimus dorsi* of pork was 42.5% of saturated, 50.3% of monounsaturated and 7.2% of polyunsaturated. The differences in fatty acid composition could be due to the differences in triglyceroles and phospholipids contents between the cuts.

In addition, consumers are urged to increase intake of PUFA, particularly n-3 PUFA, at the expense of n-6 PUFA [19]. According to various epidemiological and clinical studies: linoleic acid (LA)—an n-6 fatty acid, as well as linolenic acid, EPA, and DHA n-3 fatty acids, collectively provide significant protection against coronary heart disease (CHD). LA is the major dietary fatty acid that regulates the metabolism of low-density lipoprotein-cholesterol (LDL-C) by decreasing its production and enhancing its clearance. Moreover, the available mass of LA is the most crucial factor, directly impacting the hyperlipemic effects of other dietary fat components, such as SFA and trans fatty acids, as well as cholesterol. In turn, n-3 fatty acids, especially EPA and DHA, are strong antiarrhythmic agents. Additionally, these two fatty acids contribute to the improvement of vascular endothelial functions as well as help lower blood pressure, platelet sensitivity, and triglyceride level in the serum. The differing functions of these two families of dietary fatty acids (n-6 and n-3) maintain their balance, which is an important factor influencing cardiovascular health [51]. Due to the lack of sufficient clinical data experts do not propose any specific recommendations regarding value of n-6/n-3 ratio [52]. The Food and Agriculture Organization (FAO) report [53] indicates that consumption of n-6 fatty acids in the diet of an adult should be in the range between 2.5 and 9% of total energy intake, whereas of n-3 fatty acids from 0.5 to 2%. Nevertheless, the literature sources show that favorable n-6/n-3 ratio should preferably vary from 1/1 to 4/1 [54]. All of the tested meat samples showed an unfavorable n-6/n-3 ratio, especially organic shoulder ones (see Table 4). Ham contains large quantities of monounsaturated and polyunsaturated fatty acids, but because the proportion of n-6 PUFA is relatively high, the n6/n3 ratio is higher than recommended. Contrary to the outcomes of this study, the meat-analysis results of Średnicka-Tober et al. [47] showed the preponderance of organic meat over conventional equivalents in the context of concentrations of n-3 fatty acids, and consequently, the n-6/n-3ratio. However, they indicated that the evidence base was too small to draw any final conclusions. As in case of other studies, no difference was shown in the levels of MUFA between two analyzed pork types [47]. Similarly, considering PUFA some studies – including the present one – have shown the lack of significant differences between organic and conventional pig meat [47]. PUFA/SFA ratio is employed to verify the influence of certain foods on cardiovascular health of humans [25]. It is recommended that PUFA/SFA ratio in healthy foods should be above 0.4 [27]. In this study pork cuts were characterized by relatively low PUFA/SFA ratio (from 0.15 to 0.26). In comparison, Realini et al. [55] determined higher values for the following pork muscles: *Musculus longissimus thoracis* (0.85), *Musculus masseter* (1.19) and *Musculus semitendinosus* (1.29). Alvarenga et al. [56] showed that *Musculus longissimus dorsi* had an average PUFA/SFA ratio of 0.47, which is also significantly higher than the ratios determined in this study for the same muscle, from both organically (0.15) and conventionally (0.17) reared pigs. On the other hand, Fernández et al. [27] showed that Spanish dry-cured ham had similar PUFA/SFA ratios to those received in this study—from 0.19 to 0.3, with Jamón Serrano reaching the highest values.

The index of atherogenicity (IA) identifies atherogenic potential of fatty acids in foods. The index of thrombogenicity (IT) characterizes their thrombogenic potential by indicating relationship between pro- and anti-thrombogenic fatty acids [26]. Both indices are generally used to evaluate lamb and goat meat [47]. Średnicka-Tober et al. [47] showed that organic meats of these species were characterized by significantly lower thrombogenicity index than their conventional equivalents. The present study results do not confirm this relationship in the case of pigs. The IA ranged between 0.5 and 0.61, whereas IT between 1.1 and 1.44. Similar results were received by Pietrzak and Grela [57]. Depending on the feeding system, in their study, the IA of pork *longissimus* muscle ranged between 0.54 and 0.58, whereas IT between 1.23 and 1.32. On the other hand, Alvarenga et al. [56] received much lower AI values—0.31 for high birth-weight pigs and 0.27 for low birth-weight pigs.

The hypocholesterolemic/hypercholesterolemic ratio (h/H) is used to verify the influence of fatty acids profile on cholesterol. It denotes relationship between hypocholesterolemic and hypercholesterolemic fatty acids [58]. In this study, the h/H index ranged between 1.75 and 2.20. Organic *Musculus longissimus dorsi* had an average h/H of 1.8, whereas conventional equivalent 1.91. These results are in line with the outcomes of the study by Pietrzak and Grela [57]. They determined the h/H index value in the range 1.82–1.96 for pork *longissimus* muscle. Fernández et al. [27] showed that Spanish dry-cured hams had the h/H values in the range 2.0–2.67. Among them, Iberian hams had the most favorable ratios (above 2.5).

The nutritional value (NV) ratio of fatty acids represents relationship between saturated fatty acids (C12:0, C14:0, C16:0) and the sum of oleic and linoleic acids**.** In this study, the pork ham showed the lowest values of this indicator (0.47 organic and 0.48 conventional). The NV of loin and shoulder was in the range between 0.54 and 0.59. Estévez et al. [29] investigated differences between Iberian and white pigs. They showed that the NV for Iberian pigs (0.39) was more favorable than for white pigs (0.44). Both values are, however, lower than those received in this study for hams. Similarly, lower NV values were determined by Realini et al. [55]—from 0.27 (*Musculus semitendinosus*) to 0.39 (*Musculus longissimus thoracis*).

Conclusions

The nutritional and technological value of meat seems to highly depend on the animal husbandry system. An organic production system is of great importance as it is compatible with sustainable agriculture. This study compared the characteristics of meat from pigs reared in a traditional and organic farming system, determining the biochemical properties of pork. The effect of animal husbandry on selected parameters of meat quality was confirmed by the results, which indicated that organic meat has higher contents of protein and selected mineral compounds (copper, calcium, potassium, and zinc), as well as better fatty acid profiles. Moreover, the organic pork cuts, especially shoulder, were identified as a better source of copper, calcium, iron and zinc, while organic pork ham and loin had more potassium. On the other hand, organic hams were shown to have lower content of vitamin E and PUFA/SFA ratio, whereas organic shoulders higher n-6/n-3, PUFA/SFA and h/H ratios, and lower AI and NV ratio in comparison to their conventional equivalents. The findings of this study significantly enhanced knowledge on the dietary value of organic meat on the example of pork. They showed preponderance of organic loins and to indicated extent also organic hams and shoulders over conventional counterparts in terms of their nutritional value. Nevertheless, in the future, it is necessary to assess the technological value of meat from both breeding systems to be able to successfully produce healthy and safe meat products.

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Declarations

Conflict of interest The authors declare no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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