Bulgarian Journal of Agricultural Science, 32 (No 5) 2026, 1228–1234

DOI: https://doi.org/10.61308/CVES7231

Fatty acid composition of traditional roasted beef according to the season of slaughter and the impact of technological processing

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Abstract

Mehmeti, F., Stojanovski, M., Joshevska, E., Dimitrovska, G., Jovanovska, V., Tomovska, D. & Mehmeti, H. (2026). Fatty acid composition of traditional roasted beef according to the season of slaughter and the impact of technological processing. *Bulg. J. Agric. Sci., 32*(5), 1228–1234

This study investigated the changes in the fatty acid composition of roasted beef during traditional processing, taking into account seasonal variations in fatty acid profiles. Seasonal factors affect the nutritional quality of the meat, as cattle finished in spring or summer have higher levels of polyunsaturated fatty acids (PUFA), omega-3 fatty acids, and antioxidants compared to those finished in autumn or winter, due to differences in the quality and availability of feed.

The fatty acid composition of roasted beef changes significantly during the brining and thermal processing stages. The proportion of saturated fatty acids (SFA) increased from 45.87% before brining to 46.71% after brining and reached 48.47% after thermal processing, reflecting their greater oxidative and thermal stability compared with polyunsaturated fatty acids. Monounsaturated fatty acids (MUFA) remained relatively stable at around 44%, indicating limited changes during processing. Polyunsaturated fatty acids (PUFA) decreased significantly from 6.20% before brining to 5.38% after brining and to 5.16% after thermal processing, likely due to their high susceptibility to oxidation, which is promoted by both salt and heat. This reduction may decrease the nutritional value and alter the flavor characteristics of the product. Trans-fatty acids also decreased from 3.87% before brining to 3.65% after brining and to 2.24% after thermal processing, possibly as a result of oxidative degradation and other processing-induced transformations, which may contribute to an improved nutritional profile of the final product.

Understanding these seasonal and processing-related changes is essential for production parameters to preserve beneficial fatty acids, maintain desirable sensory properties, and ensure product safety and consistency.

Keywords: roasted beef; fatty acids; processing technology; quality

Introduction

Traditional meat products from Prizren and surrounding regions in the Republic of Kosovo, such as beef prosciutto and roasted beef, are renowned for their exceptional quality and distinctive sensory attributes, including taste, aroma, and texture (Barrère et al., 2020).

Roasted beef, in particular, is a high-quality product with excellent sensory properties and a long shelf life.

The technological processes involved in its production, including shaping, preparation, brining, and thermal treatment, are critical in achieving consistent product quality. A critical aspect influencing the quality and nutritional value of roasted beef is its fatty acid composition. Saturated fatty

acids (SFAs) contribute to fat stability, while polyunsaturated fatty acids (PUFAs), particularly omega-3 and omega-6 fatty acids, are essential for human health. However, excessive loss of PUFAs and the formation of oxidation products can impair taste and nutritional value. Therefore, monitoring changes in fatty acid composition throughout the production process is essential to improve product quality and nutritional value (Wood et al., 2008; Simopoulos, 2002; Decker and Park, 2010).

Brining involves immersing meat in a salt solution, which can affect the meat's water-holding capacity and protein structure. While specific studies on brining's impact on fatty acids are limited, it's known that salt can influence the solubility and stability of proteins, potentially affecting lipid interactions and oxidation processes during subsequent thermal treatments (Lund et al., 2011; Leygonie et al., 2012; Toldrá, 2006).

Thermal processing is a pivotal step in meat product preparation, significantly influencing the fatty acid composition. PUFAs are susceptible to oxidation when exposed to heat, leading to the formation of off-flavors and a decrease in nutritional quality (Pokorný et al., 2001; Estévez, 2015). Studies have shown that cooking methods like boiling and microwaving can reduce PUFA content in meat, with higher temperatures exacerbating these effects. MUFAs are more stable than PUFAs, but still can undergo oxidation during cooking. The extent of MUFA oxidation depends on the cooking method and temperature. SFAs are relatively stable during heat treatment. However, the overall fat content in meat can increase due to water loss during cooking, potentially altering the SFA profile. Additionally, high-temperature cooking methods can lead to the formation of trans fatty acids through the isomerization of PUFAs. For instance, heating linoleic acid to temperatures around 240°C can result in the formation of trans isomers (Jayasena and Jo, 2013; Wood et al., 2003).

Seasonal variations have been shown to affect the fatty acid profile of beef. For instance, studies have indicated that beef from cattle slaughtered in the summer contains higher amounts of essential PUFAs and hypocholesterolemic fatty acids compared to those slaughtered in winter. Similarly, research on grass-finished beef in the United States revealed that total omega-3 fatty acid content was greater in beef from cattle finished in the spring than in the fall (Scollan et al., 2014; Rule et al., 2002; Ponnampalam et al., 2006).

In the context of Kosovo, where traditional practices and local breeds prevail, understanding the seasonal impact on fatty acid composition is crucial. Such knowledge can inform production practices to enhance the nutritional profile and sensory qualities of traditional roasted beef.

Scientific studies support these findings. For instance, research on beef fatty acid profiles shows that grass-fed animals have higher concentrations of stearic acid (a neutral SFA) and oleic acid (a MUFA with cholesterol-lowering effects), along with increased PUFA content, compared to grain-fed animals (Daley et al., 2010; Gruffat et al., 2021; Berisha et al., 2023).

This study aims to investigate the fatty acid composition of traditional roasted beef produced in Kosovo, focusing on variations associated with the season of slaughter. By examining the effects of brining, heat treatment, and seasonal factors, the research seeks to provide insights into optimizing production processes to maintain and enhance the nutritional and sensory qualities of this traditional product.

Material and Methods

Three different production batches of roasted beef were produced in a traditional manner at the private slaughterhouse "Xhoshkun" in Prizren, Kosovo, in accordance with all requirements for the implementation and application of the HACCP and HALAL systems for production. The difference in the production batches is based on the slaughter season. In the first batch, the meat comes from spring slaughter of young cattle (May – June). During this season, the cattle were slaughtered after a period of intensive growth, when they had access to fresh pasture. The meat from these animals generally had higher water content and lower fat levels. The second production batch was made from meat of young cattle slaughtered in summer (June - August), when there was a combination of fresh pasture and concentrated feed. The meat was rich in fat, which increased its juiciness.

The meat used for the production of roasted meat in the third batch was obtained from winter slaughter of young cattle (November – February). During this season, the cattle were slaughtered after a period of lower activity and were mostly fed concentrated foods (hay, silage). The meat had a higher internal fat content.

Roasted meat production and sampling

During slaughtering, the carcasses of young cattle were halved, drained, and placed in a cooling chamber to reduce the temperature below 4°C, which facilitated easier shaping and cutting of the meat. After chilling and aging the meat, once the internal temperature dropped below 4°C, the halves were cut into quarters. After quartering, the meat intended for the production of roast beef was separated. After separating the meat intended for roasted meat production, shaping was performed (removal of surface fat tissue and hanging parts), which resulted in an attractive appearance. The hind

parts were cut lengthwise to preserve the natural shape of the muscles, ensuring an attractive appearance for roasting. The salting process was carried out by dry salting with salt for 21 days, which helped with preservation and flavor development. After salting, the meat was desalinated by soaking in cold water for 1 to 3 hours to remove excess salt. Then, the pieces of meat were tied with string and hung at room temperature for 24 hours to drain and dry the surface, preparing the meat for roasting. Thermal processing was performed in a chamber heated with an open fire, using naturally dried beech wood as fuel. Roasting lasted from 270 to 300 minutes at about 150°C, or until the surface of the meat acquires a shiny dark brown color, which is an indicator of the Maillard reaction and flavor development. After roasting, the meat was cooled in refrigeration chambers for 12 hours to stabilize the product. This traditional roasting method combines dry heat and slow cooking, similar to low-temperature roasting techniques, which help retain moisture and develop texture and flavor through gradual collagen breakdown and surface caramelization. During the process, samples were taken at key stages – before salting, after 21 days of salting, and after thermal processing, to monitor changes in fatty acid composition and ensure quality control.

Determination of fatty acid composition

The method of Folch et al. (1957) was used for the extraction of fatty acids from roasted beef. Obtained fatty acids were transferred to methyl esters according to AOAC Official Method 996.06 (2005), and subsequently subjected to GC-FID analysis. GC-FID analysis was performed on Hewlett Packard 5890 series II gas chromatograph with a flame ionization detector, an auto sampler, and a capillary column HP 88 (60 m × 0.250 mm × 0.20 μm). The operation parameters of the column were: initial temperature of 70°C (1 minute) ramped at 5°C/minute to 100°C and maintained for 2 minutes. The temperature was then increased at 10°C/minute to 175°C and maintained for 2 minutes, which was followed by the last increase at 3°C/minute to 220°C and hold for 5 minutes. Injector and detector temperatures were kept at 250°C and 300°C, respectively. Helium was used as a carrier gas at a flow rate of 1.4 mL/min with a split ratio 100:1. A 1 μL volume of each sample was injected two times into GC-FID for separation and identification of the FAMEs. The total run time was 38.50 minutes. FAMEs from samples were identified by comparison of their retention times to those of the FAME mix standard (Supelco 37 component FAME mix, Sigma-Aldrich, Germany). Using conversion factors (AOAC 996.06, 2005) FAMEs were converted to corresponding fatty acids. Fatty acids were quantified as a percentage of the total fatty acids in the sample.

Statistical analysis

Prior to statistical analysis, the assumptions of normality and homogeneity of variance were evaluated using SPSS Statistics v.29.0. One-way ANOVA was performed with a confidence interval of 95% ($p < 0.05$). Differences between group means were further compared using Student's t-test to determine whether there were statistically significant differences in the total fatty acid profile between the groups.

Results and Discussion

Roast beef was considered one of the highest quality cured meat products made from beef. The fatty acid composition varied significantly not only between different animal species, but also within the same species. These variations depended on the type of meat, used as raw material for production, as well as the season in which the animals were slaughtered. The results obtained from our analysis of the fatty acid composition of roast beef before brining are presented in Table 1.

Table 1. Fatty acid composition of roast beef before brining (%)

Fatty acid (%)	Batches		
	I	II	III
C10:0	0.092	0.091	0.091
C11:0	–	0.080	
C12:0	0.146	0.123	0.110
C14:0	3.686	3.234	3.751
C14:1	1.139	1.253	1.280
C15:0	0.446	0.352	0.773
C15:1	0.135	0.125	0.295
C16:0	24.269	24.435	26.636
C16:1	4.348	3.575	3.671
C17:0	1.367	1.382	1.332
C17:1	0.607	0.623	0.890
C18:0	15.051	16.390	13.755
C18:1n9t	3.744	3.236	3.902
C18:1n9c	35.881	41.850	40.220
C18:1n6t	0.217	0.206	0.313
C18:2n6c	7.950	1.965	1.724
C18:3n6	0.101	0.103	0.090
C:20:1	0.193	0.103	0.345
C18:3n3	0.623	0.872	0.733
C22:1n9	–	–	0.081
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	45.059^{a}	46.087^{b}	46.454^{c}
Monounsaturated fatty acids (MUFA)	44.555^{a}	44.873^{a}	42.848^{b}
Polyunsaturated fatty acids (PUFA)	6.423^{a}	5.680^{b}	6.483^{c}
Trans fatty acids (trans FA)	3.960^{a}	3.442^{a}	4.215^{c}

^{a,b,c} statistical differences $p \leq 0.05$ between batches

Source: Authors' own elaboration

Based on the obtained results, 20 fatty acids were identified in the fatty acid profile of fats from roasted meat prior to brining. The average content of trans-fatty acids across the examined batches was 3.87%, with significant differences observed between batches: 3.96% in the first, 3.44% in the second, and 4.22% in the third. Saturated fatty acids (SFA) averaged 45.87%, showing some variation among batches, while monounsaturated fatty acids (MUFA) remained relatively stable with minor differences ($p < 0.05$) of 45.56%, 44.87%, and 42.85% between the first and second compared to the third batch. The differences in the percentages of monounsaturated and polyunsaturated fatty acids between the batches can be linked to different biological and nutritional conditions, in which the livestock was raised, as well as seasonal variations in their diet (Enser et al., 1996; Bošković et al., 2015; Dinh et al., 2021; Fowler et al., 2023). The average content of trans-fatty acids across the examined batches was 3.87%, with significant differences between batches ($p < 0.01$): 3.96% in the first, 3.44% in the second, and 4.22% in the third. This is due to seasonal variations in diet and the conditions under which the animals are raised, which affect metabolism and the fatty acid composition, including trans isomers. During the winter period, when the diet is different and often consists of concentrated feed, higher levels of trans fatty acids can be observed in the third group compared to the summer period in the first two groups (Dannenberger et al., 2011; Scollan et al., 2014; Scollan et al., 2006; Wood et al., 2008).

During brining, the chemical and fatty acid composition of the fats in the roasted meat changed. Nitrites reacted with myoglobin, while salt altered proteins and fats, causing denaturation. Enzymes oxidized the fats, and lactic acid bacteria broke down the sugars from the brine. All these processes modified the fatty acid profile of the lipids (Lorenzo and Franco, 2012; Estévez, 2011), which affected the nutritional value, flavor, and safety of the product.

The fatty acid content in the fats of the roasted meat after brining is shown in Table 2.

Changes in the fatty acid composition of roasted meat after the salting process indicated complex biochemical reactions occurring during production (Table 2). According to the obtained results, the content of saturated fatty acids (SFA) is the highest, ranging between 46 and 48%, with statistically significant differences ($p < 0.05$) observed between different production batches. Monounsaturated fatty acids (MUFA) remained relatively stable, with minor variations around 44%, while polyunsaturated fatty acids (PUFA), although the lowest in proportion, still showed significant differences ($p < 0.05$) between batches. The greatest variability was observed in trans-fatty acids (trans-FA), with the highest value in the third batch (4.475%), which may be related to the seasonal conditions of slaughter.

Seasonal changes in the diet and living conditions of the animals significantly influenced the fatty acid profile, while technological parameters of salting, such as duration, temperature, and brine composition, can cause variations in the degree of fat oxidation and denaturation (Jain et al., 2020; Sobczuk-Szul et al., 2013).

Changes in the fatty acid profile after salting and brining resulted from complex biochemical processes, including oxidation, denaturation, and lipolysis of fats. Salt and brine affected the structure and stability of fats and proteins, inducing changes in their reactivity (Silovska-Nikolovska, 2024). Polyunsaturated fatty acids are particularly susceptible to oxidation, which can lead to alterations in the flavor, aroma, and nutritional value of the meat. These changes in the fatty acid composition are crucial for the final product,

Table 2. Fatty acid composition of roast beef after brining (%)

Fatty acid (%)	Batches		
	I	II	III
C10:0	0.090	–	
C11:0	0.082	–	–
C12:0	0.121	–	0.110
C14:0	3.230	2.587	3.131
C14:1	1.250	0.765	0.713
C15:0	0.351	0.413	0.464
C15:1	0.123	–	0.143
C16:0	24.43	25.441	24.975
C16:1	3.571	4.502	4.010
C17:0	1.381	0.957	1.372
C17:1	0.624	0.654	0.612
C18:0	16.394	17.444	16.053
C18:1n9t	3.237	3.25714	5.041
C18:1n9c	41.851	40.557	34.894
C18:2n6t	0.209	0.393	0.220
C18:2n6c	1.962	1.670	7.593
C18:3n3	–	1.030	0.622
C18:3n6	0,101	0.274	0.102
C20:1	0,10	0.494	0.191
C22:1n9		0.627	0.321
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	46.183^{a}	47.842^{b}	46.104^{c}
Monounsaturated fatty acids (MUFA)	44.865^{a}	44.159^{a}	43.751^{b}
Polyunsaturated fatty acids (PUFA)	5.568^{a}	4.912^{b}	5.669^{a}
Trans fatty acids (trans FA)	3.383^{a}	3.087^{b}	4.475^{c}

^{a,b,c} statistical differences $p \leq 0.05$ between batches

Source: Authors' own elaboration

as they affect its texture, sensory properties, and shelf life (Chris Kazala et al., 2006; Cocking et al., 2020; das Graças Padre et al., 2007).

After brining, thermal processing of the roast follows, which is essential for food safety and also affects the fatty acid composition, potentially altering the nutritional profile of the product (Table 3).

The results of the analysis showed that saturated fatty acids (SFA) are the most abundant in the fats of the roasted meat, with an average value of around 48.5%. This high prevalence was expected, as saturated fatty acids are more resistant to thermal processing and have a stable structure, which does not easily break down during roasting (Huang et al., 2011; Alina et al., 2012; Badiani et al., 2002). Statistically significant differences at the level of ($p<0.05$) were observed between production batches as a result of the seasonal nature of the meat used as raw material for production. Monounsaturated fatty acids (MUFA), with an average content of about 44.2%, are also significantly present, and their levels remain relatively stable after thermal processing. This was a positive result, as MUFAs, such as oleic acid, are known for their health benefits, including improving lipid profiles and reducing inflammatory processes. The increase in the percentage of MUFA in the third batch (45.0%) may indicate variations in the production process.

Table 3. Fatty acid composition of roast beef after thermal processing

Fatty acid (%)	Batches		
	I	II	III
C10:0	0.063	0.081	0.092
C12:0	0.102	0.1438	0.111
C14:0	3.440	4.040	2.448
C14:1	0.951	0.695	0.423
C15:0	0.542	0.653	0.263
C15:1	0.202	0.201	0.164
C16:0	27.291	28.846	28.262
C16:1	4.700	5.536	3.184
C17:0	1.341	1.4461	0.993
C17:1	0.635	0.843	0.436
C18:0	15.809	13.341	15.842
C18:1n9t	0.991	3.443	2.069
C18:1n9c	39.693	41.472	38.134
C18:2n6t	0.266	0.281	0.284
C18:2n6c	2.974	1.562	5.763
C18:3n6	0.101	0.082	0.075
C20:1	0.271	0.414	0.394
C18:3n3	0.645	0.895	0.584
C22:1n9	–	0.084	0.465
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	48.831[a]	48.551[b]	48.014[c]
Monounsaturated fatty acids (MUFA)	43.414[a]	44.093[b]	45.021[b]
Polyunsaturated fatty acids (PUFA)	6.489[a]	5.275[b]	4.601[c]
Trans fatty acids (trans FA)	2.266[a]	2.099[b]	2.363[c]

[a,b,c] statistical differences $p \leq 0.05$ between batches

Source: Authors' own elaboration

Polyunsaturated fatty acids (PUFA) were present in a smaller proportion (on average around 5.5%), which is typical for meat products after thermal processing (Wang et al., 2023; Mariutti and Bragagnolo, 2017; Wood et al., 2008). The decrease in their content from the first to the third batch, with statistically significant differences at the level of ($p < 0.01$), can be explained by their sensitivity to heat and oxidation, leading to the degradation of these fatty acids during roasting. Trans fatty acids (trans-FA) were present in the smallest amounts (around 2.2%), but their presence was significant from a health perspective. Differences in their levels between batches may be due to variations in thermal processing conditions or the source of the fats. Similar results are reported by Duckett and Wagner (1998) and Prates (2025).

Conclusions

The study results showed that brining and thermal processing significantly affect the fatty acid composition of fats in roasted beef. Saturated fatty acids (SFA) increased due to their resistance to oxidation and heat, contributing to fat stability during processing. Monounsaturated fatty acids (MUFA) remained relatively stable, indicating moderate resistance to the effects of processing. In contrast, polyunsaturated fatty acids (PUFA) and trans fatty acids (trans-FA) significantly decreased, reflecting their high sensitivity to oxidation and heat, especially in the presence of salt.

Additionally, the season of slaughter and the characteristics of the meat as raw material play an important role in the fatty acid composition and its changes during processing. Seasonal variations affected the diet and metabolism of the animals, leading to differences in the fat profile between production batches. This variability influenced how fats respond to brining and thermal processing, further impacting the nutritional quality and sensory properties of the final product.

Understanding these factors allows for effective adjustment of production parameters to preserve beneficial fatty acids, improve the stability and quality of the product, and maintain the desired taste, aroma, and texture. This contributes to increasing the product's competitiveness in the market by providing a product with high standards that meets consumer demands.

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Received: **May, 06, 2025**; *Approved*: **June, 26, 2025**; *Published*: **October, 2026**