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Comparison of the Quality of Selected Meat Products and Their Plant-Based Analogs

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The aim of this study was to compare the quality of selected meat products, *i.e.* frankfurters, Polish *kabanos* sausages, and salami, with their plant-based (vegetarian) analogs. Five items from five different product batches were analyzed in each examined product category. The analyzed items were vacuum-packaged in bags to standardize the parameters of the compared products, and their quality was evaluated before the use-by date declared by the manufacturer. Meat products had higher dry matter and lipid contents. Salami contained more protein, whereas frankfurters and *kabanos* sausages contained less protein than their respective analogs. Moreover, traditional *kabanos* sausages had a higher pH than their vegetarian alternatives. Indicators of the nutritional value of lipids and pH of vegetarian frankfurters and salami were higher than those of their meat counterparts. In turn, lipids of vegetarian *kabanos* sausages had lower ratios of unsaturated to saturated fatty acids, monounsaturated to saturated fatty acids and hypocholesterolemic to hypercholesterolemic fatty acids than traditional *kabanos* sausages. Among the color parameters, redness (a^*), yellowness (b^*) and chroma (C^*) of plant-based meat analogs were higher compared to those of meat products. These results indicate that the names of plant-based analogs, which make a direct reference to the corresponding traditional meat products, can be misleading for consumers who expect products with similar quality attributes.

Key words: meat product, plant-based meat analog, quality

INTRODUCTION

There is no doubt that the inclusion of meat in the human diet played a significant role in the development of the human race [Williams & Hill, 2017]. According to Milton [1999], the incorporation of meat into the diet of early hominid species around 2.6 million years ago was a key event in their evolution. Meat procurement strategies contributed to technical progress, including the construction of tools and weapons, and the organization of hunting expeditions promoted the formation of social bonds and structures [Hladik & Pasquet, 2002]. Over time, meat consumption induced profound biological changes, including a decrease in the size of human teeth and intestines and changes in their morphology, as well as an increase in the size of the human body and brain, which ultimately led to the emergence of modern humans [Magkos, 2022]. The growing demand for animal protein contributed to animal rearing and breeding [Cucchi & Arbuckle, 2021]. In turn, food preservation and storage techniques were developed to prevent meat from spoilage during long-term storage [Knorr & Augustin, 2022].

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At present, meat and meat products continue to play a significant role in the human diet, both in developed and developing countries. In 2018, average global *per capita* consumption of unprocessed red meat reached 51 g/day [Miller *et al.*, 2022]. Meat is popular among consumers because it is a highly versatile food with numerous preparation options, desirable sensory attributes, and a high nutritional value [Dekkers *et al.*, 2018]. Global annual meat consumption, estimated at 34 kg *per capita* in 2019, is expected to increase by 14% in 2030. The projected increase will differ across continents, and it could reach 30% in Africa, 18% in Asia and the Pacific, 12% in Latin America, 9% in North America, and 0.4% in Europe [OECD/FAO, 2021]. The demand for various meat types will also differ. In 2018, meat products had the following market share: ruminant meat – 23%, poultry – 34%, pork – 32%, and meat of other animals – 2% [Smith *et al.*, 2022].

However, despite the positive implications of meat consumption, meat intake is also associated with certain health risks. Research has shown that the consumption of red meat is correlated with the incidence of type 2 diabetes [Sanders *et al.*, 2023], coronary heart disease [Papier *et al.*, 2023], and cancer [Demeyer *et al.*, 2016]. The Working Group of the International Agency for Research on Cancer (IARC) classified red meat as potentially carcinogenic for humans (Group 2A) and processed meat as carcinogenic for humans (Group 1) [Bouvard *et al.*, 2015]. The World Cancer Research Fund International [World Cancer Research Fund International, 2018] recommends that the consumption of red meat is limited to around three servings *per* week, *i.e.* 350–500 g (700–750 g of raw meat). The use of antibiotics in livestock production (including as growth promoters), the presence of antibiotic residues in foods [Van Boeckel *et al.*, 2015], and meat-borne zoonotic diseases [Lee Bouvard *et al.*, 2022] also pose health risks for consumers. It should also be noted that meat production, especially ruminant rearing, exerts a negative impact on the environment by contributing to greenhouse emissions, increasing the demand for pasture and land for the cultivation of forage and fodder crops, increasing the demand for water, and leading to environmental pollution [González *et al.*, 2020].

The health risks associated with meat consumption and the adverse impact of meat production on the environment and the well-being of animals have led to changes in consumer perceptions of meat. Many consumers give up meat or limit their meat intake based on the recommendations made by physicians and dieticians, environmental activists (promotion of sustainable development), and animal rights activists (moral and ethical implications of meat consumption), as well as for financial reasons. These consumers switch to meat analogs containing plant proteins, mycoproteins, algal or edible insect proteins. The production of meat cultured *in vitro* is also possible in the future [Lima *et al.*, 2022a]. It should be noted that the popularity of meat substitutes extends beyond the reach of the vegetarian movement and is increasingly associated with flexitarianism [Dagevos, 2021]. As a result, the sales of meat analogs increased by 38% between 2017 and 2021 [Ishaq *et al.*, 2022]. The value of the meat substitute market is projected to reach USD 2,651 million in 2026, increasing at a compound annual growth rate (CAGR) of 5.1% in 2021–2026 [IndustryARC™, 2023]. According to the IndustryARC™ report [2023], Europe was the dominant player on the meat substitute market with a major share of 42.6% in 2020, but Asia-Pacific is expected to outpace all regions with an estimated CAGR of 6.05% in 2021–2026.

Various types of meat substitutes are being introduced to the market to cater to the growing demand for meat analogs. In general, meat alternatives can be divided into analogs that "mimic" meat in appearance, taste or preparation method, and analogs that do not resemble meat [Bryngelsson *et al.*, 2022]. The names of products that imitate meat often make a direct reference to the substituted meat product. The aim of this marketing trick is to attract the consumers' attention to items that mimic traditional meat products, and to improve the positioning of plant-based analogs in the marketplace [Lacy-Nichols *et al.*, 2021]. The practice of naming meat analogs after their traditional counterparts has stirred a debate among producers and consumers, who have observed this strategy could be misleading and could undermine the foundations of the meat industry [Froggatt & Wellesley, 2019]. The question whether the practice of labeling meat substitutes with the names of the corresponding traditional meat products is justified by similarities in their chemical composition and physicochemical properties could be answered based on the results of research. However, there is a general scarcity of published studies addressing this issue. Therefore, this study was undertaken to verify the research hypothesis postulating that meat products and plant-based meat analogs have similar quality attributes. The research hypothesis was verified by comparing the proximate chemical composition, fatty acid profile, acidity, and color parameters of selected processed meats and their plant-based analogs available in retail.

MATERIALS AND METHODS

Materials

The quality of three processed meat products, *i.e.* frankfurters, Polish *kabanos* sausages, and salami, was compared with the corresponding plant-based analogs. The ingredient lists of meat products and their analogs, declared by manufacturers, are presented in Table 1. The analyzed products were manufactured by the leading Polish suppliers, and they were purchased between October and December 2021 in a hypermarket belonging to a popular international retail chain operating in Europe and Asia. Five items from five different product batches supplied by the same manufacturer were analyzed in each examined product category. The analyzed items were vacuum-packaged in bags to standardize the parameters of the compared products, and their quality was evaluated before the use-by date declared by the manufacturer. The compared products were refrigerated under identical conditions (4°C) until analysis.

Proximate chemical composition analysis

The proximate chemical composition of the products was determined in accordance with the Official Analytical Methods [AOAC, 2005]: moisture content (sample drying at a temperature

Table 1. Ingredient lists of the meat products and their analogs, declared by manufactures.

Frankfurter		*Kabanos*		Salami	
Meat product	**Meat analog**	**Meat product**	**Meat analog**	**Meat product**	**Meat analog**
Pork (71 %), water, salt, soy protein, modified starch, pork collagen protein, glucose, stabilizers (diphosphates, triphosphates), flavor enhancer (monosodium glutamate), spices, spice extracts, antioxidant (sodium ascorbate), preservative (sodium nitrite)	Water, soy protein isolate (10.9%), rapeseed oil, wheat protein (gluten) – 7.3%, modified corn starch, salt, flavorings, thickener (carrageenan), ground red pepper, colorings (iron oxides and hydroxides), liquid hickory smoke	Pork (100 g of product was obtained from 171 g of meat), salt, spices, antioxidant (sodium erythorbate), preservative (sodium nitrite), rapeseed oil	Water, wheat protein, vegetable oil (coconut oil), soy protein, spices, salt, flavorings, spice extracts, colorings (concentrated pepper extract, fenugreek extract, concentrated beetroot juice, iron oxides)	Beef, pork (100 g of product was obtained from 70 g of beef and 56 g of pork), pork fat, salt, spices, glucose, sugar, antioxidant (sodium ascorbate), bacterial starter cultures, preservatives (sodium nitrite, potassium nitrate)	Textured soy protein (7%), rapeseed oil, wheat protein (gluten) - 5%, modified corn starch, flavorings, salt, thickener (carrageenan), spices, vinegar powder, barley malt extract, colorings (iron oxides and hydroxides)

of 105°C to constant weight), total protein content (Kjeldahl method using Kjeltec™ 2200 auto distillation unit, FOSS Analytical, Hilleroed, Denmark), lipid content (Soxhlet extraction with diethyl ether using Soxtec™ 2050 auto fat extraction system, FOSS Analytical), and ash content (sample incineration at a temperature of 550°C to constant weight).

Fatty acid profile determination

Fatty acid profile in the products was analyzed according to the analytical procedure described by Daszkiewicz & Gugołek [2020]. Fatty acids were separated on the VARIAN CP-3800 gas chromatograph (Varian Inc., Palo Alto, CA, USA) with a flame ionization detector (FID) and a capillary column (length – 50 m, inner diameter – 0.25 mm, film thickness – 0.25 µm). Helium was used as a carrier gas (flow rate – 1.2 mL/min). The results were expressed as proportions (%) of individual fatty acids in total fatty acids.

Color parameter determination

The color parameters – lightness (L^*), redness (a^*) and yellowness (b^*) – were measured in the CIE Lab system [International Commission on Illumination, 1978] using the HunterLab MiniScan XE Plus spectrophotometer (Hunter Associates Laboratory, Reston, VA, USA) with illuminant D65, 10° standard observer angle, and 2.54 cm diameter aperture. The measurements were performed at three different points over the surface area of samples (salami slices and ground frankfurters and *kabanos* sausages). Chroma (C^*) values were calculated with the formula (1):

$$C^* = (a^{*2} + b^{*2})^{1/2} \qquad (1)$$

Measurement of pH

The pH values of products were measured with the use of a Polilyte Lab electrode (Hamilton Bonaduz AG, Bonaduz, Switzerland) and an inoLab level 2 pH-meter equipped with a TFK 325 temperature sensor (WTW Wissenschaftlich-Technische Werkstatten GmbH, Weilheim, Germany). The samples of products were homogenized in redistilled water (ratio 1:1, *w/v*) before measurement [Daszkiewicz & Gugołek, 2020].

Statistical analysis

The results were processed statistically using STATISTICA software ver. 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). The effect of the experimental factor (product type – meat products *vs.* their plant-based analogs) on the evaluated quality attributes of the products was analyzed by Student's *t*-test. The significance of differences between groups was determined at $p \leq 0.05$.

RESULTS AND DISCUSSION

Proximate chemical composition of meat products and their plant-based analogs

The proximate chemical composition of the compared products is presented in Table 2. Meat products had higher ($p \leq 0.05$) dry matter content than meat substitutes, mostly due to their higher ($p \leq 0.05$) lipid content. Salami and frankfurters had also higher ($p \leq 0.05$) ash content than their plant-based counterparts. Salami contained more ($p \leq 0.05$) protein, whereas frankfurters and *kabanos* sausages contained less ($p \leq 0.05$) protein than their respective analogs.

The differences in the proximate chemical composition of meat products and their vegetarian alternatives resulted from the use of different ingredients and production technologies. Plant-based meat analogs contain a considerably lower amount of lipids, a lot of protein, and different amount of water to achieve the desired textural properties and health benefits appreciated by consumers [Kyriakopoulou *et al.*, 2021]. However, the actual protein content of plant-based products may be difficult to determine. It may vary depending on the value of the nitrogen-to-protein conversion factor (NPCF) in the Kjeldahl method. According to Fujihara *et al.* [2008], the NPCF of 6.25 has been historically applied to all proteins based on the assumptions that all proteins contain 16% nitrogen (100/16 = 6.25) and that all nitrogen is derived from protein. However, research [Krul, 2019] showed that the NPCF of 6.25 overestimates the protein content of many food products due to differences in amino acid profiles and the presence of non-protein nitrogen. This is an important consideration when assessing the actual nutritional and economic value of food products. Koletzko & Shamir [2006] suggested that the use of the NPCF of 6.25 instead of 6.38 for all dairy products would lead to a loss of approximately EUR 80 million in Europe. Therefore, all food market actors (consumers, producers of food raw materials, food processing companies, sales specialists, and nutritionists) are interested in solving the above problem and establishing NPCF values applicable to different proteins in food products that are already on the market and those that will be introduced in the future. This will apply, in particular, to analogs of traditional meat products whose quality, nutritional value and production costs should be assessed equitably. The absence of standardized methods for determining food-specific NPCF values has resulted in continued use of 6.25 [WHO/FAO, 2019]. The NPCF of 6.25 was also used in this study, but it was confronted with the average values of the ingredient-specific NPCF proposed for soybean protein (5.70) [WHO/FAO, 2020] and wheat protein (5.81) [Fujihara *et al.*, 2008] contained in the analyzed plant-based products. As a result, the protein content of vegetarian frankfurters, *kabanos* sausages and salami, determined by two different methods, differed by 1.84, 3.02 and 1.36 percentage points, respectively (Table 2). The above information may be important for persons who need a balanced diet, including older adults and individuals with special nutritional needs [Reid-McCann *et al.*, 2022], especially that the value of vegetable protein can be decreased due to amino acid composition (insufficient concentration of one or several essential amino acids). According to Hertzler *et al.* [2020], legumes are often deficient in sulfur-containing amino acids (methionine and cysteine), whereas cereals are poor in lysine. The need for accurate protein quantification in plant-based products was also emphasized by Bakaloudi *et al.* [2021] who found that vegan diets were lower in protein than all other diet types. This information and the fact that consumers' knowledge about vegetarian and vegan diets is often insufficient suggest that followers of such diets could have higher risk of developing nutrient deficiencies. Bakaloudi *et al.* [2021] reported that vegans had low intake of vitamins B$_2$, niacin (B$_3$), B$_{12}$ and D, as well as iodine, zinc, calcium, potassium, and selenium. The above authors found that daily vitamin B$_{12}$ intake among vegans was considerably lower (0.24–0.49 µg) than the recommended level (2.4 µg), and calcium intake was also below the norm (750 mg/day) in most vegan diet followers. According to Sanne & Bjørke-Monsen [2022], nutritional education should be improved as vegetarian and vegan diets are becoming increasingly popular. The cited study revealed gaps in nutritional knowledge about vegetarian diets even among Norwegian medical students who declared to be vegetarians.

Bryngelsson *et al.* [2022] assessed the nutritional quality of plant-based meat analogs available on the Swedish market based on three nutrition labeling systems. In terms of macronutrient content, most categories of meat analogs were healthier options to meat references, primarily due to their higher fiber content and lower content of lipids with saturated fatty acids. In terms of salt content, many plant-based meat analogs were healthy alternatives to processed meat products, but often less healthy options to unprocessed meat products. Similar analyses performed by Cutroneo *et al.* [2022] for commercial meat analogs available on the Italian market revealed that all analogs had

Table 2. Proximate chemical composition (g/100 g) of the meat products and their plant-based analogs.

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
Dry matter	Frankfurter	40.57^{a}	35.66^{b}	0.90	<0.001
	Kabanos	79.04^{a}	71.13^{b}	1.47	<0.001
	Salami	66.15^{a}	35.85^{b}	5.10	<0.001
Protein[1]	Frankfurter	13.24^{b}	16.73^{a}	0.59	<0.001
	Kabanos	25.16^{b}	38.50^{a}	2.38	<0.001
	Salami	22.98^{a}	17.32^{b}	0.96	<0.001
Protein[2]	Frankfurter	13.24^{b}	14.89^{a}	0.38	<0.001
	Kabanos	25.16^{b}	35.48^{a}	1.85	<0.001
	Salami	22.98^{a}	15.96^{b}	1.18	<0.001
Lipids	Frankfurter	22.21^{a}	4.35^{b}	2.99	<0.001
	Kabanos	47.87^{a}	12.09^{b}	6.33	<0.001
	Salami	35.85^{a}	5.61^{b}	5.07	<0.001
Ash	Frankfurter	2.92^{a}	1.94^{b}	0.17	<0.001
	Kabanos	4.42^{a}	4.46^{a}	0.08	0.854
	Salami	4.59^{a}	3.34^{b}	0.22	<0.001

[1] Protein content determined based on the fixed nitrogen-to-protein conversion factor (NPCF) of 6.25. [2] Protein content determined based on the average values of the ingredient-specific NPCF of 5.70 and 5.81 in plant-based products containing soybean protein and wheat protein, respectively. SEM, standard error of the mean. Values followed by different letters within the same row are significantly different ($p\leq0.05$).

higher fiber content, whereas plant-based burgers and meatballs had lower protein content than their meat counterparts. Sliced meat analogs had also lower salt content. All plant-based products had longer lists of ingredients than the corresponding animal meat products. Due to their long lists of ingredients, most of which are highly refined, meat analogs face criticism for being artificial products [Kyriakopoulou *et al.*, 2021]. Modern consumers expect food products to be healthy, nutritious, and as natural as possible (minimally processed and without additives) [Hüppe & Zander, 2021].

Table 3. Saturated fatty acid profile of the meat products and their plant-based analogs (% of individual fatty acids in total fatty acids).

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
C8:0	Frankfurter	-	-	-	-
	Kabanos	0.00^{b}	5.40^{a}	0.95	<0.001
	Salami	0.00^{a}	0.17^{a}	0.08	0.347
C10:0	Frankfurter	-	-	-	-
	Kabanos	0.00^{b}	5.17^{a}	0.91	<0.001
	Salami	0.00^{a}	0.15^{a}	0.07	0.347
C12:0	Frankfurter	0.20^{a}	0.06^{b}	0.03	<0.001
	Kabanos	0.15^{b}	39.14^{a}	6.91	<0.001
	Salami	0.62^{a}	1.16^{a}	0.52	0.635
C14:0	Frankfurter	2.35^{a}	0.41^{b}	0.32	<0.001
	Kabanos	2.16^{b}	15.38^{a}	2.36	<0.001
	Salami	2.66^{a}	0.69^{b}	0.39	0.002
C15:0	Frankfurter	0.00^{a}	0.09^{a}	0.05	0.347
	Kabanos	-	-	-	-
	Salami	0.17^{a}	0.18^{a}	0.04	0.887
C16:0	Frankfurter	35.99^{a}	8.42^{b}	4.62	<0.001
	Kabanos	32.28^{a}	11.65^{b}	3.77	<0.001
	Salami	36.01^{a}	8.00^{b}	4.72	<0.001
C17:0	Frankfurter	0.34^{a}	0.07^{b}	0.05	<0.001
	Kabanos	0.32^{a}	0.05^{b}	0.05	<0.001
	Salami	0.57^{a}	0.09^{b}	0.08	<0.001
C18:0	Frankfurter	17.80^{a}	3.19^{b}	2.45	<0.001
	Kabanos	16.21^{a}	3.47^{b}	2.28	<0.001
	Salami	19.31^{a}	3.32^{b}	2.69	<0.001
C20:0	Frankfurter	0.24^{b}	0.62^{a}	0.06	<0.001
	Kabanos	0.23^{a}	0.10^{b}	0.02	<0.001
	Salami	0.30^{b}	0.55^{a}	0.05	<0.001
C22:0	Frankfurter	0.00^{b}	0.31^{a}	0.05	<0.001
	Kabanos	0.00^{a}	0.04^{a}	0.02	0.292
	Salami	0.00^{b}	0.28^{a}	0.05	<0.001
SFAs	Frankfurter	56.93^{a}	13.17^{b}	7.33	<0.001
	Kabanos	51.36^{b}	80.39^{a}	5.38	<0.001
	Salami	59.63^{a}	14.59^{b}	7.63	<0.001

SEM, standard error of the mean; SFAs, saturated fatty acids. Values followed by different letters within the same row are significantly different ($p \leq 0.05$).

Fatty acid profile of meat products and their plant-based analogs

The fatty acid profile of the compared products, including saturated fatty acids (SFAs), unsaturated fatty acids (UFAs) and fatty acid ratios, are presented in Tables 3, 4 and 5, respectively. Vegetarian frankfurters and salami were characterized by higher ($p≤0.05$), *i.e.* more desirable, values of all analyzed indicators of the nutritional value of lipids than their meat counterparts. Vegetarian *kabanos* sausages had lower ($p≤0.05$) ratios of unsaturated to saturated fatty acids (UFAs/SFAs), monounsaturated to saturated fatty acids (MUFAs/SFAs) and ratio of hypocholesterolemic

Table 4. Unsaturated fatty acid profile of the meat products and their plant-based analogs (% of individual fatty acids in total fatty acids).

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
C14:1	Frankfurter	-	-	-	-
	Kabanos	-	-	-	-
	Salami	0.16^{a}	0.00^{a}	0.07	0.292
C16:1	Frankfurter	2.56^{a}	0.44^{b}	0.36	<0.001
	Kabanos	2.51^{a}	0.28^{b}	0.40	<0.001
	Salami	2.18^{a}	0.47^{b}	0.29	<0.001
C17:1	Frankfurter	0.16^{a}	0.07^{b}	0.02	<0.001
	Kabanos	0.21^{a}	0.03^{b}	0.03	0.001
	Salami	0.27^{a}	0.09^{b}	0.03	<0.001
C18:1 *cis*-9	Frankfurter	33.09^{b}	62.75^{a}	4.97	<0.001
	Kabanos	35.98^{a}	8.06^{b}	5.11	<0.001
	Salami	30.12^{b}	60.70^{a}	5.17	<0.001
C18:1 *cis*-11	Frankfurter	2.64^{a}	2.88^{a}	0.07	0.094
	Kabanos	2.79^{a}	0.39^{b}	0.43	<0.001
	Salami	2.10^{b}	2.69^{a}	0.10	<0.001
C18:2	Frankfurter	2.81^{b}	14.55^{a}	2.01	<0.001
	Kabanos	5.25^{a}	8.19^{a}	0.90	0.108
	Salami	3.48^{b}	15.31^{a}	2.04	<0.001
C18:3	Frankfurter	0.07^{b}	4.15^{a}	0.70	<0.001
	Kabanos	0.31^{a}	0.46^{a}	0.07	0.355
	Salami	0.17^{b}	4.57^{a}	0.76	<0.001
C20:1	Frankfurter	1.75^{a}	1.90^{a}	0.10	0.468
	Kabanos	1.40^{a}	0.17^{b}	0.23	<0.001
	Salami	1.82^{a}	1.48^{a}	0.09	0.052
C20:2	Frankfurter	0.00^{a}	0.06^{a}	0.02	0.157
	Kabanos	0.14^{a}	0.06^{a}	0.05	0.501
	Salami	0.06^{a}	0.09^{a}	0.04	0.750
C20:3	Frankfurter	-	-	-	-
	Kabanos	0.02^{a}	0.02^{a}	0.01	0.833
	Salami	-	-	-	-
C20:4	Frankfurter	-	-	-	-
	Kabanos	0.02^{a}	0.00^{a}	0.01	0.407
	Salami	-	-	-	-

Table 4. Continued.

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
C22:1	Frankfurter	0.00^{a}	0.04^{a}	0.01	0.141
	Kabanos	-	-	-	-
	Salami	0.01^{a}	0.02^{a}	0.01	0.347
MUFAs	Frankfurter	40.19^{b}	68.08^{a}	4.67	<0.001
	Kabanos	42.90^{a}	10.88^{b}	5.72	<0.001
	Salami	36.66^{b}	65.45^{a}	4.88	<0.001
PUFAs	Frankfurter	2.88^{b}	18.75^{a}	2.72	<0.001
	Kabanos	5.74^{a}	8.73^{a}	1.02	0.155
	Salami	3.71^{b}	19.96^{a}	2.79	<0.001

SEM, standard error of the mean; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids. Values followed by different letters within the same row are significantly different ($p \leq 0.05$).

Table 5. Fatty acid ratios in the meat products and their plant-based analogs.

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
UFAs/SFAs	Frankfurter	0.76^{b}	6.79^{a}	1.05	<0.001
	Kabanos	0.97^{a}	0.25^{b}	0.14	0.001
	Salami	0.68^{b}	6.76^{a}	1.21	0.003
MUFAs/SFAs	Frankfurter	0.71^{b}	5.31^{a}	0.79	<0.001
	Kabanos	0.85^{a}	0.14^{b}	0.13	<0.001
	Salami	0.62^{b}	5.17^{a}	0.91	0.003
PUFAs/SFAs	Frankfurter	0.05^{b}	1.48^{a}	0.26	<0.001
	Kabanos	0.12^{a}	0.11^{a}	0.02	0.809
	Salami	0.06^{b}	1.60^{a}	0.31	0.003
DFAs/OFAS	Frankfurter	1.56^{b}	9.22^{a}	1.32	<0.001
	Kabanos	1.89^{a}	0.30^{b}	0.29	<0.001
	Salami	1.49^{b}	9.11^{a}	1.54	0.003
EFAs	Frankfurter	2.88^{b}	18.69^{a}	2.71	<0.001
	Kabanos	5.56^{a}	8.65^{a}	0.97	0.119
	Salami	3.64^{b}	19.87^{a}	2.79	<0.001

SEM, standard error of the mean; SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; UFAs, unsaturated fatty acids (MUFAs+PUFAs); DFAs, hypocholesterolemic fatty acids (UFAs+C18:0); OFAs, hypercholesterolemic fatty acids (SFAs–C18:0); EFAs, essential fatty acids (C18:2+C18:3). Values followed by different letters within the same row are significantly different ($p \leq 0.05$).

fatty acids (UFAs+C18:0) to hypercholesterolemic fatty acids (SFAs–C18:0) (DFAs/OFAs).

The differences in the fatty acid profiles of meat products and their plant-based analogs resulted from the different origin of lipids. Long-chain fatty acids, such as palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2), predominate in lipids of meat and meat products, whereas the contents of polyunsaturated fatty acids (PUFAs) are low [Bohrer, 2019], which was also observed in this study. The proportion of PUFAs is particularly low in meat from ruminants, because they undergo biohydrogenation in the rumen. De Smet *et al.* [2004] reported that the average PUFAs/SFAs ratio in beef, lamb, and pork (steaks and chops) purchased in supermarkets in the United Kingdom was 0.11, 0.15 and 0.58, respectively. The above ratios are even lower in meat products because processing affects PUFAs [Domínguez *et al.*, 2019].

Vegetable oils/fats and animal fats differ in fatty acid composition and the mutual proportions of fatty acid groups. Different types of edible oils/fats are also characterized by considerable differences in their fatty acid profiles. Orsavova *et al.* [2015] analyzed the fatty acid composition of 14 edible vegetable oils (safflower, grape, *Silybum marianum*, hemp, sunflower, wheat germ, pumpkin seed, sesame, rice bran, almond, rapeseed, peanut, olive, and coconut oil) and found that the contents of the major fatty acids varied widely: C16:0 – from 4.6% to 20.0%, C18:1 – from 6.2% to 71.1%, and C18:2 – from 1.6% to 79%. The proportions of fatty acid groups were determined in the following ranges: SFAs – from 6.3% (rapeseed oil) to 92.1% (coconut oil), MUFAs – from 6.2% (coconut oil) to 72.8% (rapeseed oil), and PUFAs – from 54.3% (pumpkin seed oil) to 79.1% (sunflower oil). Technological processes and refinement techniques (pressing, fractionation, isomerization) can also alter the fatty acid composition of vegetable oils/fats [Bohrer, 2019].

The vast majority of vegetable oils/fat used in the production of meat analogs contain mostly UFAs. In the present study, vegetarian frankfurters and salami were produced with the use of rapeseed oil, which contributed to their desirable fatty acid profiles. Increased contents of UFAs, in particular PUFAs, in lipids of plant-based meat analogs, deliver health benefits to consumers. However, they are also susceptible to oxidation, leading to the formation of multiple chemical compounds that negatively affect the sensory properties (flavor, color) of the products, and exert adverse health effects [Domínguez *et al.*, 2019]. Physical technological treatments that can reduce the oxidation of PUFAs in oils include pre-emulsification of oil with non-meat proteins and microencapsulation [Lima *et al.*, 2022b].

Fatty acids have different melting temperatures, therefore oils used in the production of plant-based meat analogs should be carefully selected because they affect the texture of the final product. In order to impart meat-like consistency and mouthfeel, meat alternatives are produced with the use of solid fats extracted from tropical fruit such as coconuts or, less frequently, cocoa beans [Sha & Xiong, 2020]. The dominant fatty acids in coconut oil are lauric acid (12:0), myristic acid (14:0) and palmitic acid (16:0), which account for 46%, 17% and 9% of total fatty acids, respectively [Boemeke *et al.*, 2015]. In the current study, coconut oil was used in the production of vegetarian *kabanos* sausages, which explains the low values of indicators characterizing the nutritional value of lipids in this product, relative to vegetarian products containing rapeseed oil and meat products. Coconut oil consists mostly of SFAs that account for approximately 90% of its total fatty acids, which has stirred a debate about its potential adverse health effects, by analogy with animal fats. A meta-analysis of clinical trials conducted by Neelakantan *et al.* [2020] revealed that the consumption of coconut oil contributed to a greater increase in low-density lipoprotein (LDL) cholesterol levels than the consumption of non-tropical vegetable oils. However, coconut oil was not significantly associated with the markers of glycemia, inflammation or obesity. According to Hewlings [2020], the health implications of SFAs should be analyzed in both quantitative (total SFAs content) and qualitative (proportions of individual SFAs) terms. A good example is coconut oil which is classified as saturated fat although most of its fatty acids are medium-chain ones. In contrast, beef contains mostly long-chain SFAs. Medium-chain SFAs are absorbed differently than long-chain SFAs; the former have been associated with several health benefits, including improved metabolic and cognitive functions in humans [Roopashree *et al.*, 2021], which may be linked with reduced oxidative stress [Mett & Müller, 2021]. Nevertheless, the dietary intake of UFAs, in particular PUFAs, should be increased [Snetselaar *et al.*, 2021]. Further research is needed to investigate potential relationships between individual SFAs and the risk of developing certain diseases in order to establish objective guidelines for the dietary inclusion or elimination of selected SFAs.

pH and color of meat products and their plant-based analogs

The pH values and color parameters of the compared products are presented in Table 6. The greatest difference ($p \leq 0.05$) in pH was noted between salami and its plant-based analog. The pH of salami was considerably lower because it was manufactured with the use of starter bacterial cultures. According to Bis-Souza *et al.* [2020], salami is a typical dry fermented sausage, and selected starter cultures are used in the process of its fermentation. Bacteria produce lactic acid that acidifies the product, imparts a distinctive taste, and extends its shelf life [Laranjo *et al.*, 2017]. Considerable differences in average pH values ($p \leq 0.05$) were also found between frankfurters and *kabanos* sausages *vs*. their plant-based analogs. Vegetarian frankfurters had a higher pH ($p \leq 0.05$) than their meat counterparts, and traditional *kabanos* sausages had a higher pH ($p \leq 0.05$) than their vegetarian alternatives. Therefore, there is no clear correlation between product type (meat product *vs*. meat analog) and its active acidity.

Color measurements revealed (Table 6) that plant-based meat analog of frankfurter was darker in color (lower L^* value, $p \leq 0.05$) than its traditional counterpart. All vegetarian products were also characterized by higher ($p \leq 0.05$) values of parameters a^* (redness) and b^* (yellowness), and, in consequence, higher ($p \leq 0.05$) chroma (C^*) values.

The color of meat alternatives is affected by the type and amount of coloring agents that are added to mimic the color of traditional meat products. According to the information on the labels of the plant-based products analyzed in the present study, they contained the following colorants: pepper extract, fenugreek extract (*Trigonella foenum-graecum* L.), concentrated beetroot (*Beta vulgaris* L. *subsp. vulgaris*) juice, iron oxides and hydroxides. The effect exerted by colorants on the color of meat substitutes depends not only on their type, but also stability. This applies in particular to natural pigments whose stability and brightness are affected by exposure to light, temperature, and pH [Harsito *et al.*, 2021]. Similar observations were made by Ekielski *et al.* [2013] who analyzed red pepper extract and found that its color was unstable under exposure to intensive light, and that natural pigments were more sensitive to light intensity than to increasing storage temperature. Regardless of the content and transformations of colorants, the color of food products may also be affected

Table 6. Values of pH and color parameters of the meat products and their plant-based analogs.

Parameter	Product	Product type		SEM	*p*-Value
		Meat product	Meat analog		
pH	Frankfurter	6.08^{b}	6.51^{a}	0.08	<0.001
	Kabanos	5.94^{a}	5.42^{b}	0.10	<0.001
	Salami	4.83^{b}	6.22^{a}	0.23	<0.001
*L**	Frankfurter	70.52^{a}	61.42^{b}	1.55	<0.001
	Kabanos	46.34^{a}	46.07^{a}	0.66	0.854
	Salami	46.23^{a}	45.76^{a}	0.72	0.765
*a**	Frankfurter	9.15^{b}	16.49^{a}	1.23	<0.001
	Kabanos	13.79^{b}	19.87^{a}	1.10	<0.001
	Salami	16.08^{b}	23.33^{a}	1.30	<0.001
*b**	Frankfurter	16.56^{b}	26.14^{a}	1.62	<0.001
	Kabanos	16.85^{b}	30.34^{a}	2.41	<0.001
	Salami	12.06^{b}	24.31^{a}	2.10	<0.001
*C**	Frankfurter	18.92^{b}	30.91^{a}	2.02	<0.001
	Kabanos	21.78^{b}	36.26^{a}	2.59	<0.001
	Salami	19.07^{b}	34.49^{a}	2.67	<0.001

SEM, standard error of the mean; *L**, lightness; *a**, redness; *b**, yellowness; *C**, chroma. Values followed by different letters within the same row are significantly different ($p \leq 0.05$).

by other factors. Herlina *et al.* [2021] suggested that the darker color (lower brightness) of plant-based meat analogs may be due to a high content of carbohydrates that participate in Maillard reactions. Lipid autooxidation may also significantly affect the color of plant-based products have high contents of UFAs [Barden & Decker, 2016]. According to Kim *et al.* [2014], moisture can act as a substrate for lipid oxidation. In the current study, plant-based meat analogs contained more carbohydrates (according to the manufacture's declaration), UFAs (except for *kabanos* sausages), and water than traditional meat products, which could be responsible for their darker color.

CONCLUSIONS

Differences in the ingredient composition and production technology had a significant effect on the proximate chemical composition, fatty acid profile, color, and pH of the analyzed meat products (frankfurters, Polish *kabanos* sausages, and salami) and their plant-based analogs. Meat substitutes differed from meat products in chemical composition and physicochemical properties. Therefore, the names, form and packaging of plant-based analogs, which make a direct reference to the corresponding traditional meat products, can be misleading for consumers who expect products with similar quality attributes.

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CONFLICT OF INTERESTS

The authors declare that they have no competing interests.

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