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CHANGES IN FATTY ACID COMPOSITION DURING THE PRODUCTION OF TRADITIONAL BEEF PROSCIUTTO RELATED TO TECHNOLOGICAL PROCESSING

SUMMARY

This study investigates changes in the fatty acid composition of beef prosciutto during traditional production, with particular attention to seasonal variations in raw material quality. Three production batches were prepared under traditional conditions in a certified slaughterhouse facility, differing according to slaughter season (spring, summer, and winter). Samples were collected at key technological stages—before salting, after 21 days of dry salting, and after thermal processing—and analyzed to monitor changes in fatty acid composition.

Seasonal factors significantly influence nutritional characteristics, as cattle finished in spring and summer show higher levels of polyunsaturated and omega-3 fatty acids due to improved feeding conditions. Saturated fatty acids (SFA) reached their highest proportion after brining (50.276%) and lowest after thermal treatment (46.326%). Monounsaturated fatty acids (MUFA) were highest immediately after thermal processing (46.523%) and lowest after brining (42.477%). Polyunsaturated fatty acids (PUFA) were most abundant before brining (5.408%), decreasing during processing and reaching their lowest values after thermal treatment. Trans fatty acids were highest before brining (3.908%) and lowest after thermal processing (2.947%).

Observed variations result from chemical transformations occurring during processing, affecting the physical and chemical properties of fats and consequently the product's nutritional value and quality. Understanding seasonal and technological influences is essential for optimizing production parameters to preserve beneficial fatty acids, maintain desirable sensory characteristics, and ensure product safety and consistency. The study contributes to a better

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understanding of mechanisms governing quality changes in traditional meat products and supports improvements in processing practices.

Keywords: Fatty acid composition, lipid oxidation, beef prosciutto, quality, traditional processing

INTRODUCTION

The production of beef prosciutto is traditionally associated with Mediterranean countries such as Italy, Spain, France, Portugal, and Croatia, where numerous types of prosciutto with distinctive quality and protected geographical origin have been developed (Krvavica and Đugum, 2006). The characteristics of these products depend on several factors, including animal genetics and rearing conditions, feeding regime, climatic conditions, raw material quality, and applied processing technology. Standardization of production processes contributes to the preservation of traditional manufacturing methods and ensures high product quality. In the Western Balkan region, particularly in Bosnia and Herzegovina and Kosovo, beef prosciutto represents an important traditional dry-cured meat product. Although beef contains less intramuscular and extramuscular fat compared to other types of meat, properly applied processing technology can produce a product with appropriate texture, flavor, and nutritional characteristics (Alfaia *et al.*, 2010a).

Beef prosciutto production involves several technological stages: raw material preparation and cutting, salting or brining, drying, smoking, and aging (Robović *et al.*, 2003; Kurćubić and Vesković-Moračanin, 2017; Ganić *et al.*, 2019). For traditional beef prosciutto produced in Kosovo, this product may include thermal processing as part of the technological procedure, making it regionally unique.

During these processes, significant physicochemical and biochemical changes occur, directly influencing product quality and stability, particularly the lipid fraction and fatty acid composition. Technological and seasonal factors cause variations in the ratio of saturated (SFA) to unsaturated fatty acids (UFA), which are crucial for nutritional value, organoleptic properties (flavor, aroma, texture), and shelf life (Rodríguez *et al.*, 2019; Sampaio *et al.*, 2024; Lorenzo *et al.*, 2014; Garrido *et al.*, 2017; Lorenzo *et al.*, 2012).

However, despite extensive research on Mediterranean dry-cured meats, a key gap persists: the dynamics of fatty acid composition (SFA/UFA ratios and oxidation levels) during the specific stages of traditional beef prosciutto production in Kosovo remain underexplored. Existing studies focus primarily on pork prosciutto from Mediterranean regions or general beef processing, overlooking local rearing conditions, seasonal variations, and Kosovo's unique practices like optional smoking and thermal processing (Alfaia *et al.*, 2010a; Lorenzo *et al.*, 2014).

This study addresses this gap by examining how fatty acid profiles evolve across processing stages (brining → drying → smoking → aging) in Kosovo beef prosciutto. We hypothesize that these stages will drive significant shifts, with increasing UFA levels and decreasing lipid oxidation in later phases, thereby enhancing nutritional quality and stability. These region-specific insights will optimize production, preserve Kosovo's gastronomic heritage, and boost market competitiveness.

MATERIAL AND METHODS

Three different production batches of traditional beef prosciutto 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). The second production batch is made from meat of young cattle slaughtered in summer (June-August). The meat used for the production of beef prosciutto in the third batch is obtained from winter slaughter of young cattle (November-February).

Beef prosciutto production and sampling

Traditional Beef Prosciutto from Prizren: Production Process

The traditional beef prosciutto from Prizren stands out as one of the highest quality meat products due to the use of premium cuts from the back-specifically the loin or ribeye muscle (*Musculus longissimus* dorsi). This selection provides optimal texture, juiciness, and rich flavor.

Slaughtering and Initial Preparation

During slaughtering, carcasses from young cattle (typically 18-24 months old, with live weight of 400-500 kg) are halved along the midline, thoroughly exsanguinated to minimize blood residues, and immediately transferred to a cooling chamber. The chamber maintains a temperature of 0-4°C and relative humidity of 85-90% for 24-48 hours. This rapid cooling prevents microbial growth and facilitates further processing. Once the internal temperature drops below 4°C, the halves are quartered, and the target sections for prosciutto production are separated. Shaping involves removing excess fat (to 3-5 mm) and forming into a cylindrical shape for uniform roasting.

Brining - The meat is submerged in cold brine (20-25% salt, 4-6°C) for 21 days with daily agitation. This ensures preservation, flavor, and moisture retention. It is then desalinated in running water for 1-3 hours to reach 2-3% salinity.

Pre-Roasting Preparation - The pieces are tied with string and dried at room temperature for 24 hours to form a surface pellicle.

Thermal processing is conducted in a traditional wood-fired chamber using air-dried beech wood as fuel. The chamber's initial temperature ramps up to 140-160°C with relative humidity of 40-60%; the meat surface reaches 120-130°C, continuing until the internal temperature achieves 58-62°C for medium-rare doneness. The thermal process duration is 270-300 minutes (4.5-5 hours), with continuous rotation of the pieces every 30 minutes until a shiny dark brown crust is obtained.

Cooling and Stabilization - After roasting, they are rapidly cooled to 4°C and rested for 12 hours to set the structure and flavor.

Figure 1. Traditional beef prosciutto in different stages of technological processing -a -brining, -b-during thermal processing, -c- after thermal processing

During the process, exactly 20 samples per group (n=20, ~500g each) are taken at three key stages: before brining (7 samples), after 21 days of brining (7 samples for salt uptake), and after thermal processing (6 samples) to monitor fatty acid composition changes and ensure quality control, (Figure 1).

Determination of fatty acid composition

The method of Folch *et al.,* (1957) was used for the extraction of fatty acids from sausages. Obtained fatty acids, were transferred to methyl esters according 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 (60m x 0.250mm x 0.20 µm). The operation parameters of 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 than increased at 10°C/minute to 175°C and maintained for 2 minutes, which was followed by last increase at 3°C/minute to 220°C and hold for 5 minutes. Injector and detector temperatures were kept at 250ºC and 300ºC, respectively. Helium was used as a carrier gas at a flow rate of 1.4 mL/min with split ratio 100:1. 1 µL volume of each sample was injected two times into GC-FID for separation and identification of the FAMEs. Total run was 38.50 minutes. FAMEs from samples were identified by comparison of their retention times to those of FAMEs 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 percentage of total fatty acids in 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

Beef prosciutto is considered one of the highest quality cured meat products made from beef. The fatty acid composition varies significantly not only between different animal species but also within the same species. These variations depend on the specific cut of beef used for production and the season during which the cattle are slaughtered. The results obtained from our analysis of the fatty acid composition of beef prosciutto before brining is presented in (Table 1) and (Figure 2).

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

Fatty acid (%)	Batches		
	I	II	III
C10:0	0,073	0,171	0,071
C11:0	-	0,214	-
C12:0	0,094	0,230	0,104
C14:0	3,013	3,372	3,754
C14:1	0,982	0,874	0,883
C15:0	0,357	0,503	0,770
C15:1	0,095	0,221	0,291
C16:0	25,811	25,461	25,713
C16:1	3,442	3,286	3,272
C17:0	1,390	1,354	1,631
C17:1	0,469	0,603	0,890
C18:0	15,788	15,260	15,542
C18:1n9t	3,637	3,831	1,905
C18:1n9c	36,879	36,495	39,221
C18:1n6t	0,818	1,555	0,978
C18:2n6c	6,331	6,620	3,723
C18:3n6	0,075	0,191	0,092
C20:1	0,151	0,243	0,342
C18:3n3	0,541	0,514	0,733
C22:1n9	-	-	0,080
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	46,532^{a}	46,566^{a}	47,586^{b}
Monounsaturated fatty acids (MUFA)	43,872^{a}	43,820^{a}	43,850^{a}
Polyunsaturated fatty acids (PUFA)	5,139^{a}	5,227^{b}	5,679^{c}
Trans fatty acids (trans FA)	4,455^{a}	4,386^{b}	2,884^{c}

^{a,b,c} *statistical differences p≤0.05 between batches*

As shown in Table 1, saturated fatty acids (SFA) represent the dominant fraction in the fat tissue of beef prosciutto before brining. Their relatively stable distribution across the examined batches indicates a consistent lipid composition of the raw material, with only minor variations that may be attributed to natural differences in animal origin or feeding conditions. This aligns with the findings of Wood *et al.*, (2008), who pointed out that saturated fatty acids have a stable presence in cattle fat tissue and significantly influence the texture and organoleptic properties of meat.

Similar data on the dominance of SFA as the main component in the fat tissue is reported by Dinh *et al.*, (2021) and Enser *et al.*, (1996), who emphasize that their proportion varies according to feeding and rearing conditions.

Monounsaturated fatty acids (MUFA) represent the second most abundant group and show relatively consistent distribution across batches, despite statistically significant differences ($p<0.05$). Their presence plays an important role in shaping both the sensory properties and the nutritional profile of the product. These findings are supported by Bošković *et al.*, (2015), who note that MUFAs, especially oleic acid, play a significant role in enhancing the organoleptic characteristics and beneficial nutritional aspects of meat products. Additionally, Fowler *et al.*, (2023) emphasize that the stability of MUFA in beef products is a key indicator of product quality.

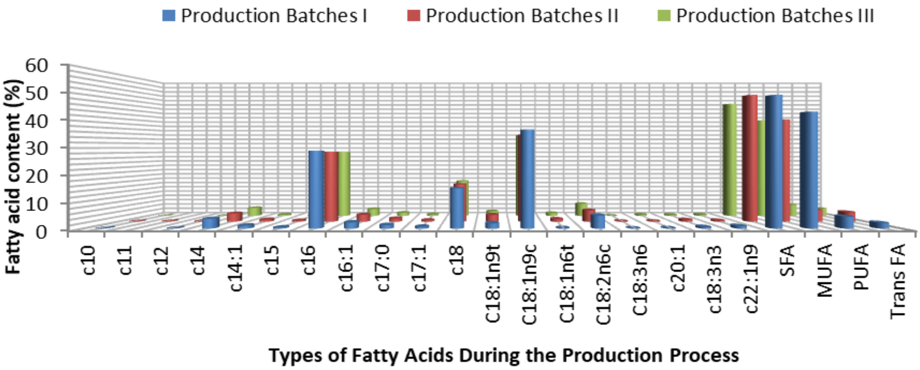

Figure 2. Dynamics of the fatty acid composition in beef prosciutto before brining

Polyunsaturated fatty acids (PUFA) show statistically significant variability ($p<0.01$), with a tendency to increase in certain batches. This variation may be associated with differences in feeding regimes or seasonal factors influencing the fatty acid composition of the raw material. This variation corresponds with observations by Scollan *et al.*, (2006, 2014) and Dannenberger *et al.*, (2011), which highlight that PUFAs are most influenced by diet and the season of the year. They point out that winter feeding, often consisting of concentrated feed, increases PUFA levels in meat compared to spring and summer periods.

Trans fatty acids, present in the lowest proportions, show statistically significant variability between batches ($p<0.01$). This variation likely reflects the influence of raw material characteristics and early processing conditions on lipid composition. These changes are consistent with studies by Lorenzo and Franco (2012), Estévez (2011), Estévez (2015), and Wood *et al.*, (2008), which indicate that trans fatty acids are sensitive to biological and seasonal factors, as well as processing and metabolic transformations in the meat. The differences can be linked to rearing conditions, nutrition, and physiological changes occurring in animals across different seasons.

Overall, the results indicate that the fatty acid composition of beef prosciutto is influenced by a complex interaction of biological factors, seasonal conditions, diet, and processing parameters. This variability reflects both raw material characteristics and technological conditions during production. This is in line with a wide range of scientific literature emphasizing that these factors collectively shape the final fatty acid profile, which is critical for the quality, nutritional value, and organoleptic characteristics of beef prosciutto (Enser *et al.*, 1996; Bošković *et al.*, 2015; Dannenberger *et al.*, 2011; Scollan *et al.*, 2006; Wood *et al.*, 2008; Lorenzo and Franco, 2012; Estévez, 2011).

During the brining process of beef prosciutto, significant changes occur in the fatty acid composition. These changes are driven by lipolytic enzyme activity naturally present in the meat, as well as by structural modifications of lipids induced by brine components, particularly salt and nitrites. As a result, the fatty acid profile is altered during processing.

From a technological perspective, these transformations highlight the importance of controlling brining conditions, such as salt concentration, duration, and temperature. Proper optimization of these parameters can help maintain desirable fatty acid profiles, improve product quality, and enhance the nutritional value of the final product.

The fatty acid content in the fats of the beef prosciutto after brining is shown in (Table 2 and Figure 3).

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

Fatty acid (%)	**Batches**		
	I	II	III
C10:0	0,092	0,172	0,065
C11:0	-	0,211	-
C12:0	0,146	0,234	0,102
C14:0	3,686	3,371	3,504
C14:1	1,139	0,872	0,551
C15:0	0,446	0,502	0,363
C15:1	0,135	0,223	0,194
C16:0	28,969	28,465	28,235
C16:1	2,348	2,891	3,014
C17:0	1,367	1,353	1,393
C17:1	0,687	0,604	0,654
C18:0	15,051	15,261	15,834
C18:1n9t	2,004	2,837	2,050
C18:1n9c	36,881	35,486	35,674
C18:2n6t	0,192	1,102	1,247
C18:2n6c	4,950	4,622	5,390
C18:3n6	0,101	0,193	0,080
C18:3n3	0,623	0,842	0,480
C20:1	0,193	0,244	0,554
C22:1n9	0,984	0,513	0,612
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	49,760^{a}	51,569^{b}	49,498^{c}
Monounsaturated fatty acids (MUFA)	43,540^{a}	41,656^{b}	42,236^{c}
Polyunsaturated fatty acids (PUFA)	4,503^{a}	4,834^{b}	4,967^{c}
Trans fatty acids (trans FA)	2,195^{a}	3,939^{b}	3,298^{c}

^{a,b,c} *statistical differences p≤0.05 between batches*

As shown in Table 2 and Figure 3, the fatty acid profile of beef prosciutto after brining differs significantly among the three production batches. Saturated fatty acids (SFA) represent the dominant fraction, with statistically significant differences ($p<0.05$), indicating that processing conditions and/or seasonal variations in the raw material affect lipid stability and composition. Monounsaturated fatty acids (MUFA) also show significant differences between batches ($p<0.05$). Polyunsaturated fatty acids (PUFA), although present in lower amounts, show a slight increasing trend across batches, which may be associated with improved nutritional quality under certain production conditions. Trans fatty acids show significant differences ($p<0.01$), highlighting the influence of technological processes such as brining and drying on lipid transformations. Their variability suggests that processing parameters may affect the formation of these less desirable compounds.

From a technological perspective, these results indicate that controlling key processing factors: such as brining duration, temperature, and drying conditions - can significantly influence lipid composition. Optimization of these parameters may help reduce the formation of trans fatty acids while preserving or enhancing beneficial unsaturated fatty acids, thereby improving the nutritional value and overall quality of the final product.

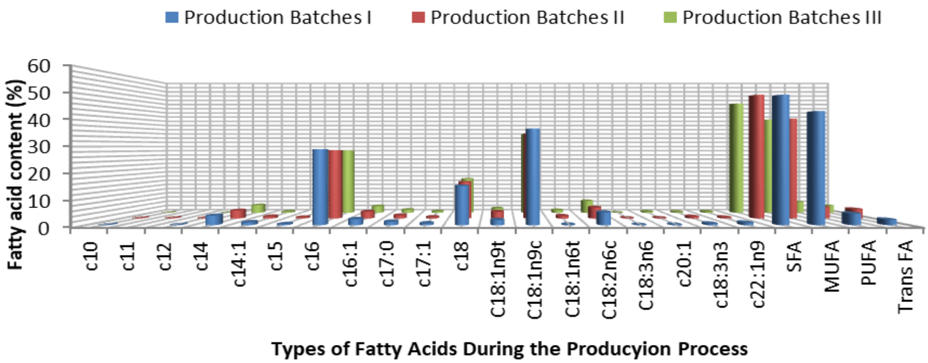

Figure 3. Dynamics of the fatty acid composition in beef prosciutto after brining

The differences in the percentages of MUFA, PUFA, and Trans FA acids between the batches can be linked to different biological and nutritional conditions under 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; S. M. Fowler *et al.,* 2023).

Changes in fatty acid composition during brining result from the interaction of brine components, lipolytic enzyme activity, and redox processes (Álvarez Sara *et al.,* 2023; Derek and Vale, 1998; Beermann *et al.,* 2003; Kazala *et al.,* 2006). Additionally, microbiological and enzymatic reactions in the salty and acidic environment further influence fatty acid stability and transformation, ultimately affecting the quality, flavor, and nutritional value of beef prosciutto.

During the thermal processing of beef prosciutto, significant changes in fatty acid composition occur due to exposure to high temperatures, leading to lipid denaturation, oxidation, and polymerization. These transformations alter the fatty acid profile and directly affect product quality and stability. From a technological perspective, controlling processing temperature and duration is crucial to limit oxidative degradation and preserve desirable fatty acids. Optimization of thermal conditions can improve lipid stability, enhance sensory properties, and maintain the nutritional value of the final product, (Table 3) and (Figure 4).

Table 3. Fatty acid composition of beef prosciutto after thermal processing (%)

Fatty acid (%)	**Batches**		
	I	II	III
C10:0	0,072	0,062	0,060
C12:0	0,091	0,088	0,101
C14:0	2,711	2,414	2,500
C14:1	0,432	0,793	0,551
C15:0	0,313	0,386	0,365
C15:1	0,214	0,190	0,194
C16:0	24,151	23,870	23,235
C16:1	2,292	2,865	3,012
C17:0	1,191	1,144	1,395
C17:1	0,584	0,494	0,654
C18:0	18,456	17,565	18,835
C18:1n9t	1,553	2,512	2,324
C18:1n9c	42,962	42,652	39,671
C18:2n9t	1,207	0,264	0,982
C18:2n6c	3,462	3,724	4,390
C18:3n6	0,108	0,094	0,082
C20:1	0,306	0,496	0,552
C18:3n3	0,893	0,750	0,484
C22:1n9	-	0,181	0,6117
Total fatty acid profile (%)			
Saturated fatty acids (SFA)	47,985	45,531	46,491
Monounsaturated fatty acids (MUFA)	44,425	46,853	45,239
Polyunsaturated fatty acids (PUFA)	3,828	4,838	4,962
Trans fatty acids (trans FA)	2,760	2,775	3,306

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

In the fats of beef prosciutto after thermal processing, 19 fatty acids were identified. The most abundant fatty acid in this group is palmitic acid (C16:0), with an average content of 23.752%, followed by stearic acid (C18:0) at 18.285%, while others such as myristic acid (C14:0) and heptadecanoic acid (C17:0) occur in smaller amounts. Statistically significant differences ($p<0.05$) were observed between the first and third batches regarding MUFA content.

Polyunsaturated fatty acids (PUFA), which are the third most abundant group, have an average content of 4.542%, with variations ranging from 3.828% to 4.838% among the batches.

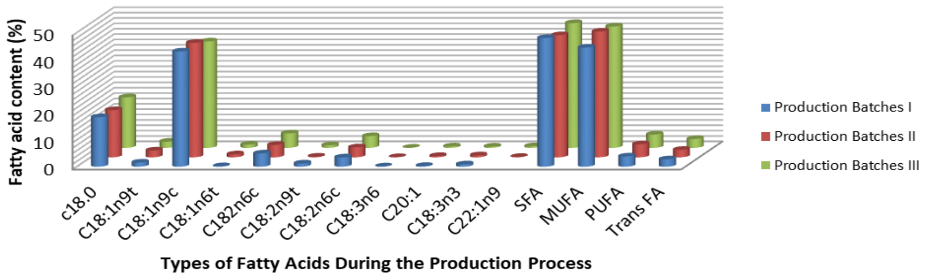

Figure 4. Dynamics of the fatty acid composition in beef prosciutto after thermal processing (%)

These results indicate relative stability in the levels of SFA and MUFA after thermal processing, while variations in PUFA and Trans fatty acids may be attributed to influences related to thermal treatment and the origin of the raw material. Thermal processing causes denaturation, oxidation, and polymerization of fats, which affect their structure and fatty acid profile. Saturated fatty acids (SFA) exhibit greater heat stability, while polyunsaturated fatty acids (PUFA) are more sensitive and prone to oxidative changes, which can influence the flavor and nutritional properties of the product (Alfaia *et al.*, 2010b; Echegaray *et al.*, 2018; Min, 2005).

Additionally, seasonal variations in the diet and rearing conditions of animals significantly affect the fatty acid composition. Winter conditions, when concentrated feeds are used, generally lead to a decrease in PUFA and an increase in Trans fatty acids, whereas in spring and summer periods, when animals graze on fresh grass rich in polyunsaturated fatty acids, higher concentrations of these fatty acids are observed (Scollan *et al.*, 2006; Dannenberger *et al.*, 2011; Wood *et al.*, 2008).

These biological and technical factors together shape the nutritional profile and organoleptic qualities of beef prosciutto, making the control of the production process and understanding of seasonal variations crucial for maintaining the quality and health value of the final product (Zarrdeto *et al.*, 2017; Blanco *et al.*, 2015; Králová, 2015).

CONCLUSIONS

The results demonstrate that both technological processes and seasonal variations significantly influence the fatty acid composition of beef prosciutto. Processing stages, particularly brining and thermal treatment, play a key role in modifying lipid profiles through biochemical and oxidative changes. From a technological perspective, controlling parameters such as salting duration, temperature, and heat treatment intensity is essential to preserve beneficial fatty acids, limit undesirable transformations, and ensure product quality and stability.

Seasonal variation in raw material quality has a notable impact, with spring and summer production associated with more favorable fatty acid profiles, particularly higher levels of polyunsaturated fatty acids due to improved feeding conditions.

These findings have practical relevance for traditional beef prosciutto production, highlighting the importance of adapting processing conditions to both raw material characteristics and seasonal factors in order to achieve consistent quality, improved nutritional value, and desirable sensory properties.

This is particularly important for Kosovo, as it supports the improvement of traditional meat production, enhances product quality, and increases competitiveness in the market

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