SCIENTIFIC JOURNAL

eISSN 2560-4295
UDK 664.9

meat technology

66 Vol.
02 No.
2025 Belgrade

Founder and Publisher
Institute of Meat Hygiene
and Technology

"Meat Technology" is the scientific journal, founded in year 1960, that publishes results of basic and applied research in the field of biotechnical sciences i.e. the following subcategories: veterinary sciences, food engineering and biotechnology.

Journal "Meat Technology" is abstracted in FSTA (Food Science and Technology Abstract). Full text is available in SCOPUS, CABI Database, EBSCO publishing, DOAJ, AGRIS, www.ifocus.my Database and www.inmes.rs. "Meat Technology" is an open access journal.

Founded in 1960.

FOUNDER AND PUBLISHER

Institute of Meat Hygiene and Technology

11000 Belgrade, Kaćanskog 13

P.O. Box 33-49

Phone 381 11 2650-655

e-mail: institut@inmes.rs

www.inmes.rs

DIRECTOR

Vesna Z. Đorđević, PhD

EDITOR IN CHIEF

Vesna Z. Đorđević, PhD

PROOFREADER FOR ENGLISH LANGUAGE

Sheryl Avery, PhD

TECHNICAL EDITION

Danijela Šarčević, PhD

Slaviša Šobot

COMPUTER PROCESSING AND PRINTING

Naučna KMD – Beograd

CIRCULATION

100 copies

PUBLICATION OF THIS JOURNAL IS FINNANCIALLY SUPPORTED BY:

Ministry of Science, Technological Development and Innovations of the Republic of Serbia

www.journalmeattechnology.com

eISSN 2560-4295
UDK 664.9

meat technology
scientific journal

Meat Technology Vol. 66 No. 2 P. 73–138 Belgrade 2025

CONTENTS

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.5.065:636.52/.58
579.67
COBISS.SR-ID: 176209417
https://doi.org/10.18485/meattech.2025.66.2.1

Original scientific paper

Comparative analysis of biofilms in the meat and poultry processing industry: taxonomy and interactions

Yulia Yushina[1], Elena Zaiko[1], Andrey Mardanov[2], Yury Nikolaev[2], Evgeniy Gruzdev[2], Ekaterina Tikhonova[2], Anastasia Semenova[1], Anzhelika Makhova[1], Maria Grudistova[1] and Dagmara Bataeva[1]*

1 V.M. Gorbatov Federal Research Center for Food Systems of RAS, Talalikhina st., 26, 109316 Moscow, Russia
2 Fundamentals of Biotechnology Federal Research Center of RAS, Leninsky Prospect, 14, 119991 Moscow, Russia

A R T I C L E   I N F O

Keywords:
Microbial surface contamination
Biofilms
High throughput sequencing

A B S T R A C T

This study aimed to compare the prevalence, taxonomic structure, and interactions of microbial communities in biofilms formed on surfaces in a meat processing plant (MPP) and a poultry processing plant (PPP). Using transmission electron microscopy and high-throughput sequencing of the 16S rRNA V3-V4 region, biofilms were detected in 25% of MPP scrape samples (2/8) and in 85.7% of PPP scrape samples (6/7). Taxonomic analysis revealed the dominance of *Proteobacteria, Bacteroidota, Actinobacteria*, and *Firmicutes* in biofilms from both facilities, with marked heterogeneity in the MPP (Chao1 index: 336.8–697.8). Network association of microorganisms has identified a synergy between the genera *Flavobacterium, Acinetobacter*, and *Psychrobacter*, and an antagonism between the *Marisediminicola* and *Pseudomonas/Acinetobacter*, which highlights the complexity of inter-microbial interactions in industrial settings.

1. Introduction

The microbial ecology of industrial food processing environments is a critical determinant of product safety and quality. Biofilms formed on equipment and surfaces in meat and poultry processing plants serve as reservoirs for spoilage microorganisms and potential pathogens, posing significant risks to both product shelf life and consumer health (*Giaouris et al.,* 2014). Despite advances in sanitation practices, persistent microbial contamination remains a challenge, particularly in facilities with complex workflows and varying environmental conditions. Understanding the composition, diversity, and interactions of microbial communities in these environments is essential for developing targeted disinfection strategies and mitigating contamination risks (*Simões et al.,* 2010).

Meat and poultry processing plants are characterized by unique environmental niches, including low temperatures, high humidity, and organic residues, which favor the proliferation of psychrotrophic and biofilm-forming bacteria (*Sofos,* 2008). These microorganisms, such as *Pseudomonas, Psychrobacter,* and *Brochothrix,* are well-known agents of food spoilage, capable of degrading proteins and lipids even under refrigeration (*Remenant et al.,* 2015). Additionally, biofilms protect embedded microbes from routine sanitation, enabling recurrent contamination (*Bridier et al.,* 2015). While traditional microbiological methods have provided foundational insights, modern molecular approaches, such as 16S rRNA amplicon sequencing, offer unprecedented resolution for mapping microbial diversity and ecological dynamics in these complex systems (*De Filippis et al.,* 2017).

Previous studies have focused on specific pathogens (e.g., *Listeria monocytogenes*, *Salmonella* spp.) or spoilage organisms in food matrices (*Carpentier & Cerf,* 2011; *Walia et al.,* 2017), but fewer have systematically analyzed biofilm communities

***Corresponding author:** Name FamilyName, *contactmail@domen.com*

Paper received: May 20th 2025. Paper accepted August 7th 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

on industrial surfaces (*Silva et al.,* 2024). Furthermore, comparative analyses between meat and poultry processing environments are scarce, despite differences in raw materials, processing stages, and sanitation protocols (*Stellato et al.,* 2016). This study addresses these gaps by investigating the taxonomic composition, diversity, and co-occurrence patterns of microbial communities in two distinct processing facilities: a meat processing plant (MPP) and a poultry processing plant (PPP) in the Moscow region.

2. Materials and Methods

2.1. Sampling

In this work, we studied samples of biofilms collected from the surfaces of industrial premises and technological equipment in various areas of a meat processing plant (MPP) and a poultry processing plant (PPP) in the Moscow region. Biofilm samples were obtained by scraping surfaces with a metal spatula before the daily routine disinfection procedure (Table 1).

The scrapings were immediately placed in sterile saline solution for molecular biological and microbiological studies. The presence of biofilms in the sampled scrapings was proved by studying the structural organization using transmission electron microscopy (TEM) of ultrathin sections of the samples.

2.2. Taxonomic analysis of biofilms. DNA isolation, amplification, and sequencing of 16S rRNA gene fragments.

Total DNA from the samples was isolated using Power Soil kits (MO BIO Laboratories, Inc., Carlsbad, CA, USA) according to the manufacturer's protocols. The variable V3-V4 region

Table 1. Samples taken for the study and conditions at the sampling sites

Sample No.	Zone	Sampled surface
	Meat Processing Plant	
1	Carcass storage. Ambient temperature 1.8 °C	The wall of the sewer ladder (drain) in the floor
2	Raw materials zone, deboning area. Ambient temperature 4 °C	Condensation from the underside of the meat crate release mechanism (elevator)
3		Conveyor lubrication
4		The wall of the sewer ladder (drain) in the floor
5		Wet piece of sealant coming off the wall
6		Surface of the frame on the crate transport trolley (interior)
7		Trolley wheels
8	Accumulator for chopped raw materials	Ice with dirt from the floor
	Poultry Processing Plant	
1	Evisceration zone	Ceiling
2	Poultry carcass disinfection zone	Underside of walkways near the Morris Bath
3		The ceiling above Morris' bathroom
4	Cooling tunnel. Ambient temperature 0 °C	Wall in the carcass cooling tunnel
5		Plastic conveyor roller (top) in the cooling tunnel
6	Packaging zone	Trolley wheels (plastic) at the beginning of the packaging room
7		Trolley wheels (plastic) at the end of the packaging room

of the 16S rRNA gene was amplified using universal primers 341F (5'-CCT AYG GGD BGC WSC AG-3') and 806R (5'-GGA CTA CNV GGG THT CTA AT-3'). The resulting PCR fragments were purified using Agencourt AMPure magnetic beads (Beckman Coulter, Brea, CA, USA) and concentration was measured using Qubit dsDNA HS Assay Kits (Invitrogen, Carlsbad, CA, USA). The PCR fragments were sequenced on an Illumina MiSeq instrument (Illumina, San Diego, CA, USA) in the format of 2×300 nucleotide pair-end reads.

2.3. Bioinformatic analysis

Paired readings were combined using the FLASH v.1.2.11 program (*Magoč and Salzberg,* 2011). After merging, low-quality reads, singletons, and chimeras were excluded. To determine the proportion of operational taxonomic units (OTUs) in each of the samples, original reads (including low-quality and singletons) were superimposed on representative OTU sequences with a minimum identity of 97% over the entire length of the reading. To perform all these procedures, the USEARCH v.11 software package (*Edgar,* 2010) was used. Taxonomic identification of microorganisms by 16S rRNA gene sequences was performed using the VSEARCH v.2.14.1 algorithm in the Silva v.138 database (*Rognes et al.,* 2016). The analysis of co-presence (absence) networks was carried out based on the Sperman correlation matrix (*Langfelder* et al., 2012) and constructed using only significant correlation coefficients (*Barberán* et al., 2014). The threshold for correlation coefficients was set at 0.7 and the threshold for adjusted p values was 0.001. The analysis included only OTUs, the relative content of which was at least 5.0% in at least one sample. Alpha diversity was assessed using the Chao1 and Shannon E indices. The calculations were performed using the Usearch v11 package. Visualization and statistical analysis of diversity data were performed in QIIME. Visualization of the co-occurrence network was performed using the software package Cytoscape v.3.8.2 (*Shannon et al.* 2003; *Faust & Raes,* 2016). All raw data obtained of 16S rRNA gene fragments were deposited in the NCBI database and are available within the BioProject PRJNA850912 project.

2.4 Microscopic analysis of biofilms

The structural organization of material in the scrapings was studied using transmission electron microscopy (TEM) of their ultrathin sections. Each material was immediately placed in a 2.5% solution of glutaraldehyde in cacodylate buffer (0.05 M sodium cacodylate solution, pH 7.0–7.5) and kept at 4 °C for a day. Then, it was washed three times with the same buffer solution for 5 min and fixed in a solution of OsO4 (1% OsO_4 0.7% solution of ruthenium red in cacodylate buffer) for 1.5 h at 4 °C. After fixation, the materials were placed in 2% agar-agar and sequentially kept in a 3% solution of uranyl acetate in 30% ethanol for 4 h, then in 70% ethanol for 12 h at 4 °C. The material was dehydrated in 96% ethanol (2 times for 15 min), then in absolute acetone (3 times for 10 min). Dehydrated materials were then soaked with EPON-812 resin (Epoxy Embedding Medium Epon® 812, Sigma-Aldrich, USA) kept in a mixture of resin: acetone in a ratio of 1:1 for 1 h, then in a mixture of resin: acetone in a ratio of 2:1 in for 1 hour. The resulting material was poured into resin capsules and polymerized at a temperature of 37 °C for a day, then at 60 °C for a day. Ultrathin sections were obtained on an LKB-III microtome (LKB, Sweden) and contrasted in an aqueous solution of 3% uranyl acetate (30 min), then in an aqueous solution of 4% lead citrate (30 min). To detect acid mucopolysaccharides in biofilms, rutheniwum red dye (Sigma, USA) was used, when it was added in an amount of 0.7% together with OsO4, with which it interacted. Using ruthenium red, the presence of extracellular polysaccharides in biofilms of a number of bacteria was shown (Smirnova et al., 2010). The resulting preparations were analyzed using a JEM 100SHP electron microscope (JEOL, Japan) at an accelerating voltage of 80 kV and an operating magnification of 5000–50000×. Photo documentation of the materials was performed using a Morada G2 digital optical imaging system.

3. Results

All the material scrapings obtained were evaluated for the presence of biofilms by studying the structural organization using TEM of ultrathin sections of the samples. The material scrapings were identified as biofilms when the presence of a polysaccharide matrix and a characteristic cluster of cells was visible. At the MPP, out of eight samples taken, the presence of biofilm was proven in only two samples (Table 1 and 2). Biofilms were found in sample 2, taken from the bottom surface (with condensate) during the delivery of meat boxes to the raw material area and in sample 7, taken from the wheels of a jack-cart trolley. Of the seven samples from the PPP, six contained biofilms of varying maturity (Tables 1 and 2).

3.1 Composition of microflora of biofilms

The taxonomic composition of fifteen selected samples for MPP and PPP was determined based on the analysis of the V3-V4 variable region of the 16S rRNA gene. In total, 435,101 sequences of variable V3-V4 fragments of the 16S rRNA gene were determined in all samples of surface biofilm contamination (Table 2). The results of clustering the obtained sequences showed the presence of 14 archaeal and 2619 bacterial OTUs with 97% sequence identity.

In the MPP, biofilms from the two locations differed in the taxonomic diversity of their microbial communities (Table 2). The condensate sample from the lower surface of the elevator for the boxes (2MPP, Chao1 — 336.8) showed lower taxonomic diversity compared to the biofilm material collected

Table 2. Chao1 and Shannon diversity indices of the studied surface biofilms obtained from the meat processing plant (MPP) and poutry processing plant (PPP)

Biofilm (refer to Table 1 for the equivalent sample locations)	Diversity indices		Number of readings (included OTUs)
	Chao1	Shannon_E	
Meat processing plant			
2MPP	336.8	3.19	65091
7MPP	697.8	4.44	42882
Poultry processing plant			
1PPP	298.6	3.82	7528
2PPP	265.3	3.80	10669
3PPP	364.8	4.05	6911
4PPP	77.1	1.68	5373
6PPP	172.3	3.32	6617
7PPP	289.8	3.77	5638

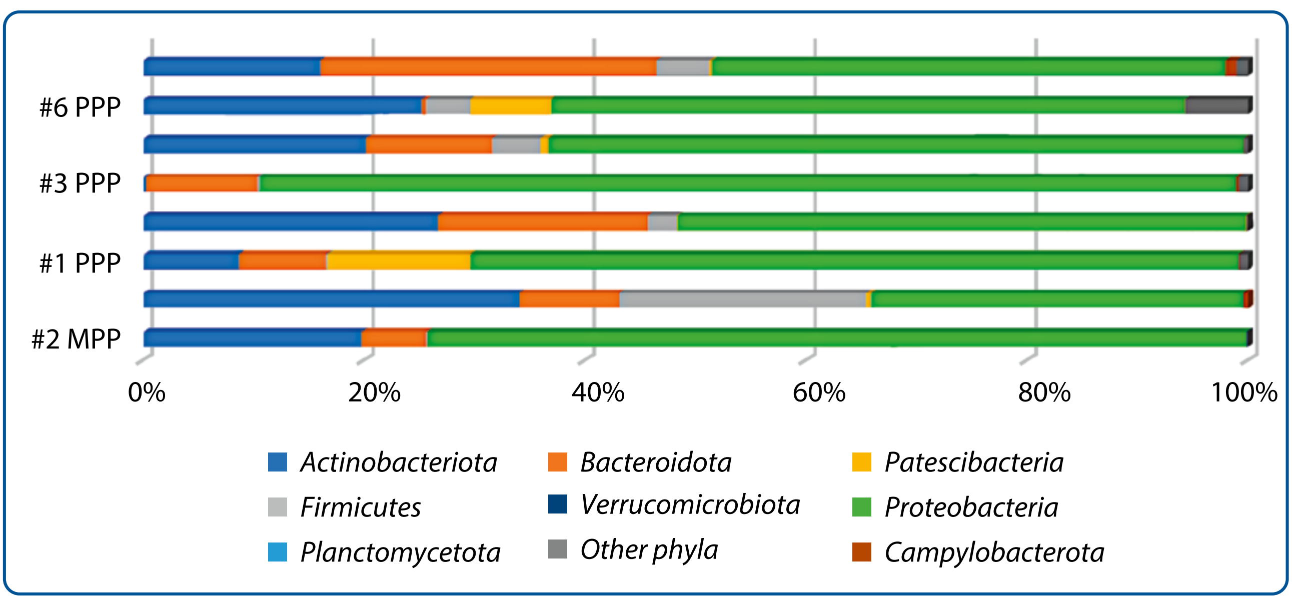

Figure 1. Distribution by class of microorganisms identified in biofilms collected from the studied meat processing plant (MPP) and poultry processing plant (PPP)

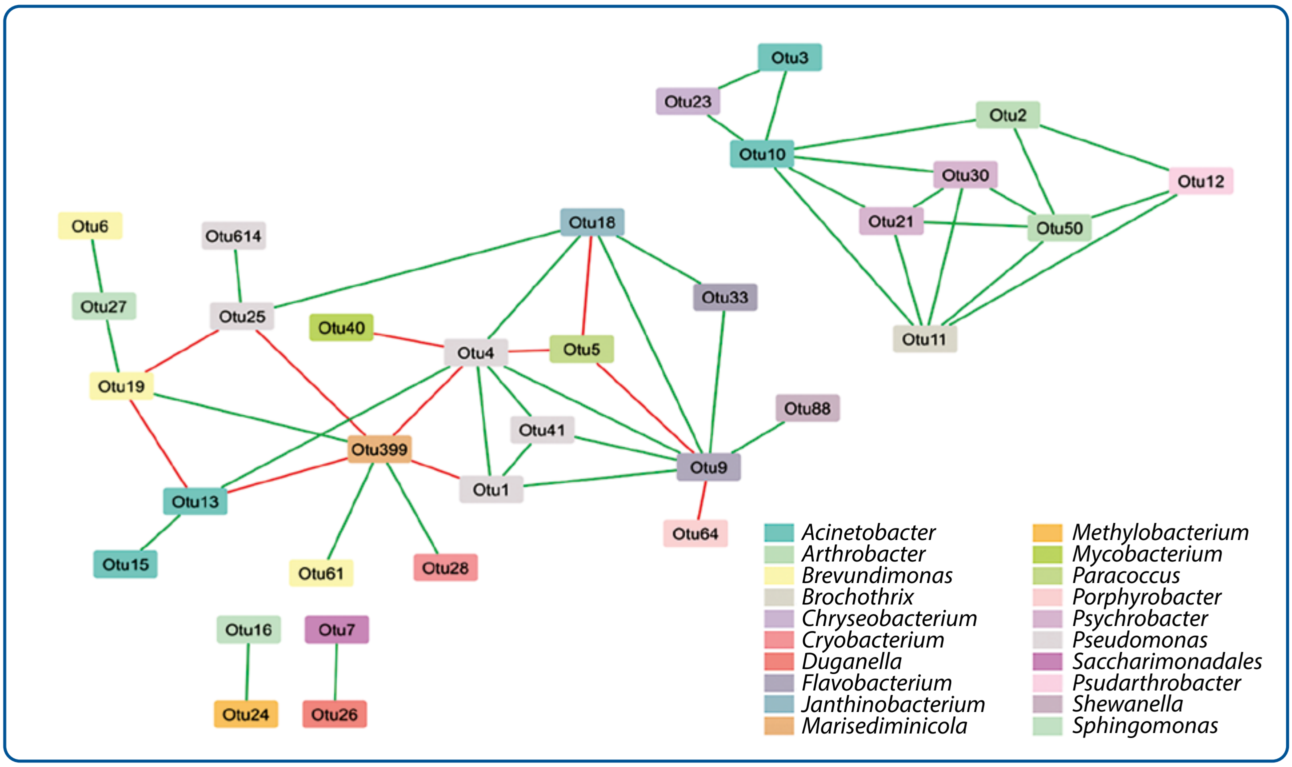

Figure 2. Network analysis of microbial interactions based on correlation analysis. Green indicates a positive interaction between operational taxonomic units (OTUs), while red indicates a mutual exclusion of OTUs.

from a trolley wheel (7MPP, Chao1 — 697.8). The taxonomic diversity of microbial communities in the biofilms from the PPP was less pronounced, as the greatest diversity was observed in biofilm 3PPP (the ceiling near the Morris bath), with a Chao1 diversity index of 364.8. The lowest taxonomic diversity was noted in biofilm 4PPP, where the Chao1 diversity index was only 77.1.

Among the bacteria detected in the biofilms, representatives of the phyla *Actinobacteriota, Bacteroidota, Proteobacteria, Firmicutes, Patescibacteria* were dominant (Figure 1).

The microbial composition of the two biofilms from the MPP differed (Figure 1). The microbial composition of biofilm 7MPP was more diverse than in biofilm 2MPP and contained a large number of classes of microorganisms. Representatives of the *Actinobacteriota* class were almost twice as numerous in the biofilm on the cart wheel (7MPP) as in biofilm 2MPP, taken fom meat crate condensate. In biofilm 2MPP, most of the microbial community was occupied by a representative of the Proteobacteria class. At the same time, no representatives of the Firmicutes class were found in biofilm 2MPP, but this contrasted with biofilm 7MPP, in which they made up 22.34% of the total biofilm microorganisms detected.

The biofilms from the SPP contained representatives of *Actinobacteria, Bacteroidota, Proteobacteria, Firmicutes* and *Proteobacteria* in different proportions (Figure 1). The microbial community was least diverse in biofilm 3PPP (ceiling near the Morris bath), where the bulk of the microbial community was *Proteobacteria* (88.36%) (Table 2). The most diverse microbial compositions were in biofilm 6PPP (trolley wheels (plastic) at the beginning of the workshop) and biofilm 4PPP (wall in the carcass cooling tunnel).

3.2. Network analysis of interactions of microorganisms in the studied samples

Network analysis showed the largest number of positive relationships were found for representatives of the dominant genera (Figure 2). Therefore, OTU 9 (*Flavobacterium*) and OTU 10 (*Acinetobacter*) each had six possible associations with representatives of the *Psychrobacter, Pseudomonas, Brochothrix, Chryseobacterium, Arthrobacter*, and *Shewanella* genera.

The largest number of mutual exclusion relationships was found for OTU 399, belonging to the genus *Marisediminicola* (a soil bacterium) with three representatives of *Pseudomonas* (OTU 25, OTU 4, OTU 1) and one representative of *Acinetobacter* (OTU 13) (Figure 2).

4. Discussion

The study made it possible to characterize in detail the composition of microbial communities in biofilms formed on the surfaces of a MPP and a PPP. The data obtained demonstrate significant differences in taxonomic diversity and community structure between the two types of industries, which is consistent with the previously described features of microbiomes in the food industry (for example, *Bokulich* et al., 2016). The Chao1 and Shannon indices, reflecting alpha diversity, were significantly higher in biofilm materials from the MPP than in those from the PPP, which is likely due to more the heterogeneous environmental conditions in the MPP, including temperature fluctuations and the presence of organic substrates in the areas of cutting and storage of raw materials. On the contrary, the lower diversity in PPP can also be explained by strict temperature conditions (for example, a cooling tunnel kept at 0 °C) and regular disinfection procedures that limit the growth of some microorganisms. The dominant phyla (*Actinobacteriota, Bacteroidota, Proteobacteria, Firmicutes*) are typical of biofilms that form in food production plants, which is confirmed by numerous studies (*Abdallah* et al., 2014; *Nikolaev* et al., 2022; *Fagerlund* et al., 2021). However, unique features were observed in individual biofilms in the current study. For example, the high proportion of *Firmicutes* and *Actinobacteriota* in biofilm 7MPP (up to 22.34% and 34.03%, respectively) could be related to their resistance to drying and disinfectants, which was previously noted for industrial surfaces (*Alonso* et al., 2024).

DNA sequencing allowed for a detailed analysis of the microbial composition of the biofilm materials, which provides valuable information for assessing the risks associated with possible sources of contamination and the spread of pathogenic microorganisms. A key result revealed by taxonomic analysis was that biofilms at both types of meat processing plant were dominated by *Proteobacteria, Bacteroidota, Actinobacteria,* and *Firmicutes*—phyla that contain foodborne pathogens and spoilage organisms. These four phyla made up a significant part of the total microbial populations at both enterprises. It is important to note that these groups include both non-pathogenic and potentially pathogenic species. For example, representatives of the genus *Escherichia* are classified in the phylum *Proteobacteria*, including *Escherichia coli*, one of the main causative agents of foodborne infections. The prominence of *Proteobacteria* in biofilm 2MPP (condensate) correlates with findings by *Barcenilla* et al. (2024), confirming that in meat processing conditions with low temperatures and high humidity, Proteobacteria (especially the genera Pseudomonas, Acinetobacter, and Enterobacteriaceae) become key components of biofilms on equipment surfaces. Notably, *Firmicutes* (which made up 22.34% of biofilm 7MPP) include the genera *Listeria* and *Staphylococcus*, which thrive on equipment surfaces (*Fagerlund* et al., 2017). The absence of *Firmicutes* in biofilm 2MPP could indicate localized antimicrobial interventions or nutrient limitations, warranting further investigation into site-specific microbial selection pressures.

The striking diversity disparity between the two biofilms from the MPP (Chao1: 336.8 vs. 697.8) underscores microenvironmental heterogeneity. The high diversity in biofilm 7MPP (trolley wheel) likely reflects cross-contamination from diverse sources, including soil and organic debris. In the PPP, the dominance of *Proteobacteria* (88.36%) in biofilm 3PPP (ceiling near Morris bathtub) suggests aerosolized contamination from water sources, a phenomenon documented by *Elafify et al*. (2024). Conversely, the low diversity in biofilm 4PPP (Chao1: 77.1) could indicate selective pressure from disinfectants, favoring resilient taxa like *Pseudomonas*.

Network analysis of microbial communities makes it possible to identify patterns of joint representation of different members of the studied communities. The network analysis conducted in the current study revealed cooperative interactions among *Flavobacterium, Acinetobacter,* and *Psychrobacter* — genera known for synergistic biofilm matrix production (*Machado et al., 2020*). These mutualistic relationships could enhance biofilm resilience, complicating eradication efforts. Conversely, the antagonism between *Marisediminicola* (soil-associated) and *Pseudomonas/Acinetobacter* suggests niche exclusion, possibly due to competition for iron or antimicrobial metabolite production (*Coyte et al., 2015*). However, we hypothesize that *Marisediminicola* (OTU 399) was the most unadapted (of all the organisms we detected) to the conditions of the food plants, but was not actually an antagonist of *Pseudomonas* or *Arthrobacteria*. This finding contrasts with typical biofilm synergy, highlighting the complexity of microbial interactions in industrial settings.

5. Conclusion

Based on the conducted research of microbial biofilms at meat processing and poultry processing enterprises, the following key conclusions can be drawn. Firstly, the prevalence and diversity of biofilms varied significantly between enterprises: biofilms were detected in only 2 out of 8 samples (25%) in MPP, while in 6 out of 7 samples (86%) in PPP, which indicates more favorable conditions for their formation in PPP. Secondly, microbial diversity (estimated by Chao1 and Shannon indices) was higher in MPP biofilms, especially on the surface of cart wheels (sample 7MPP, Chao1 = 697.8), which is explained by the transfer of microorganisms from soil and raw materials, while in MPP the greatest diversity was observed on the ceiling near the Morris tub (3PP, Chao1 = 364.8), and the minimum is in the cooling tunnel (4PPP, Chao1 = 77.1) due to low temperatures (0 °C) and disinfection. Thirdly, the taxonomic composition of the dominant phylum (*Proteobacteria, Actinobacteriota, Bacteroidota, Firmicutes*) is consistent with typical meat industry communities, but their distribution depended on location: *Proteobacteria* (88.36%) prevailed in the condensate of the raw material elevator (2MPP), while as on trolley wheels (7MPP), *Firmicutes* (22.34%) and *Actinobacteriota* (34.03%). Fourth, a network association of microorganisms has identified a synergy between the genera *Flavobacterium, Acinetobacter*, and *Psychrobacter*, and an antagonism between the *Marisediminicola* and *Pseudomonas/Acinetobacter*, which highlights the complexity of inter-microbial interactions in industrial settings.

Uporedna analiza biofilmova u industriji prerade mesa i živine: taksonomija i interakcije

Yulia Yushina, Elena Zaiko, Andrey Mardanov, Yury Nikolaev, Evgeniy Gruzdev, Ekaterina Tikhonova, Anastasia Semenova, Anzhelika Makhova, Maria Grudistova and Dagmara Bataeva

I N F O R M A C I J E O R A D U

Ključne reči:
Mikrobna kontaminacija površina
Biofilmovi
Sekvenciranje visoke propusnosti

A P S T R A K T

Apstrakt: Cilj ove studije bio je da se uporedi zastupljenost, taksonomska struktura i međusobne interakcije mikrobnih zajednica unutar biofilmova formiranih na površinama u pogonima za preradu mesa (MPP) i živine (PPP). Korišćenjem transmisione elektronske mikroskopije i sekvenciranja visoke propusnosti regije V3–V4 16S rRNA gena, biofilmovi su otkriveni u 25% uzoraka iz MPP postrojenja (2/8) i u 85,7% uzoraka iz PPP postrojenja (6/7), što ukazuje na značaj uticaja faktora sredine (npr. vlažnost, higijenska praksa) na formiranje biofilmova. Taksonomska analiza pokazala je dominaciju bakterijskih koljena Proteobacteria, Bacteroidota, Actinobacteria i Firmicutes u biofilmima oba pogona, uz izraženu heterogenost u MPP uzorcima (Chao1 indeks: 336,8–697,8). Analiza mreža interakcija otkrila je kooperativne odnose između rodova Flavobacterium, Acinetobacter i Psychrobacter, koji doprinose otpornosti biofilmova, kao i antagonizam između bakterija iz zemljišta roda Marisediminicola i autohtonih Pseudomonas. Dobijeni rezultati naglašavaju potrebu za specifično prilagođenim higijenskim protokolima usmerenim na zone sa visokom vlagom i mobilnu opremu, kao i značaj narušavanja mikrobnih interakcija u cilju efikasne kontrole formiranja biofilmova.

Disclosure statement: No potential conflict of interest was reported by the authors.

References

Abdallah, M., Benoliel, C., Drider, D., Dhulster, P., & Chihib, N. E. (2014). Biofilm formation and persistence on abiotic surfaces in the context of food and medical environments. *Archives of Microbiology*, 196(7), 453–472.

Alonso, V. P. P, Furtado, M. M., Iwase, C. H. T., Brondi-Mendes, J. Z., &Nascimento, M. D. S. (2024). Microbial resistance to sanitizers in the food industry: review. *Critical Reviews in Food Science and Nutrition*, 64(3), 654–669.

Barberán, A., Ramirez, K. S., Leff, J. W., & Bradford, M. A. (2014). Why are some microbes more ubiquitous than others? Predicting the habitat breadth of soil bacteria. *Ecology Letters,* 17, 794–802.

Barcenilla, C., Cobo-Díaz, J.F., Puente A., Valentino V., De Filippis F., Ercolini D., Carlino N., Pinto F., Segata N., Prieto M., López M., Alvarez-Ordóñez A. (2024). In-depth characterization of food and environmental microbiomes across different meat processing plants. *Microbiome* 12, 199.

Bokulich, N. A., Lewis, Z. T., Boundy-Mills, K., & Mills, D.A. (2016). A new perspective on microbial landscapes within food production. *Current Opinion in Biotechnology*, 37, 182–189.

Bridier A, Sanchez-Vizuete P, Guilbaud M, Piard JC, Naïtali M, Briandet R. (2015). Biofilm-associated persistence of food-borne pathogens. *Food Microbiology,* 45(Part B), 167–178.

Carpentier, B., & Cerf, O. (2011). Persistence of *Listeria monocytogenes* in food industry equipment and premises. *International Journal of Food Microbiology*, 145(1), 1–8.

Coyte, K. Z., Schluter, J., & Foster, K. R. (2015). The ecology of the microbiome: Networks, competition, and stability. *Science,* 350(6261), 663–666.

De Filippis, F., Parente, E., & Ercolini, D. (2017). Metagenomics insights into food fermentations. *Microbial Biotechnology*, 10(1), 91–102.

Edgar, R. C. (2010). Search and clustering orders of magnitude faster than BLAST. *Bioinformatics*, 26, 2460–2461.

Elafify, M, Liao, X, Feng, J, Ahn, J, Ding, T. (2024). Biofilm formation in food industries: Challenges and control strategies for food safety. *Food Research International*, 190, 114650.

Fagerlund A., Langsrud S., Møretrø T. (2021). Microbial diversity and ecology of biofilms in food industry environments associated with Listeria monocytogenes persistence. *Current Opinion in Food Science*, 37, 171–178.

Faust, K., & Raes J. (2016). CoNet app: inference of biological association networks using Cytoscape. *F1000Res.* 5, 1519.

Giaouris, E., Heir, E., Hébraud, M., et al. (2014). Attachment and biofilm formation by foodborne bacteria in meat processing environments: causes, implications, role of bacterial interactions and control by alternative novel methods. *Meat Science,* 97(3), 298–309.

Magoč, T. & Salzberg, S. L. (2011). FLASH: fast length adjustment of short reads to improve genome assemblies. *Bioinformatics*, 27(21), 2957–2963.

Nikolaev, Y., Yushina, Y., Mardanov, A., Gruzdev, E., Tikhonova, E., El-Registan, G., Beletskiy, A., Semenova, A., Zaiko, E., Bataeva, D., Polishchuk, E. (2022). Microbial Biofilms at Meat-Processing Plant as Possible Places of Bacteria Survival. *Microorganisms*, 10(8), 1583.

Rognes, T., Flouri, T., Nichols, B., Quince, C. & Mahé, F. (2016). VSEARCH: a versatile open-source tool for metagenomics. *PeerJ*, 4, e2584.

Shannon, P., Markiel, A., Ozier, O., Baliga, N. S., Wang, J. T., Ramage, D., Amin, N., Schwikowski, B., & Ideker, T. (2003). Cytoscape: a software environment for integrated models of biomolecular interaction networks. *Genome Research,* 11, 2498–2504.

Silva, A., Silva, V., Gomes, J. P., et al. (2024). *Listeria monocytogenes* from food products and food associated environments: Antimicrobial resistance, genetic clustering and biofilm insights. *Antibiotics (Basel)*, 13(5), 447.

Simões, M., Simões, L. C., & Vieira, M. J. (2010). A review of current and emergent biofilm control strategies. *LWT - Food Science and Technology*, 43(4), 573–583.

Smirnova, T. A., Didenko, L. V., Tiganova, I. G., Andreevskaya, S. G., Alekseeva, N. V., Stepanova, T. V., & Romanova, Yu. M. (2010). Study of the structures of biofilms formed by *Salmonella* Typhimurium bacteria on abiotic surfaces by the methods of light and transmission electron microscopy. *Applied Biochemistry and Microbiology*, 46 (7), 706–711.

Sofos, J. N. (2008). Challenges to meat safety in the 21st century. *Meat Science*, 78(1–2), 3–13.

Stellato, G., La Storia, A., De Filippis, F., Borriello, G., Villani, F., & Ercolini, D. (2016). Overlap of Spoilage-Associated Microbiota between Meat and the Meat Processing Environment in Small-Scale and Large-Scale Retail Distributions. *Applied and Environmental Microbiology - ASM Journals*, 82(13), 4045–4054.

Walia K, Argüello H, Lynch H, et al. (2017). The efficacy of different cleaning and disinfection procedures to reduce *Salmonella* and Enterobacteriaceae in the lairage environment of a pig abattoir. *International Journal of Food Microbiology.,* 246, 64–71.

Authors info

Yulia Yushina, https://orcid.org/0000-0001-9265-5511
Elena Zaiko, https://orcid.org/0000-0002-5048-9321
Andrey Mardanov, https://orcid.org/0000-0002-8245-8757
Yury Nikolaev, https://orcid.org/0000-0002-2264-6764
Evgeniy Gruzdev, https://orcid.org/0000-0001-7958-8457
Ekaterina Tikhonova, https://orcid.org/0000-0002-5306-9322
Anastasia Semenova, https://orcid.org/0000-0002-4372-6448
Anzhelika Makhova, https://orcid.org/0000-0002-2508-2888
Maria Grudistova, https://orcid.org/0000-0002-8581-2379
Dagmara Bataeva, https://orcid.org/0000-0002-1374-2746

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.5.056:636.295
COBISS.SR-ID: 176262665
https://doi.org/10.18485/meattech.2025.66.2.2

Original scientific paper

A non-destructive method for evaluating camel meat during freeze-thaw cycles using bio-impedance analysis

Saliha Lakehal[1*] and *Brahim Lakehal*[2]

[1] *University of Batna 1, Institute of Veterinary Science and Agricultural Sciences, ESPA laboratory, Department of Veterinary Sciences, Batna, Algeria*
[2] *University of Batna 2, Institute of Hygiene and Industrial Security, Batna, Algeria*

A R T I C L E I N F O

Keywords:
Electrical impedance
Camel meat
Meat quality
Freeze-thaw cycles

A B S T R A C T

Camel meat has a high nutrient profile and is susceptible to deterioration when stored, primarily due to temperature fluctuation in the cold chain. In this study, we utilized electrical impedance to monitor the quality of camel meat following repeated freeze-thaw cycles (tow, four and six). Meat properties monitored were colour, pH, and electrical conductivity. Conductivity and pH of camel meat increased, and all colour indices (L*), (a*), and (b*) also underwent significant changes when the meat was subjected to freeze-thaw cycles . The results suggested a reduction in electrical impedance with each freeze-thaw cycle, indicating increased cell membrane permeability and ice crystal-associated structural damage. This study recognizes the potential of electrical impedance to define camel meat quality as a method of further interpreting quality faults associated with freeze-thaw treatment.

1. Introduction

Camel meat, although less common than chicken or beef, is a source of protein. It is distinguished by its mild taste and high nutritional value, including low cholesterol and fat content (*Kadim et al.*, 2022; *Baba et al.*, 2021). Moreover, it contains minerals, essential amino acids, vitamins, biologically active substances, and essential fatty acids such as omega-3 (*Mohammed et al.*, 2020). Camel meat consists of 76–78% water, 19–22% protein, 2.9–3.2% fat, and 1.2% ash (*Abdelhadi et al.*, 2012). It is traditionally used to treat several diseases, for example respiratory diseases, hypertension, cardiovascular diseases, and pneumonia (*Si et al.*, 2022).

In Algeria, where camel meat is very well-regarded for its nutritional composition, this meat is largely produced in the country's southern regions, whereas consumption is dispersed across the country (*Djenane et al.*, 2020). However, like any other meat, it is highly prone to spoilage during storage and, hence, needs the use of proper preservation methods to ensure its shelf life (*Lakehal et al.,* 2021). Freezing remains one of the most extensive technologies in the meat industry to maintain quality and acts by slowing down microbial growth and minimizing nutrient losses (*Daszkiewicz et al.*, 2018; *Medić et al.*, 2018). On the other hand, during transportation, storage and delivery, camel meat is affected by repeated, fluctuating temperature changes.

Changes in storage temperature have a significant effect on meat's physicochemical properties, which compromise its overall quality (*Rahman et al.*, 2014; *Cheng et al.* 2019; Qi et al., 2012). Monitoring and detecting such changes are, therefore, necessary to maintain product safety and consumer trust. One monitoring means is electrical impedance, now becoming a powerful means for evaluating the quality of biological tissues like meat (*Caicedo-Eraso et al.*, 2020; *Zhao et al.*, 2017). The technique can

***Corresponding author:** Saliha Lakehal, *saliha.lakehal@univ-batna.dz*

Paper received: Jun 10th 2025. Paper accepted July 3rd 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

quantify variations in electrical properties resulting from physiological changes in meat during freezing and thawing (*Fuentes et al.,* 2013).

Previous studies have established that electrical impedance is capable of differentiating fresh from thawed beef, chicken, pork, and fish meats (*Bai et al.*, 2018; *Wei et al.*, 2016; *Dell'Osa et al.*, 2021; *Chen et al.*, 2017). There are limited studies on camel meat, however. This study aimed to fill this gap by introducing a new method for detecting camel meat freeze-thaw cycles through bioimpedance measurement. Through the investigation of electrical impedance change, this research aimed to provide the first fundamental data for considering bioimpedance as a tool for camel meat quality monitoring during storage, thus improving camel meat cold chain management.

2. Materials and Methods

Eleven camel (*Camelus dromedarius*) meat samples were obtained from an Algerian municipal slaughterhouse in El Ouadi. Sections of biceps femoris were selected 48 hours post-mortem. Each section was cut into pieces of approximately equal weight, individually vacuum-packed, and stored frozen at −20 °C in a freezer (CRF-NT64GF40, Condor, Algeria). The freezing temperature was monitored using an infrared thermometer (TIA 101, China). The meat samples were then subjected to a series of freezing and thawing cycles (two, four and six) at controlled temperatures to mimic the temperature fluctuations of the cold chain. In each cycle, the meat samples were frozen for one week at −20 °C and thawed at a refrigerator temperature of 4 °C. A group of meat samples was also used as a control group, i.e., they were not subjected to freeze-thawing and were measured directly in the fresh state.

2.1 pH measurement

The pH of each meat sample was measured in a mixture resulting from homogenizing 10 g of meat in 90 mL of distilled water (*Zhu et al.*, 2019). The pH meter (INOLAB) used was previously calibrated before inserting the electrode into the homogenate .

2.2 Electrical conductivity

Electrical conductivity was assessed using a conductivity meter (WTW Lab 540). Briefly, 9 g of each meat sample was homogenized with 90 mL of distilled water and stirred for 20 min. Electrical conductivity levels were then measured.

2.3 Colour

Before the colorimetric analysis, camel meat samples, approximatively 1.5 cm thick were prepared. images were captured using a computer vision system consisting of a custom-designed enclosure equipped with two adjustable lamps positioned 50 cm above the samples at a 45° angle to achieve consistent illumination. A digital camera (Canon DS126621, China) was fixed vertically at a distance of 30 cm from the sample surface. To reduce external light interference, the interior of the enclosure was covered with light-absorbing black fabric (*Lakehal and Lakehal*, 2023). Digital analysis of colourimetric parameters, including Lab, HSI, and RGB, was performed using Adobe Photoshop CS3 software.

2.4 Impedance measurement

The electrical impedance measurement was performed using a portable LCR meter (LCR meter BR 2832, China) equipped with a two-needle system, each needle having two Kelvin electrodes. The device utilizes colour-coded cables with gold-plated contacts and reinforced protection. The needles, with dimensions of 10 mm in length, 2.5 mm in width, and 2 mm in height, were placed on the surface of the meat sample to complete the circuit. Measurements were taken at four different frequencies: 10 kHz, 1 kHz, 120 Hz and 100 Hz at four different regions of the meat. For each meat sample, both needles were inserted parallel to the direction of the muscle fibres to a depth of 13 mm, with a 2 cm distance between them. All measurements were conducted at a temperature of 4°C ± 1°C and repeated four times at each frequency, both on fresh meat and after each freeze-thaw cycle.

2.5 Statistical analysis

The data were statistically analysed using analysis of variance (ANOVA), which was done with IBM SPSS Statistics version 26. The means were compared with Tukey's post-hoc test. A difference was regarded significant if the probability was $p < 0.05$.

3. Results and Discussion

3.1 pH

The pH of camel meat remained almost constant after the second freeze-thaw cycle (Table 1). However, it significantly increased to 5.41±07 after the fourth cycle, compared to fresh meat (pH 5.16). By the end of the sixth cycle, the pH measured was 5.54±04. This result corroborates the findings of *Qi et al.* (2012), who observed an increase in pH after five freeze-thaw cycles of beef ($p<0.05$). This increase in pH after a series of cycles, measured in the current study, could be linked to the release of free amino acids and dipeptides resulting from protein hydrolysis (*Hou et al*., 2020). Additionally, *Ali et al.* (2015) reported a significant reduction in pH after the sixth cycle. In our previous research (*Lakehal et al*. 2023), we concluded that the variation in meat pH relative to its initial value was affected by oxidation rates, microbial growth, and exudate. This phenomenon may result from the loss of minerals and small protein compounds in the form of exudates, leading to an ionic imbalance in the meat (*Baygar and Alparslan*, 2015).

3.2 Electrical conductivity

Table 1, which shows the influence of freeze-thaw cycles on electrical conductivity, demonstrates a progressive increase with each cycle, with values rising from 1426 ± 23 to 1993 ± 22. It is important to note that there was no significant difference between fresh meat and the second cycles (C2). However, starting from cycle 4 (C4), a notable difference emerges, marked by a sharp increase in conductivity, reaching 1893, then 1993 in cycle 4. Indeed, each cycle causes cell membrane degradation, leading to the release of intracellular fluids, which increases conductivity (*Leng et al*. 2020). Thus, this increase reflects the deterioration of meat quality. Electrical conductivity is commonly used to assess the freshness of frozen meat, serving as a reliable indicator of product quality (*Leng et al.*, 2024). Electrical conductivity is a useful parameter for assessing the impact of freezing on meat (*Lakehal et al*. 2021).

3.3 Colour

The evolution of the colour parameters is presented according to the number of freeze-thaw cycles (Table 1). From the first thawing cycle, the lightness of the fresh meat was significantly lower than that of the meat that underwent the freeze-thaw process. The increase in the lightness of red meat after freeze-thaw cycles was observed by *Xia et al*. (2009) in a study on pork. This increase was attributed to the greater light reflection caused by an increased amount of free water, a consequence of heightened protein denaturation (*Holman et al*., 2017; *Seong et al*. 2017), or by an increase in intramuscular fat content (*Pinheiro et al*. 2019).

The redness (a*) values of the meat revealed a decrease following the first cycle, but a significant difference ($P < 0.05$) was only detected in the last freeze-thaw cycle (C6) compared to the others (Table 1). These results are similar to those observed by *Qi et al*. (2012), who also noted a decreasing trend in redness with an increasing number of freeze-thaw cycles in lamb meat. The colour changes in the meat during the freeze-thaw cycles can be attributed to the reduction of myoglobin in its chemical form (*Shang et al*. 2020). Indeed, the free radicals generated during lipid oxidation can alter the structure of the haeme group and trigger myoglobin oxidation, leading to a loss of meat colour, which manifests as a decrease in redness intensity. (*Xia et al*., 2009; *Utrera et al.* 2014).

Table1. Physicochemical properties of camel meat subjected to multiple freeze-thaw cycles

Physico-chemical parameters	C0	C2	C4	C6
pH	5.165±0.01^{c}	5.2375±0.06^{c}	5.4175±0.07^{b}	5.545±0.04^{a}
Electrical conductivity (µS/cm)	1426± 23.3^{b}	1504.5± 35.32^{b}	1893± 45.32^{a}	1993± 21.59^{a}
L* value (lightness)	31.14±3.21^{b}	34.28± 4.23 ^{a}	33.85±3.07^{a}	34±3.02^{a}
a* value (redness)	13±1.73^{a}	10.28±0.98^{a}	10.14±1.56^{ab}	9.42±2.07^{b}
b* value (yellowness)	8.71±2.98^{b}	10.42±1.85^{ab}	11.71±1.45^{ab}	14.14±1.52^{a}

Legend: C0: fresh meat; C2: two freeze–thaw cycles; C4: four freeze–thaw cycles, C6: six freeze–thaw cycles. Data are given as mean values ± standard deviation. $^{a,\,b}$ different letters show a statistically significant difference ($p<0.05$).

The yellowness (b*) values of camel meat showed an increase from the first freeze-thaw cycle, reaching their maximum at the sixth cycle (Table 1). This evolution could be attributed to the denaturation of myoglobin, the accumulation of metmyoglobin, and an increase in lipid oxidation (*Rahman et al.*, 2014; *Pinheiro et al.,* 2019). In contrast, *Jeong et al.* (2011) observed a decrease in the b* value after two freeze-thaw cycles, where the meat was stored at −65°C for 12 hours, followed by thawing at 4 °C for 12 hours.

3.4 Evolution of meat impedance during freeze-thaw cycles

The meat impedance measured in on four different regions of the meat sample and at various frequencies are presented in Figure 1. In the fresh muscle, the impedance measured in region 4 was the highest (570.9 ± 1.20 Ω), while region 3 showed the lowest impedance (501.1 ± 0.80 Ω) among the four initial measurement locations. These observed variations likely reflect differences in tissue composition or materials measured, particularly regarding the amount of lipids present (*Fan et al.,* 2021; *Li et al.,* 2019). As the excitation frequency increased, the impedance of camel muscle decreased. This was probably due to the high capacitive reactance of the cell membrane at low frequency, where the current flows mainly through the extracellular fluid *(Dell'Osa et al.*, 2021). However, at higher frequencies, the capacitive reactance of the cell membrane decreases, allowing the current to pass through the intracellular fluid as well (*Zavadlav et al.,* 2016).

Impedance values gradually decreased with the repeating of freeze-thaw cycles (Figure 1), suggesting that this procedure enhanced the permeability of cell membranes (*Leng et al.*, 2024). Major structural and chemical changes occur in frozen muscle meat as a result of primary and secondary nucleation and crystal formation during freezing-thawing (*Dang et al.*, 2021). Significant osmotic pressure across the sarcolemma

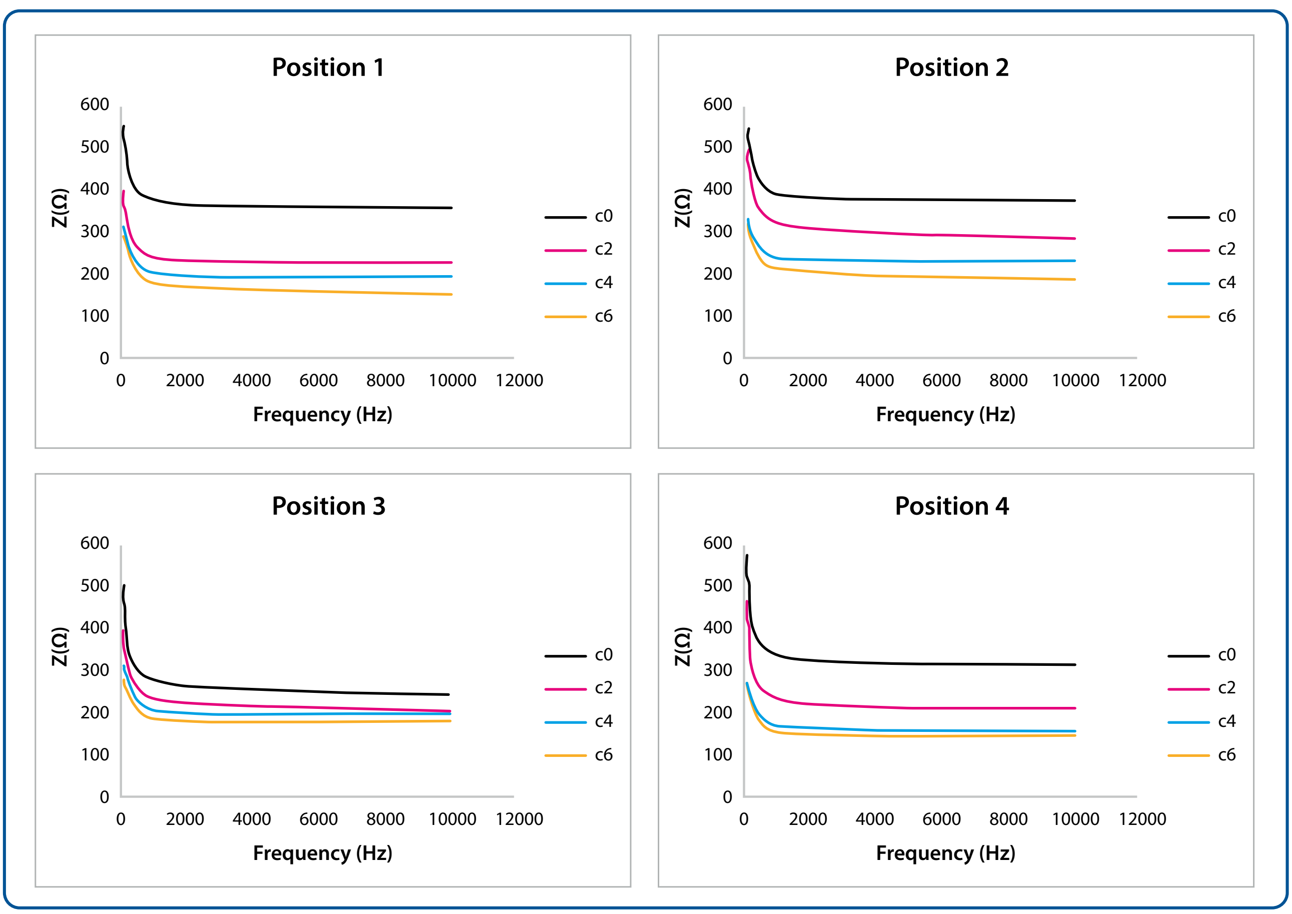

Figure 1. Changes of impedance (Z, Ω) of camel meat at various frequencies and different positions subjected to multiple freeze-thaw cycles.

Legend: C0: fresh meat; C2: two freeze–thaw cycles; C4: four freeze–thaw cycles, C6: six freeze–thaw cycles. Data are given as mean values ± standard deviation is created when ice crystals develop, which increases the deformation of muscle microstructures and causes membrane rupture that allows cell contents to leak out (*Zhang et al.*, 2023). Enzymatic activity and oxidation are both accelerated by this process, which can have an impact on several aspects of meat quality.

4. Conclusion

The present study showed that electrical impedance is an effective method of monitoring the quality of camel meat during freeze-thaw processes . Impedances became lower with an increasing number of freeze-thaw cycles. This was presumed to be a consequence of a breakdown of the cell membrane induced by formation of ice crystals. The findings indicate that electrical impedance is a non-invasive method for detecting certain aspects of quality change in camel meat subjected to multiple freeze-thaw cycles.

Having realized the influence of freezing and thawing cycles on camel meat, electrical impedance spectroscopy could be a valuable tool in monitoring the quality of meat in industrial scale.

Nedestruktivna metoda za procenu kvaliteta mesa kamile tokom ciklusa zamrzavanja i odtapanja korišćenjem analize bioimpedanse

Saliha Lakehal i Brahim Lakehal

INFORMACIJE O RADU

Ključne reči:
Električna impedansa
Meso kamile
Kvalitet mesa
Ciklusi zamrzavanja i odmrzavanja

APSTRAKT

Meso kamile karakteriše visok nutritivni kvalitet, ali je podložno degradaciji tokom skladištenja, pre svega usled temperaturnih fluktuacija u hladnom lancu. U ovoj studiji korišćena je električna impedansa za praćenje kvaliteta mesa kamile nakon ponovljenih ciklusa zamrzavanja i odmrzavanja (dva, četiri i šest ciklusa). Praćene su sledeće osobine mesa: boja, pH vrednost i električna provodljivost. Utvrđeno je da se pH vrednost i električna provodljivost mesa kamile povećavaju, dok su svi parametri boje (L*, a*, b*) značajno promenjeni nakon izlaganja ciklusima zamrzavanja i odmrzavanja. Rezultati su ukazali na smanjenje električne impedanse sa svakim dodatnim ciklusom, što sugeriše povećanu propustljivost ćelijskih membrana i strukturna oštećenja izazvana formiranjem kristala leda. Ova studija ukazuje na potencijal primene električne impedanse kao metode za određivanje kvaliteta mesa kamile i bolju interpretaciju oštećenja kvaliteta povezanih sa tretmanima zamrzavanja i odmrzavanja.

Disclosure statement: No potential conflict of interest was reported by authors.

References

Abdelhadi , O. M. A., Babiker, S. A., Picard, B., Jurie, C., Jailler, R., Hocquette, J. F., & Faye, B. (2012). Effect of season on contractile and metabolic properties of desert camel muscle (*Camelus dromedarius*). *Meat Science*, 90(1), 139–144. https://doi.org.10.1016/j.meatsci.2011.06.012

Ali, S., Zhang, W., Rajput, N., Khan, M. A., Li, C. B., & Zhou, G. H. (2015). Effect of multiple freeze–thaw cycles on the quality of chicken breast meat. Food Chemistry, 173, 808–814. https://doi.org. 10.1016/j.foodchem.2014.09.095

Baba, W. N., Rasool, N., Selvamuthukumara, M., & Maqsood, S. (2021). A review on nutritional composition, health benefits, and technological interventions for improving consumer acceptability of camel meat: an ethnic food of Middle East. *Journal of Ethnic Foods*, 8, 1–13. https://doi.org.10.1186/s42779-021-00089-1

Bai, X., Hou, J., Wang, L., Wang, M., Wang, X., Wu, C., … & Sun, Y. (2018). Electrical impedance analysis of pork tissues during storage. *Journal of Food Measurement and Characterization*, 12, 164–172. https://doi.org. 10.1016/j.meatsci.2019.108014

Baygar, T., & Alparslan, Y. (2015). Effects of multiple freezing (− 18±2° C) and microwave thawing cycles on the quality changes of sea bass (Dicentrarchus labrax). *Journal of Food Science and Technology*, 52, 3458–3465. https://doi.org. 10.1007/s13197-014-1373-z

Caicedo-Eraso, J. C., Díaz-Arango, F. O., & Osorio-Alturo, A. (2020). Electrical impedance spectroscopy applied to quality control in the food industry. *Ciencia y Tecnología Agropecuaria*, 21(1), 100–119. https://doi.org.10.1016/j.meatsci.2012.06.009

Chen, T. H., Zhu, Y. P., Han, M. Y., Wang, P., Wei, R., Xu, X. L., & Zhou, G. H. (2017). Classification of chicken muscle with different freeze–thaw cycles using impedance and physicochemical properties. *Journal of Food Engineering*, 196, 94–100. https://doi.org.10.1016/j.jfoodeng.2016.10.003

Cheng, S., Wang, X., Li, R., Yang, H., Wang, H., Wang, H., & Tan, M. (2019). Influence of multiple freeze-thaw cycles on quality characteristics of beef semimembranous muscle: With emphasis on water status and distribution by LF-NMR and MRI. *Meat Science*, 147, 44–52. https://doi.org.10.1016/j.meatsci.2018.08.020

Daszkiewicz, T., Purwin, C., Kubiak, D., Fijałkowska, M., Kozłowska, E., & Antoszkiewicz, Z. (2018). Changes in the quality of meat (Longissimus thoracis et lumborum) from Kamieniec lambs during long-term freezer storage. *Animal Science Journal*, 89(9), 1323–1330. https://doi.org.10.1111/asj.13037

Dell'Osa, A. H., Battacone, G., Pulina, G., Fois, A., Tocco, F., Loviselli, A., … & Velluzzi, F. (2021). Electrical impedance to easily discover undeclared freeze-thaw cycles in slaughtered bovine meat. *Journal of Electrical Bioimpedance*, 12(1), 3. https://doi.org.10.2478/joeb-2021-0002.

Djenane, D., Aboudaou, M., Djenane, F., García-Gonzalo, D., & Pagán, R. (2020). Improvement of the shelf-life status of modified atmosphere packaged camel meat using nisin and *Olea europaea* subsp. laperrinei leaf extract. *Foods*, 9(9), 1336. https://doi.org.10.3390/foods9091336.

Fan, X., Lin, X., Wu, C., Zhang, N., Cheng, Q., Qi, H., … & Dong, X. (2021). Estimating freshness of ice storage rainbow trout using bioelectrical impedance analysis. *Food Science & Nutrition*, 9(1), 154–163. https://doi.org.0.1002/fsn3.1974

Fuentes, A., Masot, R., Fernández-Segovia, I., Ruiz-Rico, M., Alcañiz, M., & Barat, J. M. (2013). Differentiation between fresh and frozen-thawed sea bream (*Sparus aurata*) using impedance spectroscopy techniques. *Innovative Food Science & Emerging Technologies*, 19, 210–217. https://doi.org.10.1016/j.ifset.2013.05.001

Holman, B. W., Coombs, C. E., Morris, S., Kerr, M. J., & Hopkins, D. L. (2017). Effect of long term chilled (up to 5 weeks) then frozen (up to 12 months) storage at two different sub-zero holding temperatures on beef: 1. Meat quality and microbial loads. *Meat Science*, 133, 133–142. https://doi.org.10.1016/j.meatsci.2017.06.015

Hou, Q., Cheng, Y. P., Kang, D. C., Zhang, W. G., & Zhou, G. H. (2020). Quality changes of pork during frozen storage: Comparison of immersion solution freezing and air blast freezing. *International Journal of Food Science and Technology*, 55(1), 109–118. https://doi.org.10.1111/ijfs.14257

Kadim, I. T., Al-Amri, I. S., Alkindi, A. Y., & Haq, Q. M. (2022). Nutritional values and health benefits of dromedary camel meat. *Animal Frontiers*, 12(4), 61–70. https://doi.org.10.1093/af/vfac051.

Lakehal, S., Bennoune, O., & Ayachi, A. (2021). Investigation of the physico-chemical and microstructure changes of beef meat during frozen storage at-23° C. *Meat Technology*, 62(2),121–129. https://doi.org.10.18485/meattech.2021.62.2.5

Lakehal, S., Lakehal, A., Lakehal, S., Bennoune, O., & Ammar, A. (2023). Physicochemical and structural properties of beef meat thawed using various methods. *Revista Científica de la Facultad de Ciencias Veterinarias*, 33, 1–7. https://doi.org.10.52973/rcfcv-e33242

Lakehal, S., & Lakehal, B. (2023). Storage time prediction of frozen meat using artificial neural network modeling with color values. Revista Científica De La Facultad De Ciencias Veterinarias, XXXIII, 2, 1–6. https://doi.org/10.52973/rcfcv-e33268

Leng, Y., Sun, Y., Wang, X., Hou, J., Zhao, X., & Zhang, Y . (2020). Electrical impedance estimation for pork tissues during chilled storage. *Meat Science*, 161, 108014. https://doi.org.10.1016/j.meatsci.2019.108014

Leng, Y., Zhang, C., Gao, Y., & Wang, X. (2024). Bio-impedance measurements for meat quality determination of pork loins under repeated freeze-thaw treatments. *Journal of Food Composition and Analysis*, 125, 105779. https://doi.org.10.1016/j.jfca.2023.105779

Li, S., Li, F., Tang, J., Koral, T., & Jiao, Y. (2019). Influence of composition, temperature, and frequency on dielectric properties of selected saltwater and freshwater fish. International Journal of Food Properties, 22(1), 1920–1934. https://doi.org.10.1080/10942912.2019

Medić, H., Kušec, I. D., Pleadin, J., Kozačinski, L., Njari, B., Hengl, B., & Kušec, G. (2018). The impact of frozen storage duration on physical, chemical and microbiological properties of pork. *Meat Science*, 140, 119–127. https://doi.org. 10.1016/j.meatsci.2018.03.006

Mohammed, H. H. H., Jin, G., Ma, M., Khalifa, I., Shukat, R., Elkhedir, A. E., Zeng, Q & Noman, A. E. (2020). Comparative characterization of proximate nutritional compositions, microbial quality and safety of camel meat in relation to mutton, beef, and chicken. *LWT*, 118, 108714. https://doi.org/10.1016/j.lwt.2019.108714

Pinheiro, R. S. B., Francisco, C. L., Lino, D. M., & Borba, H. (2019). Meat quality of Santa Inês lamb chilled-then-frozen storage up to 12 months. *Meat Science*, 148, 72–78. https://doi.org. 10.1016/j.meatsci.2018.09.017

Qi, J., Li, C., Chen, Y., Gao, F., Xu, X., & Zhou, G. (2012). Changes in meat quality of ovine longissimus dorsi muscle in response to repeated freeze and thaw. *Meat Science*, 92(4), 619–626. https://doi.org/10.1016/j.meatsci.2012.06.009

Rahman, M. H., Hossain, M. M., Rahman, S. M. E., Hashem, M. A., & Oh, D. H. (2014). Effect of repeated freeze-thaw cycles on beef quality and safety. *Korean Journal for Food Science of Animal Resources*, 34(4), 482. https://doi.org.10.5851/kosfa.2014.34.4.482

Seong, P. N., Seo, H. W., Kim, J. H., Kang, G. H., Cho, S. H., Chae, H. S., … & Van Ba, H. (2017). Assessment of frozen storage duration effect on quality characteristics of various horse muscles. *Asian-Australasian Journal of Animal Sciences*, 30(12), 1756. https://doi.org.10.5713/ajas.17.0039

Shang, X., Yan, X., Li, Q., Liu, Z., & Teng, A. (2020). Effect of multiple freeze-thaw cycles on myoglobin and lipid oxidations of grass carp (*Ctenopharyngodon idella*) surimi with different pork back fat content. *Food Science of Animal Resources*, 40(6), 969. https://doi.org.10.5851/kosfa.2020.e67

Si, R., Na, Q., Wu, D., Wu, X., Ming, L., & Ji, R. (2022). Effects of age and muscle type on the chemical composition and quality characteristics of Bactrian camel (*Camelus bactrianus*) meat. *Foods*, 11(7), 1021. https://doi.org.10.3390/foods11071021

Utrera, M., Parra, V., & Estévez, M. (2014). Protein oxidation during frozen storage and subsequent processing of different beef muscles. *Meat Science*, 96(2), 812–820. https://doi.org. 10.1016/j.meatsci.2013.09.006

Wei, R., Wang, P., Han, M., Chen, T., Xu, X., & Zhou, G. (2016). Effect of freezing on electrical properties and quality of thawed chicken breast meat. *Asian-Australasian Journal of Animal Sciences*, 30(4), 569. https://doi.org.10.5713/ajas.16.0435

Xia, X., Kong, B., Liu, Q., & Liu, J. (2009). Physicochemical change and protein oxidation in porcine longissimus dorsi as influenced by different freeze–thaw cycles. *Meat Science*, 83(2), 239–245. https://doi.org.10.1016/j.meatsci.2009.05.003

Zavadlav, S., Janči, T., Lacković, I., Karlović, S., Rogulj, I., & Vidaček, S. (2016). Assessment of storage shelf life of European squid (cephalopod: Loliginidae, *Loligo vulgaris*) by bioelectrical impedance measurements. *Journal of Food Engineering*, 184, 44–52. https://doi.org.10.1016/j.jfoodeng.2016.03.022

Zhao, X., Zhuang, H., Yoon, S. C., Dong, Y., Wang, W., & Zhao, W. (2017). Electrical impedance spectroscopy for quality assessment of meat and fish: A review on basic principles, measurement methods, and recent advances. *Journal of Food Quality*, 2017(1), 6370739. https://doi.org.10.1155/2017/6370739

Zhu, M. M., Peng, Z. Y., Lu, S., He, H. J., Kang, Z. L., Ma, H. J., … & Wang, Z. R. (2019). Physicochemical properties and protein denaturation of pork longissimus dorsi muscle subjected to six microwave-based thawing methods. *Foods*, 9(1), 26. https://doi.org.10.3390/foods9010026

Authors info

Saliha Lakehal, https://orcid.org/0000-0002-3721-0920
Brahim Lakehal, https://orcid.org/0000-0003-0020-2377

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.522.053:636.2
COBISS.SR-ID: 176252425
https://doi.org/10.18485/meattech.2025.66.2.3

Original scientific paper

The effects of dry ageing period and subsequent culinary methods on the oral processing parameters of beef

Ivana D. Tomašević[1], *Igor Tomašević*[2*], *Nedim Turković*[2], *Đorđević Vesna*[1], *Aristide Maggiolino*[3], *Volker Heinz*[4] *and Ilija Djekić*[2]

[1] Institute of Meat Hygiene and Technology, Kaćanskog 13, Belgrade, 11040, Serbia
[2] University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, Serbia
[3] Università degli studi di Bari Aldo Moro, Piazza Umberto I, 1, 70121 Bari, Italy
[4] German Institute of Food Technologies (DIL), Professor-von-Klitzing-Straße 7, 49610 Quackenbruck, Germany

ARTICLE INFO

Keywords:
Grill
Sous-vide
Particle size
Chewing rate
Eating rate

ABSTRACT

This study investigates the impact of dry aging duration and subsequent cooking methods on the oral processing parameters of beef. Dry aging is a traditional technique that enhances beef by controlled environmental and enzymatic changes. Two dry aging periods (21 and 42 days) were combined with two cooking methods (grilling and sous vide). A sensory panel evaluated the beef samples, assessing parameters such as particle size, chewing rate, and eating rate. The breakdown of food structures during oral processing influences the sensory perception of texture, flavor, and taste, thereby determining a food's overall acceptability and palatability. Results showed that shorter dry aging duration and cooking method significantly affected only some of the oral processing parameters. Shorter dry aging period (21 days) generally led to increased total number and share of smaller particle sizes. In these terms, sous vide cooking resulted in improved oral processing profiles compared to grilling. The longer period (42 days) of dry ageing was without an effect on beef oral processing, irrespective of culinary method applied. These findings contribute to a better understanding of how dry aging and cooking methods influence the sensory experience of beef, potentially aiding in the development of products tailored to consumer preferences.

1. Introduction

Dry aging is a traditional method that enhances beef by exposing it to controlled environmental and enzymatic changes. This technique improves tenderness, deepens flavor, and imparts distinctive texture characteristics. It involves storing large beef cuts, such as ribeye or strip loin, in a tightly regulated setting—typically maintained at low temperatures (2–4 °C), around 85% humidity, and with consistent airflow (*Khan Muhammad et al*., 2016). Over a period of several weeks to months, natural enzymes in the meat, like calpains and cathepsins, break down complex proteins into smaller peptides and amino acids. This enzymatic activity softens the meat and contributes to the development of rich, umami flavours (*O'Quinn et al*., 2018).

The length of the aging period plays a crucial role in determining the final flavor and texture. Generally, longer aging enhances flavour intensity, but the ideal duration depends on factors such as the beef's original quality, the specific aging conditions, and the desired flavor profile (*Cenci-Goga et al.*, 2020). If not carefully monitored, the aging environment—particularly its heat and air circulation—can cause excessive water loss and protein denaturation, leading to a drier texture (*Jadhav et al.*, 2021). Sous vide—meaning "under vacuum"—uses a water bath

***Corresponding author:** Igor Tomasević, *tbigor@agrif.bg.ac.rs*

Paper received: July 9th 2025. Paper accepted September 2nd 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

to cook meat at precisely controlled low temperatures, usually between 50 °C and 85 °C (*Gómez and Beriain*, 2019). This method ensures even heat distribution throughout the meat, minimizing temperature differences and allowing for accurate control of internal temperature and protein denaturation (*Przybylski et al.*, 2021).

Oral processing, a multifaceted and intricate initial stage of digestion, encompasses a series of actions within the oral cavity that prepare food for swallowing and subsequent breakdown in the gastrointestinal tract. This process integrates muscle activity, jaw movements, and tongue movements, all contributing to the transformation of food structure into a bolus suitable for ingestion (*Koç et al.*, 2013). The breakdown of food structures during oral processing directly influences the sensory perception of texture, flavor, and taste, thereby determining a food's overall acceptability and palatability (*Foegeding et al*., 2015). The parameters of oral processing, including chewing rate, bolus formation time, and salivary flow rate, are highly variable and are influenced by an array of factors, such as individual physiology, food properties, and cognitive expectations (*Campbell et al.*, 2017). The way that food undergoes changes in the mouth has a big impact on how we experience its texture, which is a core feature that affects how much we enjoy eating (*Devezeaux De Lavergne et al.*, 2021). The idea of this research was to examine the effects of dry ageing duration (21 and 42 days) and subsequent culinary methods (grill and sous vide) on the oral processing parameters of beef.

2. Materials and Methods

2.1. Meat samples and ageing process

Beef hindlegs (shank and chump off, n = 12) were collected from six beef carcasses on the day of slaughter. Paired legs (left and right) from the same animal were randomly assigned to two ageing treatments: in-bag dry-ageing (21 days) or in-bag dry-ageing (42 days). Briefly, in-bag dry-ageing was carried out in water permeable ageing bags (TUBLIN® 10, 50 μm thick, polyamide mix with water vapor transmission rate 920 g/50 μ/m^2/24 h at 7 °C, 50 % RH, and oxygen transmission rate 660 g/m^2/24 h at 7 °C, 50 % RH, TUB-EX ApS, Denmark) at 2 ± 0.5 °C, 0.5 m.s^{-1} air velocity and relative humidity of 75 ± 5 %. Samples without a period of dry ageing were investigated as control samples.

2.2. Food oral processing panel

The food oral processing (FOP) panel consisted of eight panellists (four male and four female members, normal body mass index 18–25 kg/m^2) with previous experience in similar studies. They all confirmed two main pre-conditions for performing this type of research—good general health condition and no dental problems (*Forde et al*., 2013). Before performing the planned FOP study, one 2-hour training session was organized to get the panellists familiar with the methods to be employed (*Djekic et al.*, 2021). During this initial session, all panellists signed written consent to participate voluntarily.

2.3. Oral processing analysis

The first task for the panellists was to consume cubical meat samples (2×2×2 cm). The chewing process was recorded using a digital video camera that was placed 30 cm from each panellist (*Forde et al*., 2013). Video recordings were analysed using stopwatch. This enabled counting of the number of chews and total oral consumption time (*Hennequin et al.*, 2005). In parallel, panellists raised their hand when swallowing to enable counting of the number of swallows per sample (*Djekic et al.*, 2021). The mass of each sample before consumption was measured using a technical balance of 0.01 g accuracy. Based on recorded data, food oral processing parameters were calculated (*Aguayo-Mendoza et al*., 2019). All panellists received two samples from each aging period and another two samples from each culinary method.

2.4. Particle size analysis

To analyse particle distribution of the boluses, the same types of meat samples (2×2×2 cm) were collected from each panellist at the moment before swallowing by expectorating (*Djekic et al.*, 2021). Upon collection, they were: (i) rinsed using distilled water on filter paper; (ii) spread out on white plates and, (iii) photographed with a digital camera. The spreading of boluses was performed with care to prevent damage of the particles. Image analysis was conducted using ImageJ software. This enabled counting of the number of particles and calculation of their surface area (Rizo et al., 2019). Bolus analysis was performed in two replicates.

2.5. Statistical analysis

Data from the texture profile analysis and food oral processing study were subjected to analysis of variance as follows: one-way ANOVA was employed for the effects of culinary method (C), aging days (D), and for the number of particles. The statistical significance of the factors C and D was determined using the Tukey HSD test ($p < 0.05$). The chi-square test for association was used in analysing possible relationships between particle size fragmentation and aging of meat ($p < 0.05$).

3. Results and Discussion

Understanding the relationship between the structure of solid foods and their oral processing is paramount for enhancing features such as texture and taste (*Guo*, 2021). The number of particles in food oral processing relates to the degree of food breakdown during chewing and bolus formation (*van der Bilt*, 2009). The "ideal" number of particles depends on the desired sensory experience and functionality of the food product and there isn't a universally "better" option between a larger or smaller number of particles (*Tyle et al*., 1990). Our results clearly demonstrated that the sous-vide cooking technique resulted in a notably larger number of particles compared to grilling the meat, both without and with the period of dry ageing (Figure 1). However, no significant differences were found in the number of particles between the samples dry aged for 21 and 42 days, irrespective of the cooking technique applied.

The oral processing of food involves the breakdown of food structure into a bolus suitable for swallowing, with particle size being a key characteristic of this bolus (*Koç et al*., 2013). Food particle size plays a critical role in food oral processing, influencing texture perception, taste, and digestion (*Devezeaux De Lavergne et al*., 2021). Smaller particle sizes within the bolus create a larger surface area for digestive enzymes to act upon. This increased surface area facilitates more efficient enzymatic breakdown of carbohydrates, proteins, and fats *(Ramírez et al*., 2019).

Our results demonstrate that the percentage of small particles in the boluses significantly decreased (by 18.41% in grilled and 11.75% in sous-vide beef samples) after the aging period of 21 days compared to day 0, irrespective of the culinary technique applied. Further ageing for the subsequent three weeks increased the number of small particles by only a relatively insignificant margin of only 2.4% on average for

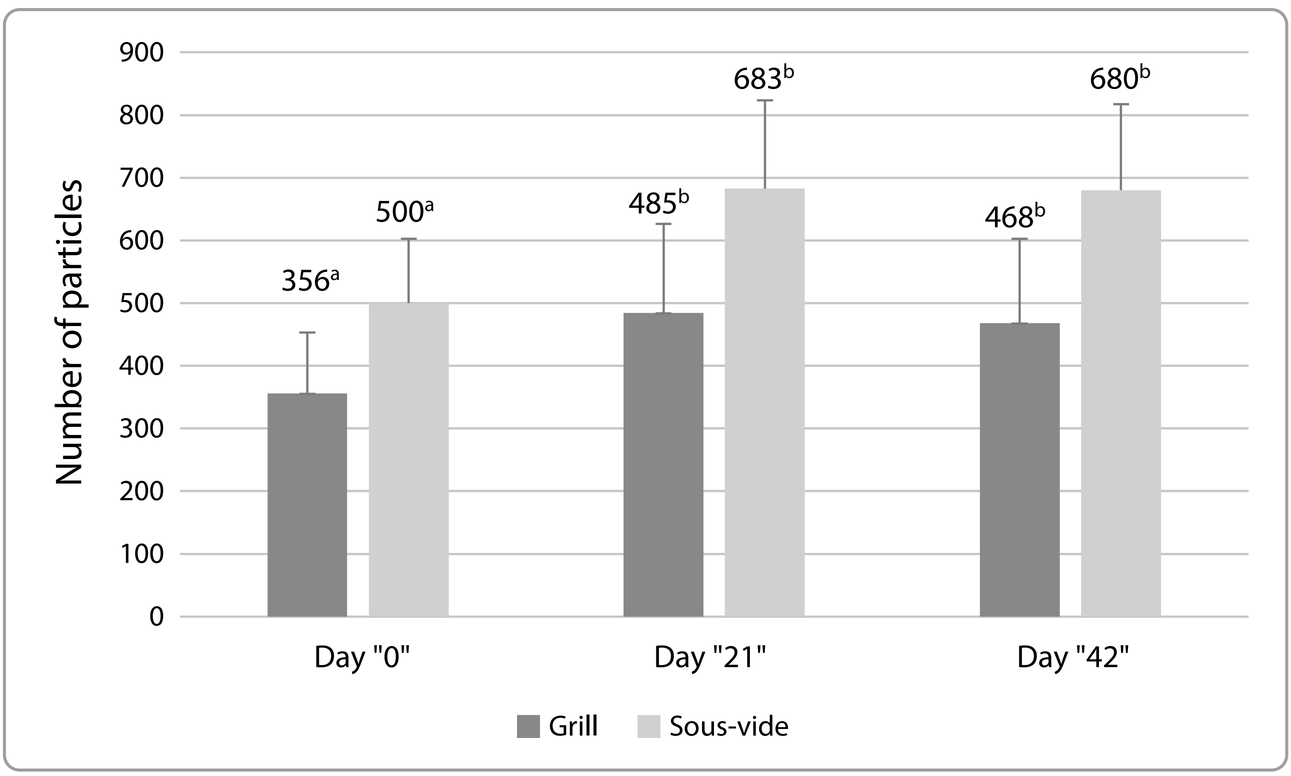

Figure 1. Number of particles of samples obtained in vivo during the aging time for grilled samples (dark grey bars) and sous-vide (light grey bars). Different letters indicate significant differences according to Tukey's test (α=0.05)

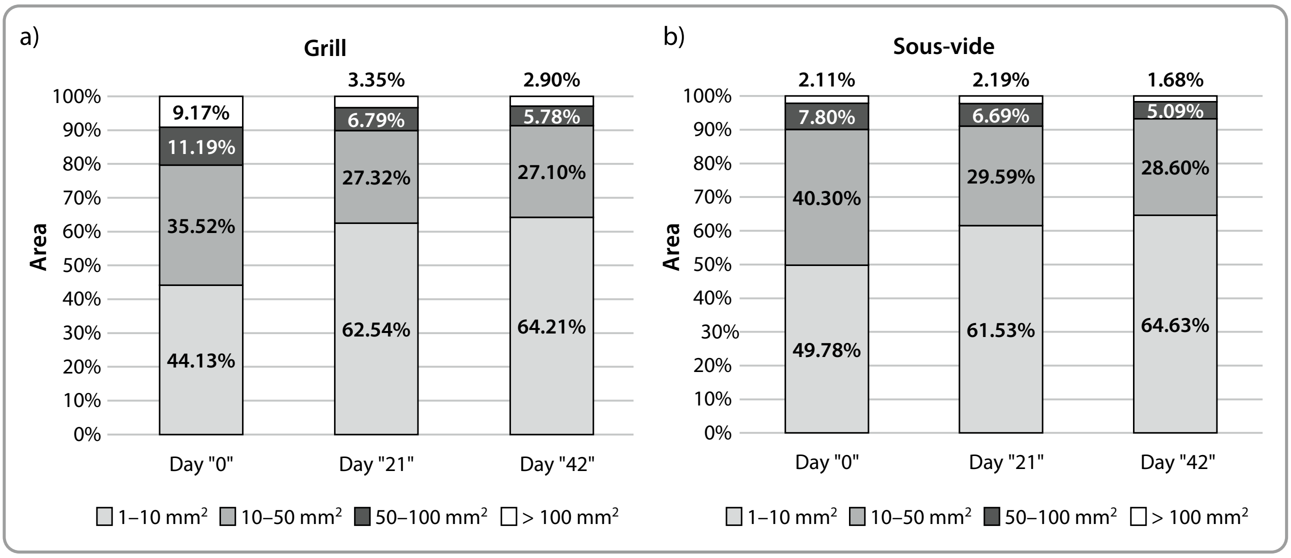

Figure 2. Percentage of area occupied by particles of size: 1–10 mm^2 (light grey), 10–50 mm^2 (dark grey), 50–100 mm^2 (black color), and >100 mm^2 (white color) depending on the aging time

grilled and sous-vide samples. The number of large particles (>100mm^2) for grilled samples was greater than for sous-vide samples by 4-fold on day 0 and continued to remain on the lesser side during the whole period of dry ageing. We already know that a higher number of smaller particles in food samples may result in a smoother texture, while fewer, larger particles could create a coarser or chunkier sensation (*Guo*, 2021).

Eating rate, or how quickly one consumes food, plays a significant role in food oral processing, influencing both sensory perception and overall food intake (Wee et al., 2018). It affects the duration of oral exposure, the number of chews, and the bolus properties at the point of swallowing (*Goh et al*., 2021). Chewing rate specifically measures how quickly someone chews their food and focuses solely on the mastication process, regardless of the amount of food consumed (*Sánchez-Ayala et al*., 2013). Surprisingly, our results did not reveal a statistically significant influence of either dry ageing or the cooking technique applied on any of the food oral processing parameters presented in Table 1. Chewing cycle duration, chewing and rate remained almost a constant throughout the study. Consumption time for one bite and the number of chews were altered by the duration of dry ageing and cooking method, but never to an extent where the differences could be perceived as statistically significant.

Table 1. Food oral processing parameters of beef subjected to grilling and sous-vide cooking methods.

Meat cooking method	Number of chews	Consumption time for one bite [s]	Number of swallows	Chewing cycle duration [s/chew]	Chewing rate [chew/s]	Eating rate [g/s]
Grilling						
Day 0	43.5 ± 12.4	31.2 ± 9.5	2.9 ± 1.3	0.7 ± 0.2	1.4 ± 0.3	0.4 ± 0.1
Day 21	39.0 ± 6.7	26.3 ± 4.7	2.4 ± 1.2	0.7 ± 0.1	1.5 ± 0.1	0.4 ± 0.1
Day 42	39.6 ± 11.7	26.9 ± 6.9	2.4 ± 1.0	0.7 ± 0.1	1.5 ± 0.1	0.4 ± 0.1
Sous-vide						
Day 0	40.9 ± 15.1	31.3 ± 20.5	2.9 ± 1.2	0.7 ± 0.2	1.4 ± 0.3	0.4 ± 0.1
Day 21	53.1 ± 13.5	37.9 ± 8.5	3.4 ± 0.9	0.7 ± 0.1	1.4 ± 0.2	0.3 ± 0.1
Day 42	41.4 ± 23.3	31.2 ± 20.2	2.8 ± 1.1	0.7 ± 0.1	1.4 ± 0.2	0.4 ± 0.2

Testing was performed in two replicates. Data are mean values ± standard deviation.

4. Conclusion

Three weeks of dry ageing resulted in partly improved oral processing of beef, but only in terms of the increased total number of particles and percentage of area occupied by particles of smaller size, which might have an indirect positive effect on meats' texture, digestion and nutrient absorption. In the same terms, sous-vide was not perceived as a favourable culinary method compared to grilling. Dry ageing for a prolonged period of time, i.e., an additional three weeks, had no effect on beef oral processing. However, a limitation of this study was the food oral processing panel that was not tested for reliability, repeatability, or consistency. Also, further research is needed where the difference between dry ageing periods would be smaller, which could lead to more statistically robust and reliable results; instrumental textural analysis is also needed to confirm the sensory findings. The results of these studies could also be compared with the results of sensory evaluation and textural characteristics.

Uticaj perioda suvog zrenja i naknadnih kulinarskih metoda na parametre oralne obrade govedine

Ivana D. Tomasević, Igor Tomašević, Nedim Turković, Djordjević Vesna, Aristide Maggiolino, Volker Heinz i Ilija Djekić

INFORMACIJE O RADU

Ključne reči:
Suvo zrenje
Roštilj
Sous-vide
Veličina čestica
Brzina žvakanja
Brzina jedenja
Oralna obrada
Tekstura go

APSTRAKT

Ova studija istražuje uticaj trajanja suvog zrenja i naknadnih metoda termičke obrade na parametre oralne obrade govedine. Suvo zrenje je tradicionalna tehnika koja poboljšava cenzorni kvalitet govedine u kontrolisanim uslovima usled dejstva enzima. Dva perioda suvog zrenja (21 i 42 dana) kombinovana su sa dve metode termičke obrade (roštilj i suvid). Senzorni panel je ocenio uzorke govedine, procenjujući parametre kao što su veličina čestica, brzina žvakanja i brzina jedenja. Razgradnja strukture hrane tokom oralne obrade utiče na senzornu percepciju teksture, ukusa i arome, čime određuje ukupnu prihvatljivost i ukus mesa. Rezultati su pokazali da kraće trajanje suvog zrenja i metod termičke obrade značajno utiču samo na neke od parametara oralne obrade. Kraći period suvog zrenja (21 dan) generalno je doveo do povećanja ukupnog broja i udela čestica manjih veličina. U tom smislu, su-vid kuvanje je rezultiralo poboljšanim profilima oralne obrade u poređenju sa roštiljanjem. Duži period (42 dana) suvog zrenja nije imao uticaja na oralnu obradu govedine, bez obzira na primenjeni kulinarski metod. Ovi nalazi doprinose boljem razumevanju kako suvo starenje i metode termičke obrade utiču na senzorno iskustvo govedine, što potencijalno pomaže u razvoju proizvoda prilagođenih željama potrošača.

Disclosure statement: No potential conflict of interest was reported by the authors.

References

Aguayo-Mendoza, M. G., Ketel, E. C., van der Linden, E., Forde, C. G., Piqueras-Fiszman, B., & Stieger, M. (2019). Oral processing behavior of drinkable, spoonable and chewable foods is primarily determined by rheological and mechanical food properties. *Food Quality and Preference*, 71, 87–95. https://doi.org/https://doi.org/10.1016/j.foodqual.2018.06.006

Campbell, C. L., Wagoner, T. B., & Foegeding, E. A. (2017). Designing foods for satiety: The roles of food structure and oral processing in satiation and satiety. *Food Structure*, 13, 1–12. https://doi.org/https://doi.org/10.1016/j.foostr.2016.08.002

Cenci-Goga, B. T., Iulietto, M. F., Sechi, P., Borgogni, E., Karama, M., & Grispoldi, L. (2020). New Trends in Meat Packaging. *Microbiology Research*, 11(2), 56–67.

Devezeaux De Lavergne, M., Young, A. K., Engmann, J., & Hartmann, C. (2021). Food Oral Processing—An Industry Perspective [Perspective]. *Frontiers in Nutrition*, *vol.* 8 - 2021. https://doi.org/10.3389/fnut.2021.634410

Djekic, I., Ilic, J., Lorenzo, J. M., & Tomasevic, I. (2021). How do culinary methods affect quality and oral processing characteristics of pork ham? *Journal of Texture Studies*, 52(1), 36–44. https://doi.org/https://doi.org/10.1111/jtxs.12557

Djekic, I., Ilić, J., Chen, J., Djekic, R., Sołowiej, B. G., Vujadinović, D., & Tomasevic, I. (2021). Analysis of Pungency Sensation Effects from an Oral Processing, Sensorial and Emotions Detection Perspective—Case Study with Grilled Pork Meat. *Applied Sciences*, 11(21), 10459.

Foegeding, E. A., Vinyard, C. J., Essick, G., Guest, S., & Campbell, C. (2015). Transforming Structural Breakdown into Sensory Perception of Texture. *Journal of Texture Studies*, 46(3), 152–170. https://doi.org/https://doi.org/10.1111/jtxs.12105

Forde, C. G., van Kuijk, N., Thaler, T., de Graaf, C., & Martin, N. (2013). Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation. *Appetite*, 60, 208–219. https://doi.org/https://doi.org/10.1016/j.appet.2012.09.015

Goh, A. T., Chatonidi, G., Choy, M., Ponnalagu, S., Stieger, M., & Forde, C. G. (2021). Impact of Individual Differences in Eating Rate on Oral Processing, Bolus Properties and Post-Meal Glucose Responses. *Physiology & Behavior*, 238, 113495. https://doi.org/https://doi.org/10.1016/j.physbeh.2021.113495

Gómez, I., C., I. F., & Beriain, M. J. (2019). Physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations. *International Journal of Food Properties*, 22(1), 1693–1708. https://doi.org/10.1080/10942912.2019.1666869

Guo, Q. (2021). Understanding the oral processing of solid foods: Insights from food structure. *Comprehensive Reviews in Food Science and Food Safety*, 20(3), 2941–2967. https://doi.org/https://doi.org/10.1111/1541-4337.12745

Hennequin, M., Allison, P. J., Veyrune, J. L., Faye, M., & Peyron, M. (2005). Clinical evaluation of mastication: validation of video versus electromyography. *Clinical Nutrition*, 24(2), 314–320. https://doi.org/10.1016/j.clnu.2004.11.010

Jadhav, H. B., Annapure, U. S., & Deshmukh, R. R. (2021). Non-thermal Technologies for Food Processing [Review]. *Frontiers in Nutrition*, vol. 8 - 2021. https://doi.org/10.3389/fnut.2021.657090

Khan Muhammad, I., Jung, S., Nam Ki, C., & Jo, C. (2016). Postmortem Aging of Beef with a Special Reference to the Dry Aging. 한국축산식품학회지, 36(2), 159–169. https://doi.org/10.5851/KOSFA.2016.36.2.159

Koç, H., Vinyard, C. J., Essick, G. K., & Foegeding, E. A. (2013). Food Oral Processing: Conversion of Food Structure to Textural Perception. *Annual Review of Food Science and Technology*, 4(2013), 237–266. https://doi.org/https://doi.org/10.1146/annurev-food-030212-182637

O'Quinn, T. G., Legako, J. F., Brooks, J. C., & Miller, M. F. (2018). Evaluation of the contribution of tenderness, juiciness, and flavor to the overall consumer beef eating experience1. *Translational Animal Science*, 2(1), 26–36. https://doi.org/10.1093/tas/txx008

Przybylski, W., Jaworska, D., Kajak-Siemaszko, K., Sałek, P., & Pakuła, K. (2021). Effect of Heat Treatment by the Sous-Vide Method on the Quality of Poultry Meat. *Foods*, 10(7), 1610. https://doi.org/https://doi.org/10.3390/foods10071610

Ramírez, C., Millón, C., Nuñez, H., del Campo, V., Almonacid, S., & Simpson, R. (2019). Effect of particle size distribution on the in vitro digestion of calcium alginate-starchy model foods. *Journal of Food Process Engineering*, 42(5), e13097. https://doi.org/https://doi.org/10.1111/jfpe.13097

Rizo, A., Peña, E., Alarcon-Rojo, A. D., Fiszman, S., & Tarrega, A. (2019). Relating texture perception of cooked ham to the bolus evolution in the mouth. *Food Research International*, 118, 4–12. https://doi.org/https://doi.org/10.1016/j.foodres.2018.02.073

Sánchez-Ayala, A., Arcelino, F.-N., Nara, H. C., & and Matheus Rodrigues Garcia, R. C. (2013). Relationship Between Chewing Rate and Masticatory Performance. *CRANIO*®, 31(2), 118–122. https://doi.org/10.1179/crn.2013.019

Tyle, P., Cary, K., Lauri, G., & and Jarosz, P. (1990). Effect of Size, Shape and Hardness of Particles in Suspension on Oral Palatability. *Drug Development and Industrial Pharmacy*, 16(8), 1339–1364. https://doi.org/10.3109/03639049009115965

van der Bilt, A. (2009). 1 - Oral physiology, mastication and food perception. In D. J. McClements & E. A. Decker (Eds.), *Designing Functional Foods* (pp. 3–37). Woodhead Publishing. https://doi.org/https://doi.org/10.1533/9781845696603.1.3

Wee, M. S. M., Goh, A. T., Stieger, M., & Forde, C. G. (2018). Correlation of instrumental texture properties from textural profile analysis (TPA) with eating behaviours and macronutrient composition for a wide range of solid foods [10.1039/C8FO00791H]. *Food & Function*, 9(10), 5301–5312. https://doi.org/10.1039/C8FO00791H

Authors info

Ivana D. Tomasević, https://orcid.org/0009-0007-1448-6557

Igor Tomašević, https://orcid.org/0000-0002-1611-2264

Nedim Turković /

Djordjević Vesna, https://orcid.org/0009-0008-5187-4089

Aristide Maggiolino, https://orcid.org/0000-0001-7128-8556

Volker Heinz, https://orcid.org/0009-0001-7019-5400

Ilija Djekić, https://orcid.org/0000-0002-8132-8299

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 504.5:546.49(497.11)
COBISS.SR-ID: 176168713
https://doi.org/10.18485/meattech.2025.66.2.4

Original scientific paper

Assessment of Mercury contamination in liver and muscle tissue of mallards (Anas platyrhynchos) as bioindicators at three locations in Serbia

Damjan Gavrilović[1], Nikola Borjan[1], Milenko Babić[1], Ognjen Krnjaja[1], Slobodan Dojčinović[2], Aleksandar Bajčić[1] and Saša Janković[1]*

[1] Institute of Meat and Hygiene and Technology, Kaćanskog 13, 11000 Beograd, Serbia
[2] Food Safety Agency of Bosnia and Herzegovina, Kneza Višeslava bb, 88000 Mostar, Bosnia and Herzegovina

A R T I C L E I N F O

Keywords:
Mercury
Mallard
Liver
Muscle
Biomonitoring

A B S T R A C T

The aim of this study was to investigate the presence and distribution of mercury (Hg) in the liver and muscle tissue of Mallards (Anas platyrhynchos) collected from three locations in Serbia. A total of 55 samples were analyzed, including 23 from the Belegiš site, 12 from Pločica, and 20 from Vršački Ritovi. Mercury concentrations were determined using the ICP-MS method. Mercury levels in the liver ranged from 0.009 to 0.239 mg kg^{-1}, while concentrations in muscle tissue ranged from 0.005 to 0.069 mg kg^{-1}. The mean values for liver tissue were 0.097 mg/kg (Belegiš), 0.108 mg/kg (Pločica), and 0.025 mg kg^{-1} (Vršački Ritovi), whereas for muscle tissue they were 0.030 mg kg^{-1} (Belegiš and Pločica) and 0.008 mg kg^{-1} (Vršački Ritovi). Statistical analysis included descriptive statistics, Pearson correlation test, analysis of variance (ANOVA) with Tukey post hoc test, Levene's test for homogeneity of variances, Kruskal–Wallis test, and Mann–Whitney test. The findings provide insight into potential differences in mercury contamination levels between different ecosystems, as well as the relationship between different tissues in wild birds.

1. Introduction

Heavy metals have always been present as natural components of the environment, typically occurring at very low concentrations under normal conditions. However, both historically and in the present day, human activities have significantly contributed to their release into the environment. Particular concern is raised by the effects of certain metals, such as mercury, which can seriously threaten ecosystem stability. With the rise of public awareness regarding environmental issues, there is an increasing need for systematic monitoring, assessment, management, and remediation of pollution-related damage. Given the complexity of ecosystems, it is impossible to monitor all of their components, functions, and properties; therefore, selected biological indicators are used for this purpose. Birds, as one of the organism groups for which exposure to and toxicity of heavy metals have been extensively studied, serve as useful bioindicators of overall ecological status (*Zolfaghari et al.* 2007).

Mercury is released into the environment through both natural processes (such as volcanic activity, oceans, and vegetation) and anthropogenic activities (*Ribeiro & Germano,* 2015). Anthropogenic sources of mercury emissions are divided into primary sources, in which geologically derived mercury is mobilized into the environment (e.g., mining and the combustion of fossil fuels), and secondary sources, which involve the intentional use of mercury in industry, consumer products, dentistry, and artisanal and small scale

***Corresponding author:** Damjan Gavrilović, *damjan.gavrilovic@inmes.rs*

Paper received: June 20th 2025. Paper accepted July 7th 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

gold mining (ASGM). Among the primary sources, the largest contribution to pollution comes from sectors where mercury is released as an unintentional byproduct, particularly coal combustion, metal production, and cement manufacturing. Secondary sources also significantly contribute to mercury emissions, with ASGM predominantly occurring in impoverished regions of Africa, Asia, and South America remaining the largest global consumer of mercury (*Pacyna et al.,* 2010). In the environment, mercury can exist in three forms: elemental (Hg^0), inorganic (Hg^{2+}), and organic (methylmercury, MeHg). Through complex biogeochemical cycles, it enters the food chain and accumulates in the tissues of animals and fish. According to EFSA (European Food Safety Authority), the majority of mercury found in fish is in the form of methylmercury (80–100%), whereas in other food sources, it is predominantly present in its inorganic form (*Ribeiro & Germano,* 2015).

Over the past decades, the potential harmful effects of mercury (Hg) have been studied from both ecological and public health perspectives. Mercury is particularly dangerous because it can cause adverse effects in humans and other organisms, with these effects depending on various factors such as the chemical form of mercury, the amount, the route of exposure, and individual susceptibility. Humans can be exposed to mercury through different pathways, including food consumption (especially fish). The effects of mercury encompass a wide range of syndromes, including neurological, immunological, renal, cardiovascular, endocrine, and reproductive disorders. Exposure to high levels of mercury can cause tremors, emotional changes, insomnia, weakness, and sensory disturbances. Although toxic effects of mercury are present in many ecosystems, research on mercury contamination has primarily focused on freshwater fish and birds, as these

Table 1. Mercury Levels in Different Organs of Birds

Animal	Sample	Range (mg kg^{-1})	Mean Value (mg kg^{-1})	Technique	Source
Pheasant (Phasianidae)	Tail feathers	0.150–0.220	0.180	AAS	Zolfaghari et al. (2007)
Hawk	Tail feathers	0.950–1.500	1.250	AAS	Zolfaghari et al. (2007)
Mallard	Liver	0.010–0.689	0.154	CV-AAS	Żarski et al. (2017)
Mallard	Kidney	0.013–0.423	0.122	CV-AAS	Żarski et al. (2017)
Mallard	Muscle	0.009–0.925	0.110	CV-AAS	Żarski et al. (2017)
Mallard	Breast muscle	0.008–0.938	0.133	AAS	Kalisinska et al. (2013)
Mallard	Liver	0.016–0.966	0.248	AAS	Kalisinska et al. (2013)
Mallard	Kidney	0.010–1.499	0.270	AAS	Kalisinska et al. (2013)
Mallard	Breast feathers	0.037–3.475	0.634	AAS	Kalisinska et al. (2013)
Mallard	Liver	0.080–0.510	0.300	CV-AAS	Aazami et al. (2011)
Mallard	Kidney	0.070–0.450	0.260	CV-AAS	Aazami et al. (2011)
Mallard	Feathers	0.500–1.600	1.040	CV-AAS	Aazami et al. (2011)
Mallard	Muscle	0.030–0.160	0.110	CV-AAS	Aazami et al. (2011)
Pheasant	Leg skeletal muscle	0.003–0.019	0.009	AAS	Gasparik et al. (2010)
Mallard	Leg skeletal muscle	0.001–0.023	0.009	AAS	Gasparik et al. (2010)
Eurasian coot	Leg skeletal muscle	0.005–0.015	0.010	AAS	Gasparik et al. (2010)
Common pochard	Liver female Liver male	0.001–0.277 0.001–0.016	0.093 0.006	AAS	Florijancic et al. (2009)
Mallard	Liver female Liver male	0.037–0.197 0.072–0.262	0.111 0.122	AAS	*Florijancic et al. (2009)*

species represent a major protein source for many human populations (*Lemaire et al.,* 2018*; Kim et al.,* 2016).

The mallard (Anas platyrhynchos) is frequently used as a bioindicator of habitat pollution due to its wide distribution. This species is suitable for ecological studies because of its large population size, pronounced sexual dimorphism, long lifespan, and the ability to study long-term exposure to pollutants. Additionally, the mallard is a game species, and its meat is consumed by humans. Therefore, understanding the levels of toxic metals in its body is important for food safety (*Żarski et al.,* 2017).

This study investigated mercury concentrations in liver and muscle tissue samples of wild mallards collected from three locations: near Belegiš on the Danube (Srem District), near Pločica on the Danube (South Banat), and from a fishpond near Vršački Ritovi during 2024. To better understand the extent of contamination, Table 1 presents results from scientific studies addressing similar topics, providing an overview of mercury concentrations in various tissues of wild birds.

The aim of this study was to examine and compare whether there is a statistically significant difference in mercury concentrations in the liver and muscle tissues of mallards collected from three different locations, each representing a distinct type of ecosystem. Two of the sites, Belegiš (Srem District) and Pločica (South Banat District), are located along the Danube River and are exposed to pollution due to intensive industrial activities in this section of the river. In contrast, the third site a fishpond near the Vršački Ritovi represents a relatively isolated and preserved ecosystem, without direct sources of anthropogenic contamination.

2. Materials and Methods

Mercury levels were measured in liver and muscle samples of mallards at three different locations: Belegiš (Srem District) and Pločica (South Banat District), along the course of the Danube River, and in a fishpond near the Vršački Ritovi during the 2024 calendar year. The total number of analyzed samples was 55, including both liver and muscle tissues of wild mallards. A total of 23 samples were collected from the Belegiš site (12 muscle tissue samples and 11 liver samples), 12 samples from the Pločica site (6 liver and 6 muscle samples), and 20 samples from the Vršački Ritovi site (10 liver and 10 muscle tissue samples).

The samples were stored at −18 °C until the time of analysis. One day prior to laboratory processing, the frozen samples were gradually thawed at 4 °C and subsequently homogenized. Approximately 0.3 g of tissue (± 0.001 g) was weighed for each sample and transferred into a Teflon vessel of a microwave digestion system. Nitric acid (67% Trace Metal Grade, Fisher Scientific, Bishop, UK) and deionized water (0.063 μS/cm) obtained from a water purification system (Purelab DV35, ELGA, Buckinghamshire, UK), were added to the sample in quantities of 5 mL each. The microwave digestion system (MARS 6, CEM Corporation, Matthews, NC, USA) was programmed as follows: 5 min from initial temperature to 180°C, hold at 180°C for another 10 min, cooling and venting for 20 min. Digested samples were quantitatively transferred into 100 mL polypropylene volumetric flasks and diluted with deionized water (0.063 μS).

The determination of the ^{202}Hg isotope was performed using inductively coupled plasma mass spectrometry (ICP-MS) on an iCap Qc instrument (Thermo Scientific, Bremen, Germany), equipped with a collision cell and operated in kinetic energy discrimination (KED) mode. Quantitative analysis was based on a five-point calibration curve, including a zero point. A multielement internal standard (^{6}Li and ^{45}Sc at a concentration of 10 ng ml^{-1}; ^{71}Ga, ^{89}Y, and ^{209}Bi at a concentration of 2 ng mL^{-1}) was introduced via an additional peristaltic pump line to ensure measurement accuracy. Each sample was measured in duplicate, and the mean value was used, corrected for internal standard response factors. The quality of the analytical procedure was verified by the analysis of certified reference material (NIST 1577c - bovine liver, Gaithersburg, MD, USA), which was prepared in the same manner as the samples, using microwave digestion. Repeated measurements of the reference material yielded results within the range of certified values.

2.1.1 Statistical analysis

Statistical analysis was performed using Minitab® 17.1.0. Descriptive statistics and Pearson correlation were applied. ANOVA with Tukey post hoc test was used to assess significant differences in liver mercury concentrations between locations. For muscle tissue, the Kruskal–Wallis and Mann–Whitney U tests were employed to determine differences among sites.

3. Results

Tables 2 and 3 present the results of descriptive statistics for mercury concentrations in liver and muscle tissue samples of mallards from different locations. The tables include median values, ranges (min–max), arithmetic means, standard deviations, and the number of analyzed samples (n) for each sampling site.

Based on the presented results, mercury (Hg) concentrations in the liver of mallards from all three locations ranged from 0.009 to 0.239 mg kg^{-1}, with the highest recorded concentration found in an individual from the Belegiš site, measuring 0.239 mg kg^{-1} (Table 2). According to the boxplot diagram (Figure 1), the highest

Table 2. Mercury Concentration in Liver Tissue of Mallards

Location	Number of Samples (n)	Median (mg kg^{-1})	Range (mg kg^{-1})	Mean ± standard deviation (mg kg^{-1})
Belegiš	11	0.100	0.023-0.239	0.097±0.056
Pločica	6	0.069	0.039-0.205	0.108±0.073
Vršački Ritovi	10	0.020	0.009-0.070	0.025±0.018

Table 3. Mercury Concentration in Muscle Tissue of Mallards

Location	Number of Samples (n)	Median (mg kg^{-1})	Range (mg kg^{-1})	Mean ± standard deviation (mg kg^{-1})
Belegiš	12	0.022	0.007-0.069	0.030±**0.021**
Pločica	6	0.027	0.013-0.054	0.030±**0.018**
Vršački Ritovi	10	0.007	0.005-0.022	0.008±0.005

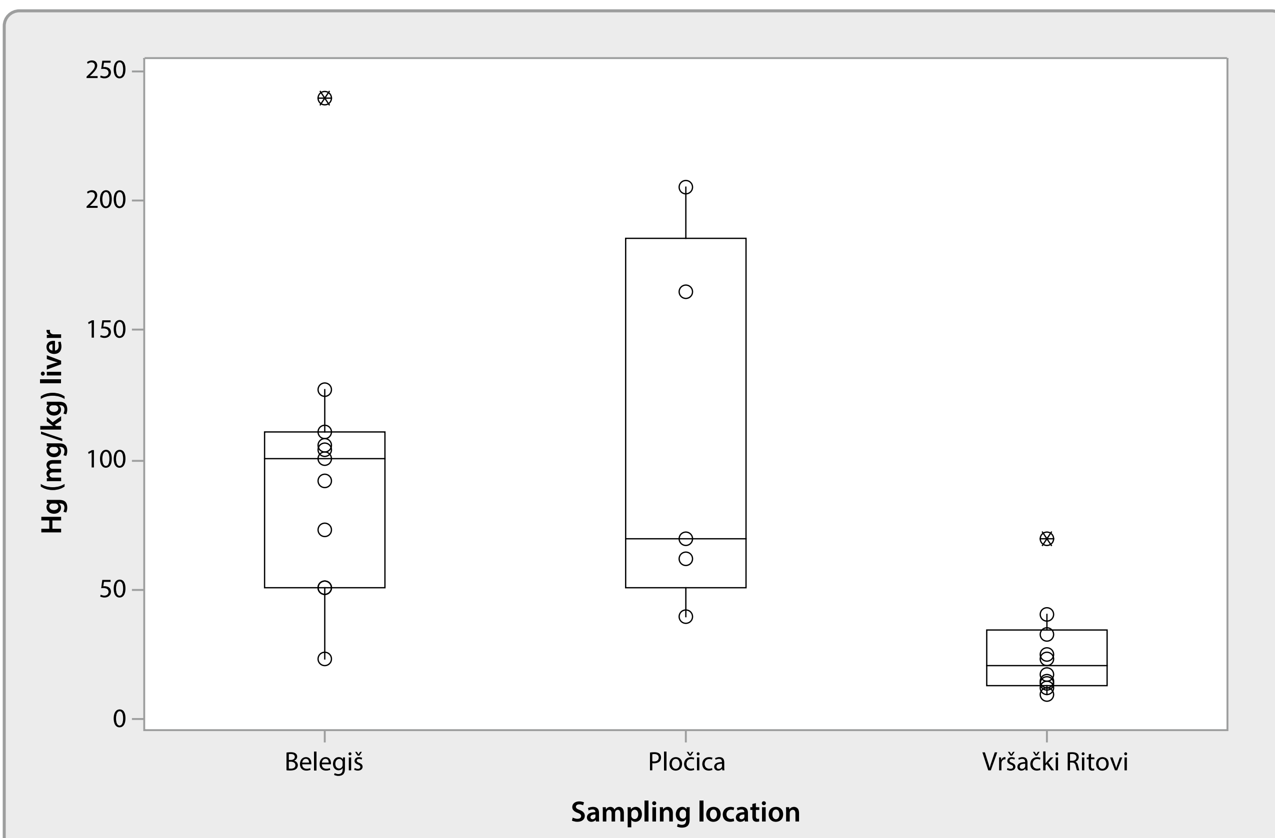

Figure 1. Mercury Levels (mg kg^{-1}) in Liver Samples of Mallards

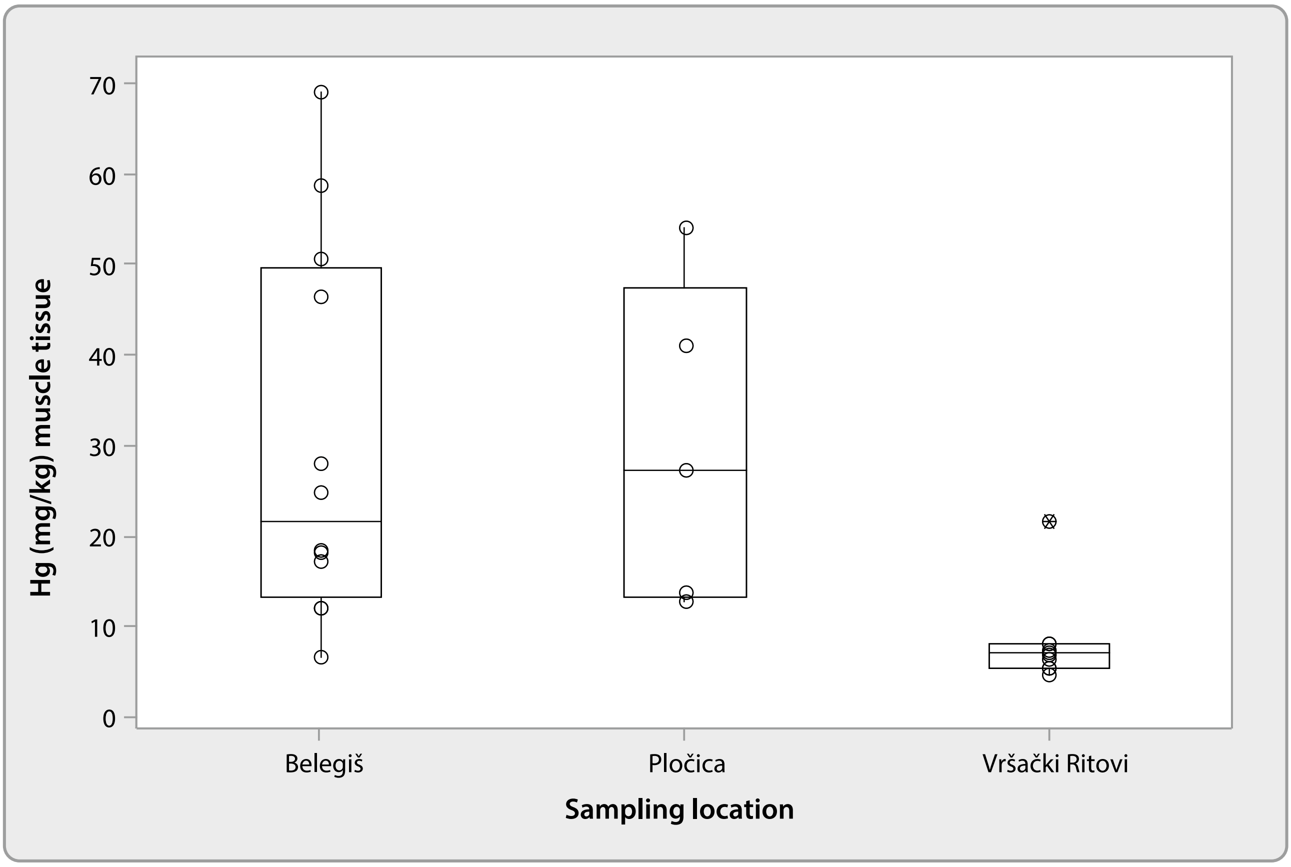

Figure 2. Mercury Levels (mg kg^{-1}) in Muscle Tissue Samples of Mallards

mean mercury concentration in liver samples was observed at the Pločica site, while the highest median value was recorded at Belegiš. Regarding mercury (Hg) concentrations in the muscle tissue of mallards, values at all three locations ranged from 0.005 to 0.069 mg kg^{-1}. The highest concentration was again recorded at the Belegiš site, measuring 0.069 mg kg^{-1} (Table 3 and Figure 2). The mean values for Belegiš and Pločica were identical at 0.030 mg kg^{-1}, while the median was slightly higher at Pločica.

Pearson correlation tests were performed at all three locations to examine the relationship between mercury concentrations in the liver and muscle tissues of mallards. At the Vršački Ritovi site, a very strong positive correlation coefficient ($r = 0.880$) was obtained, with a statistically significant p-value ($p = 0.001$), indicating a clear association between the two tissues. At Belegiš, a moderate positive correlation was found ($r = 0.539$), but the p-value ($p = 0.087$) suggests the relationship is not statistically significant. Similarly, at Pločica, a comparable correlation coefficient ($r = 0.508$) was observed, but with a high p-value ($p = 0.382$), indicating no statistically significant correlation.

Based on one-way analysis of variance (One-Way ANOVA), a statistically significant difference was found in mercury concentrations in the liver of mallards among the three studied locations ($P = 0.004$), indicating that location significantly affects mercury accumulation in liver tissue. A post hoc Tukey HSD test revealed no significant difference between Pločica and Belegiš, grouping them both into statistical group A, while Vršački Ritovi was significantly different from both (group B) with a notably lower average mercury concentration. Before analyzing differences in mercury concentrations in muscle tissue of mallards across the three studied locations, Levene's test was performed to check for homogeneity of variances. Since the test indicated unequal variances, the nonparametric Kruskal–Wallis test was applied. The results showed a statistically significant difference in mercury concentration in muscle tissue among the locations ($P = 0.001$). Following the Kruskal–Wallis test, a post hoc Mann–Whitney test revealed significant differences between Vršački Ritovi and Belegiš ($p = 0.0014$), as well as between Vršački Ritovi and Pločica ($p = 0.0059$). In contrast, no significant difference was found between Belegiš and Pločica ($p = 0.9580$).

4. Discussion

Differences in mercury concentrations between the examined locations were statistically confirmed using one-way analysis of variance (ANOVA) and Tukey post hoc test, with the most pronounced differences observed in liver tissue. The results indicate that habitat characteristics, as well as the presence of potential pollution sources along the course of the Danube River, significantly influence mercury accumulation in organisms. The Vršacki Ritovi site clearly stands out as the least contaminated, which may be attributed to its isolation from direct sources of pollution and limited bird migration. In contrast, the Belegiš and Pločica sites, located along the open flow of the river, exhibited higher levels of contamination. Although it was expected, based on geographic position, that mercury concentrations would be higher at Pločica located downstream from Belegiš and directly following the urban and industrial zones of Belgrade and Pančevo the statistical analysis did not confirm this assumption, which is most likely explained by the limited number of samples collected at that site. A similar pattern of differences was observed in muscle tissue, where the Kruskal–Wallis and Mann–Whitney U tests revealed statistically significant differences between locations. The lowest mercury concentrations in this tissue were also recorded at the Vršački Ritovi site, clearly demonstrating the difference in mercury accumulation between distinct ecosystems, compared to the higher and more variable contamination levels observed at sites along the Danube River.

The results of this study were compared with data from two studies conducted in Poland. In the study by *Żarski et al.* (2017), carried out in the area of the Włocławek reservoir, the average mercury concentrations in the liver and muscle tissue of mallards were 0.154 mg kg^{-1} and 0.110 mg kg^{-1}, respectively. Similarly, in the study by *Kalisinska et al.* (2013), conducted near the city of Szczecin, even higher concentrations were reported, with mean values of 0.248 mg kg^{-1} in the liver and 0.133 mg kg^{-1} in the pectoral muscles. In comparison, mercury concentrations at all study sites in Serbia were significantly lower. These differences are most likely the result of varying degrees of industrialization and exposure to anthropogenic pollution sources. The Polish sites, particularly near Szczecin, are heavily influenced by coal-fired power plants, chemical industries, and shipyards, whereas the Serbian locations especially Vršački Ritovi are situated in considerably less contaminated ecosystems. The lower mercury burden observed in mallards from Serbia supports the conclusion that local ecological conditions and anthropogenic pressures play a crucial role in determining the level of heavy metal accumulation in bird tissues.

Additionally, the results obtained in this study were compared with those reported by *Gasparik et al.* (2010), in which the average mercury concentration in the skeletal muscles of mallards in Slovakia was 0.0086 mg kg^{-1}. This value is nearly identical to the concentration measured at the Vršački Ritovi site (0.008 mg kg^{-1}), suggesting that both locations share similar ecological characteristics, with limited industrial influence. In contrast, slightly higher mercury concentrations were recorded at the Belegiš and Pločica sites, which can be associated with greater anthropogenic impact, although these values remain substantially lower than those reported in studies from Poland. Furthermore, a comparison was made with the results of the study by *Florijančić et al.* (2009), conducted in eastern Croatia, where the average mercury concentration in mallard liver tissue was 0.116 mg kg^{-1}. In comparison, the values recorded in this study were slightly lower at Belegiš (0.097 mg kg^{-1}) and Pločica (0.108 mg kg^{-1}), and substantially lower at Vršački Ritovi (0.025 mg kg^{-1}). Given that the Croatian study site is geographically and ecologically closer to the Serbian localities than the Polish and Slovak sites, these findings further support the conclusion that the mercury concentrations observed in this study are consistent with regional environmental conditions. The differences in mercury levels between sites are likely attributable to varying degrees of exposure to local pollution sources, as well as differences in the feeding behavior of the birds.

5. Conclusion

The results of this study indicate that mallards can be considered reliable bioindicators of mercury contamination in aquatic ecosystems, due to their pronounced ability to accumulate this metal in both liver and muscle tissues. Statistical analyses revealed significant differences in mercury concentrations between the Vršački Ritovi ecosystem, which is isolated and subject to limited anthropogenic influence, and the Belegiš and Pločica sites, located along the open-flow section of the Danube River. However, no statistically significant difference was observed between Belegiš and Pločica, which is likely attributable to the limited number of samples collected from the Pločica site. Based on the mean values of mercury concentrations in liver and muscle tissues, a higher degree of contamination can be inferred in Pločica, consistent with its downstream position and greater exposure to potential urban and industrial pollution sources originating from Belgrade and Pančevo.

Procena kontaminacije živom u jetri i mišićnom tkivu divljih pataka (Anas platyrhynchos) sa tri lokaliteta u Srbiji

Damjan Gavrilović, Nikola Borjan, Milenko Babić, Ognjen Krnjaja, Slobodan Dojčinović, Aleksandar Bajčić i Saša Janković

INFORMACIJE O RADU

Ključne reči:
Živa
Divlja patka
Jetra
Mišić
Biomonitoring

APSTRAKT

Cilj ovog rada bio je da se ispita prisustvo i distribucija žive (Hg) u jetri i mišićnom tkivu divljih pataka (Anas platyrhynchos), prikupljenih na tri lokaliteta u Srbiji: Belegiš, Pločica i Vršački Ritovi. Ukupno je analizirano 55 uzorka, od čega 23 sa lokaliteta Belegiš, 12 sa lokaliteta Pločica i 20 sa lokaliteta Vršački Ritovi. Određivanje koncentracije žive vršeno je primenom ICP-MS metode. Koncentracije žive u jetri kretale su se u opsegu od 0,009 do 0,239 mg kg^{-1}, dok su u mišićnom tkivu bile u rasponu od 0,005 do 0,069 mg kg^{-1}. Srednje vrednosti za jetru iznosile su 0,097 mg kg^{-1} (Belegiš), 0,108 mg kg^{-1} (Pločica) i 0,025 mg kg^{-1} (Vršački Ritovi), dok su za mišićno tkivo iznosile 0,030 mg kg^{-1} (Belegiš i Pločica) i 0,008 mg kg^{-1} (Vršački Ritovi). Statistička analiza obuhvatila je deskriptivnu statistiku, Pirsonov test korelacije, analizu varijanse (ANOVA) sa Tukey post hoc testom, test homogenosti varijansi (Levene), Kruskal–Wallis test i Mann–Whitney test. Dobijeni nalazi pružaju uvid u potencijalne razlike u nivou kontaminacije živom između dva različita ekosistema, kao i povezanost između različitih tkiva divljih pataka.

Disclosure statement: No potential conflict of interest was reported by authors.

Funding: The research results presented in this paper were funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under the Agreement on the Implementation and Financing of Scientific Research Work of NIO for the year 2025, No. 451-03-136/2025-03/200050 dated 4.2.2025.

References

Aazami, J., Esmaili-Sari, A., Bahramifar, N., Ghasempouri, M., & Savabieasfahani, M. (2011). Mercury in liver, kidney, feather and muscle of seabirds from major wetlands of the Caspian Sea, Iran. *Bulletin of Environmental Contamination and Toxicology, 86*(6), 657–661. https://doi.org/10.1007/s00128-011-0271-6

Florijancic, T., Opacak, A., Boskovic, I., Jelkić, D., Ozimec, S., Bogdanovic, T., Listes, I., Škrivanko, M., & Puskadija, Z. (2009). Heavy metal concentrations in the liver of two wild duck species: Influence of species and gender. *Italian Journal of Animal Science, 8*(3), 222–224. https://doi.org/10.4081/ijas.2009.s3.222

Gasparik, J., Vladarova, D., Capcarova, M., Smehyl, P., Slamecka, J., Garaj, P., Stawarz, R., & Massanyi, P. (2010). Concentration of lead, cadmium, mercury and arsenic in leg skeletal muscles of three species of wild birds. *Journal of Environmental Science and Health, Part A, 45(7)*, 818–823. https://doi.org/10.1080/10934521003708992

Kalisinska, E., Kosik-Bogacka, D. I., Lisowski, P., Lanocha, N., & Jackowski, A. (2013). Mercury in the body of the most commonly occurring European game duck, the mallard (Anas platyrhynchos L. 1758), from northwestern Poland. *Archives of Environmental Contamination and Toxicology, 64*, 583–593. https://doi.org/10.1007/s00244-012-9860-6

Kim, K.-H., Kabir, E., & Jahan, S. A. (2016). A review on the distribution of Hg in the environment and its human health impacts. *Journal of Hazardous Materials,* 306, 376–385. https://doi.org/10.1016/j.jhazmat.2015.11.031

Lemaire, J., Bustamante, P., Olivier, A., Lourdais, O., Michaud, B., Boissinot, A., Galán, P., & Bris, F. (2018). Determinants of mercury contamination in viperine snakes, Natrix maura, in Western Europe. *Science of the Total Environment,* 635, 20–25. https://doi.org/10.1016/j.scitotenv.2018.04.029

Pacyna, E. G., Pacyna, J. M., Sundseth, K., Munthe, J., Kindbom, K., Wilson, S., Steenhuisen, F., & Maxson, P. (2010). Global emission of mercury to the atmosphere from anthropogenic sources in 2005 and projections to 2020. *Atmospheric Environment,* 44(20), 2487–2499. https://doi.org/10.1016/j.atmosenv.2009.06.009

Ribeiro, R. F. L., & Germano, A. (2015). Development and validation of a method for the determination of Hg in animal tissues (equine muscle, bovine kidney and swine kidney, and poultry muscle) by direct mercury analysis (DMA). *Microchemical Journal,* 121, 237–243. https://doi.org/10.1016/j.microc.2015.03.005

Żarski, J. F., Skibniewski, M., Skibniewska, E., Żarski, T. P., & Majdecka, T. (2017). The presence of mercury in the tissues of mallards (Anas platyrhynchos L.) from Włocławek Reservoir in Poland. *Biological Trace Element Research,* 176, 384–390. https://doi.org/10.1007/s12011-016-0845-6

Zolfaghari, G., Esmaili-Sari, A., Ghasempouri, S. M., & Kiabi, B. H. (2007). Examination of mercury concentration in the feathers of 18 species of birds in southwest Iran. *Environmental Research,* 104(7), 258–265. https://doi.org/10.1016/j.envres.2009.07.001

Authors info

Damjan Gavrilović, https://orcid.org/0009-0000-3786-496X
Nikola Borjan, https://orcid.org/0000-0003-4067-3755
Milenko Babić https://orcid.org/0009-0006-6467-6757
Ognjen Krnjaja, https://orcid.org/0009-0005-2242-0457
Slobodan Dojčinović /
Aleksandar Bajčić, https://orcid.org/0000-0003-2923-4137
Sasa Janković, https://orcid.org/0000-0002-5223-6993

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.55.039:636.294
COBISS.SR-ID: 176216841
https://doi.org/10.18485/meattech.2025.66.2.5

Original scientific paper

The effect of marinating on the quality of deer meat

Hiroko Seki[1*]

[1] *University of Yamanashi, Department of Local Produce and Food Sciences, Faculty of Life and Environmental Sciences, 4-4-37, Takeda, Kofu, Yamanashi, 400-8510 Japan*

A R T I C L E I N F O

Keywords:
Deer meat
Meat quality
Marination
Water retention
Odour

A B S T R A C T

Deer meat differs from common livestock meat by its distinctive odour and toughness. Hexanal, the primary odour-causing substance, can be reduced through casein adsorption or metal ion chelation. To improve texture, increasing water retention and utilising proteolytic enzymes may be effective. However, while these approaches show promise in isolated studies, their comprehensive efficacy and optimal application in deer meat processing, particularly in a practical culinary context, remain largely unverified and underexplored. Therefore, the aim of this study was to investigate the effects of marinating deer meat using lemon juice, honey, banana, and yoghurt, all of which have potential deodorising and tenderising properties. Deer meat was marinated for 12 h in each substance and then heated by baking. After cooking, the pH, moisture content, firmness, odour, and taste components of the meat were measured. The results showed that pH was higher in all groups of marinated deer meat after baking, water retention was highest in lemon- and honey-marinated meat, while lemon-, yoghurt-, and banana-marinated deer meat was less firm than the control meat. Yoghurt was the most effective food ingredient in reducing the deer meat's odour, while lemon and yoghurt induced higher inosinic acid and alanine levels than in the control. Overall, the findings indicate that lemon juice is the most effective food ingredient for improving deer meat quality.

1. Introduction

Deer meat has a distinctive odour (*Kogiso and Kaneko*, 2015) and is characterised by its toughness (*Yoshimura et al.*, 2011). Therefore, cooking methods that can improve both its aroma and tenderness are necessary. The primary odour-causing substance in deer meat is hexanal, which can be reduced by adsorption onto casein, a protein found in milk (*Kogiso and Kanego*, 2015). Additionally, hexanal formation is promoted by copper and iron ions during lipid oxidation (*Koyanagi*, 2013). Adding iron chelators to pork, beef, and chicken meat has been shown to reduce hexanal production by more than 90% (*Todokoro et al.*, 2021). This suggests that food items containing chelating agents may help mitigate hexanal levels in deer meat. One such ingredient with chelating properties is citric acid, which is abundant in lemons.

Regarding firmness, immersing chicken meat in a honey concentration of 0–50% increased water retention proportionally, with a honey concentration of up to 40% leading to increased retention. In a sensory test, many respondents reported that the meat became softer as water retention increased (*Shimizu and Nakamura*, 2001). Moreover, soaking chicken meat in a solution containing the proteolytic enzyme ficin decreased its shear strength value (*Güven et al.*, 2021). Based on these findings, casein adsorption, citric acid chelation, improving water retention using honey, and adding proteolytic enzymes to enhance softness appear to be effective cooking methods for improving the odour and tenderness of deer meat.

Milk, yoghurt, cheese, and other dairy products contain casein, with yoghurt having a protein composition similar to that of milk (*Naito et al.*, 2019). Yoghurt is fermented with lactic acid bacteria

***Corresponding author:** Hiroko Seki, *hiroko.sk@yamanashi.ac.jp*

Paper received: Jun 26th 2025. Paper accepted July 1st 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

(*Tsuchihashi*, 2022), which is expected to have a greater tenderising effect than unfermented cow's milk owing to its lactic acid content. Bananas also contain high levels of ficin, which may contribute to softening.

Amino acids and nucleotides influence flavour development in meat. After an animal's death, proteases in the muscle break down proteins, generating amino acids, such as glutamic acid. Simultaneously, inosinic acid is produced when ATP degrades to ADP, AMP, and IMP via ATP-degrading enzymes. In common livestock, meat is typically aged for a certain period after slaughter, which causes rapid degradation of nucleic acid-based taste components and an increase in amino acid-based taste components. Conversely, deer meat differs from other meats in that inosinic acid remains stable while amino acid accumulation is low (*Yamazaki et al.*, 2024), leading to lower concentrations of amino acid-based taste components. The glutamic acid content in deer meat is relatively low, whereas alanine and glutamine, which contribute to sweetness, are found in abundance (*Fujiwara et al.*, 2018).

However, despite these promising theoretical approaches and insights from other meat types, there are no comprehensive reports verifying the physical and chemical quality of deer meat using these specific, naturally derived ingredients in practical processing methods. While individual components such as citric acid or ficin have shown promise, their combined effects and overall efficacy in a real-world culinary context for deer meat remain largely unverified and underexplored. This highlights a significant gap in understanding how accessible ingredients can effectively address the distinctive challenges of deer meat quality.

Given this unexplored area, this study aimed to evaluate the effects of honey, lemon, yoghurt, and banana marinades on the pH, moisture content, firmness, odour, and taste of deer meat. Based on the results, the optimal seasoning conditions that improve the quality and palatability of deer meat were identified.

2. Materials and Methods

2.1. Ethical approval

Ethical approval for animal use was not required for this study as commercially sourced deer meat was purchased, and no animals were directly involved in the research.

2.2. Sample and marinade preparation

Frozen deer meat, sourced from Kyushu, Japan, was thawed overnight at 4 °C. It was then cut into small pieces (approximately 2 cm long × 2 cm wide × 1 cm high). Lemon juice, multifloral honey, yoghurt, and finely chopped un-peeled bananas were each mixed in a 1:1 ratio with water to prepare pickling solutions. These four pickling solutions defined the experimental groups, with each group comprising three replicates, containing one deer meat sample per replicate. The meat samples were marinated in their respective solutions for 12 h. Following marination, meat samples were baked using an induction cooker (IRIS OHYAMA Inc., Miyagi, Japan) set at 1000 W. The meat was heated to 75 °C for 1 min and maintained at this temperature until its core temperature reached 75 °C.

2.3. Physical properties of deer meat after marination

2.3.1. pH

A pH meter (Sato Shoji Co., Ltd., Kanagawa, Japan) was used to measure the pH levels of the marinated deer meat both before and after heating. The samples were allowed to cool for 5 min before pH measurement.

2.3.2. Water holding capacity

After cooking, 0.5 g of accurately weighed deer meat was wrapped in filter paper (QL-C, particle retention capacity: 10 µm, diameter: 70 mm, SANSYO Co., Ltd., Tokyo, Japan). The wrapped samples were then centrifuged (2200 *g*, 30 min, 4 °C), and the samples were weighed once more.

2.3.3. Breaking strength

Deer meat was cooled for 5 min after heating, after which breaking stress was measured using a creep meter (YAMADEN Co., Ltd., Tokyo, Japan). The cylindrical plunger had a 3-mm diameter, and breaking strength was measured at a strain rate of 70% and a velocity of 1.00 mm/s.

2.3.4. Moisture content

After preheating to 105 °C, 1.0 g of chopped and cooked deer meat samples were accurately weighed into a weighing jar and then dried at 105 °C for 170 min. After cooling, the samples were weighed again, and the moisture content was calculated.

2.4. Chemical composition of deer meat after marination

2.4.1. Hexanal

The hexanal measurement method was modified based on the methods used by *Fujino et al.* (1991). Deer meat samples (2 g) were accurately weighed, and hexanal was extracted using 99% ethanol (Tokyo Chemical Industry Co., Ltd., Tokyo, Japan). The extract was centrifuged (20321 *g*, 5 min, 5 °C) and diluted to 5 mL.

Next, 500 µL of this solution were mixed with 500 µL 2,4-dinitrophenylhydrazine (DNPH) solution. The DNPH solution was prepared by dissolving 50 mg DNPH (FUJIFILM Wako Pure Chemical Corporation, Osaka, Japan) in 40 mL ethanol (FUJIFILM Wako Pure Chemical Corporation), 1 mL hydrochloric acid (FUJIFILM Wako Pure Chemical Corporation), and 4 mL pure water.

The resulting mixture was heated in a heat block at 45 °C for 45 min, cooled in cold water, and filtered through a 0.22 µm membrane filter (Hangzhou Cobetter Filtration Equipment Co., Ltd., Hangzhou, China). The filtered solution was then analysed using high-performance liquid chromatography (HPLC, SHIMADZU CORPORATION, Kyoto, Japan).

The HPLC system utilised a Luster C18 column (150 × 4.6 mm, LCScience Co., Ltd., Nara, Japan) with a mobile phase of acetonitrile (FUJIFILM Wako Pure Chemical Corporation) and water (8:2). The flow rate was 1.0 mL/min, the column temperature was 40 °C, and detection was performed using a UV detector at a wavelength of 360 nm. The injection volume was 20 µL.

2.4.2. Inosinic acid

Inosinic acid was measured according to the methods used in *Seki* (2024). Accurately weighed deer meat (2.5 g) was placed in a 15 mL centrifuge tube and homogenised in 4 mL 10% perchloric acid (KANTO CHEMICAL Co., Inc., Tokyo, Japan) to extract amino acids and inosinic acid. After centrifugation (17075 *g*, 10 min, 5 °C), the supernatant was transferred to a new 15 mL centrifuge tube. This extraction and centrifugation procedure was repeated once more. The final volume was then adjusted to 10 mL.

Next, 1 mL of the extract was neutralised to pH 7 using 10 M potassium hydroxide solution (FUJIFILM Wako Pure Chemical Corporation) and centrifuged (20321 *g*, 5 min, 5 °C). The supernatant was then collected and transferred to a new 15 mL centrifuge tube. The remaining precipitate was resuspended in 1 mL deionised water. This precipitation and supernatant collection procedure was repeated two times, and the combined supernatants were then diluted to 5 mL with water. The final solution was filtered through a 0.22 µm membrane filter and analysed using HPLC.

HPLC analysis was performed using a SHIMADZU CORPORATION system equipped with a COSMOSIL 5C18-PAQ column (150 × 4.6 mm, NACALAI TESQUE, INC., Kyoto, Japan). The mobile phase consisted of 20 mM NaH_2PO_4 adjusted to pH 2.8. A constant flow rate of 0.50 mL/min was maintained, and the column temperature was set at 40 °C. Detection was carried out using a UV detector at a wavelength of 260 nm, with an injection volume of 20 µL.

2.4.3. Alanine and glutamine

The measurement method for alanine and glutamine was modified based on the methods in *Seki* (2021). For this assay, 20 µL of the sample from the inosinic acid assay were combined with 70 µL ethanol (FUJIFILM Wako Pure Chemical Corporation), 20 µL triethylamine (FUJIFILM Wako Pure Chemical Corporation), and 20 µL phenyl isothiocyanate (KANTO CHEMICAL Co., Inc.). This combination was thoroughly mixed and then incubated at 25 °C for 30 min.

Following incubation, a 500 µL solution of 250 mM acetic acid buffer (pH 6.6) and acetonitrile (97:3) were added and mixed. The resulting solution was then filtered through a 0.22 µm membrane filter before HPLC analysis.

HPLC analysis was performed using a SHIMADZU CORPORATION system equipped with a COSMOSIL 5C18-MS-II column (150 × 4.6 mm, COSMOSIL; NACALAI TESQUE, Inc.). The mobile phase comprised two components: mobile phase A, which consisted of 250 mM acetic acid buffer (pH 6.6) with acetonitrile (97:3), and mobile phase B, which was a mixture of acetonitrile (FUJIFILM Wako Pure Chemical Corporation) and water (6:4).

A constant flow rate of 1.0 mL/min was maintained with the following gradient program: 0 min (B 5%) → 16 min (B 100%) → 20 min (B 5%) → 25 min (B 5%). The column temperature was set at 40 °C. Detection was performed using a UV detector at a wavelength of 254 nm, and the injection volume was 20 µL.

2.5. Statistical analysis

Statistical analysis was performed according to Fisher's three principles of experimental design. Comparisons between two groups were conducted using *t*-tests, while one-way analysis of variance (ANOVA) was applied for comparisons involving three or more groups. All analyses were performed using Microsoft Excel, with a significance level set at 5%.

3. Results

3.1. Physical properties of deer meat after marination

3.1.1. pH

Table 1 shows the pH, water holding capacity, breaking strength, and moisture content of deer meat marinated in different pickling solutions. The initial pH of the deer meat in the control (water-only marinade) was 6.11, significantly higher than that of deer meat marinated in honey (5.23), lemon (3.53), yoghurt (5.29), and banana (5.63) ($p<0.001$ for all comparisons). Post heating, the pH levels were significantly higher in all deer meat groups than in corresponding groups prior to heating ($p<0.001$). The pH of the deer meat in the control sample (water only) was 6.49, which remained significantly higher than that of meat marinated in honey (5.74), lemon (3.96), yoghurt (5.72), and banana (6.05) ($p<0.001$ for all comparisons).

3.1.2. Water holding capacity

In terms of water retention, lemon-marinated (85.6%) and honey-marinated (78.7%) deer meat showed significantly higher levels ($p=0.0019$ and $p=0.014$, respectively) than did the control deer meat (68.5%). Conversely, yoghurt-marinated (63.3%) and banana-marinated (66.5%) deer meat produced slightly lower water retention levels than did the control (deer meat marinated in water; 68.5%), although these differences were not statistically significant ($p=0.15$ and $p=0.39$, respectively).

3.1.3. Breaking strength

Regarding breaking strength, the control and honey-marinated deer meat exhibited similar values (13.6 N and 13.4 N, respectively, $p=0.87$). In contrast, lemon-, yoghurt-, and banana-marinated deer meat showed significantly lower breaking strength than did the control ($p=0.015$, $p=0.018$, and $p=0.032$, respectively). No significant difference in breaking strength was observed among the lemon, yoghurt, and banana treatments ($p=0.88$; ANOVA).

Table 1. Physical properties of deer meat after marination

	pH		Water holding capacity (%)	Breaking strength (N)	Moisture (%)
	Before heating	After heating			
Control (water-only)	6.11±0.010	6.49±0.04	68.5±3.2	13.6±1.2	60.8±0.91
Honey	5.23±0.057^{a}	5.74±0.048^{b}	78.7±1.3^{c}	13.4±1.3	72.0±1.1^{e}
Lemon	3.53±0.06^{a}	3.96±0.05^{b}	85.6±2.6^{c}	9.57±1.2^{d}	66.3±1.2^{e}
Yoghurt	5.29±0.04^{a}	5.72±0.069^{b}	63.3±4.0	9.59±1.3^{d}	56.0±0.46^{e}
Banana	5.63±0.02^{a}	6.05±0.039^{b}	66.5±1.2	9.91±1.5^{d}	57.5±0.31^{e}
p	$p<0.001^{a}$	$p<0.001^{b}$	$p<0.05^{c}$	$p<0.05^{d}$	$p<0.05^{e}$

Legend: Mean values for pH and breaking strength are reported for each marinade (n=9), based on three technical and three biological replicates. For water holding capacity and moisture content, mean values are given for each solution (n=3), derived from three technical and one biological replicate. In all cases ± denotes the standard deviation. Significance levels are as follows: $p<0.001^{a}$: Significant difference compared to the control pH. $p<0.001^{b}$: Significant difference compared to the control pH and the pH before heating. $p<0.05^{c}$: Significant difference compared to the control water holding capacity. $p<0.05^{d}$: Significant difference compared to the control breaking strength. $p<0.05^{e}$: Significant difference compared to the control moisture content.

3.1.4. Moisture content

The moisture content of honey-marinated (72.0%) and lemon-marinated (66.3%) deer meat was significantly higher than that of the control (60.8%) ($p=0.00018$ and $p=0.0033$, respectively). In contrast, yoghurt-marinated (56.0%) and banana-marinated (57.5%) deer meat showed significantly lower moisture content than that did the control ($p=0.0038$ and $p=0.028$, respectively).

3.2. Chemical composition of deer meat after marination

3.2.1. Hexanal

Table 2 summarises the amounts of hexanal, alanine, glutamine, and inosinate in the marinated deer meat. The honey-marinated deer meat exhibited a significantly higher mean hexanal level (1.74 µg g^{-1}) than the control (1.56 µg g^{-1}) ($p=0.0027$). The banana-marinated deer meat showed an elevated hexanal content (1.72 µg g^{-1}) relative to the control ($p=0.17$). Conversely, the yoghurt-marinated deer meat had the lowest hexanal content (0.859 µg g^{-1}) ($p=0.017$) among the groups. The lemon-marinated meat had a slightly lower hexanal content (1.54 µg g^{-1}) than did the control, although this difference was not statistically significant ($p=0.46$).

3.2.2. Inosinic acid

Inosinic acid, a key taste compound, was significantly higher in lemon-marinated (1.31 mg g^{-1}) and honey-marinated (1.19 mg g^{-1}) deer meat ($p=0.0065$ and $p=0.026$, respectively) than in the control (0.966 mg g^{-1}). However, there was little change in the inosinic acid concentration of the yoghurt-marinated deer meat (0.957 mg g^{-1}) when compared with the control ($p=0.85$). Conversely, the banana-marinated deer meat exhibited the lowest inosinic acid concentration (0.725 mg g^{-1}) ($p=0.0179$) among the groups.

3.2.3. Alanine and glutamine

The alanine level in the yoghurt-marinated deer meat (0.918 mg g^{-1}) was significantly higher than that in the control (0.854 mg g^{-1}) ($p=0.0072$). The honey-marinated deer meat (0.884 mg g^{-1}) had a slightly higher alanine content than did the control ($p=0.15$). In contrast, lemon-marinated (0.742 mg g^{-1}) and banana-marinated (0.720 mg g^{-1}) deer meat contained significantly lower alanine levels than did the control ($p=0.0044$ and $p=0.0071$, respectively). Glutamine levels varied across treatments. The lemon-marinated deer meat (0.205 mg g^{-1}) exhibited slightly higher glutamine content than the control (0.187 mg g^{-1}) ($p=0.36$). Conversely, the glutamine content in the

Table 2. Chemical composition of deer meat after marination

	Hexanal (µg g^{-1})	**Inosinic acid (mg g^{-1})**	**Alanine (mg g^{-1})**	**Glutamine (mg g^{-1})**
Control (water-only)	1.56±0.026	0.966±0.016	0.854±0.014	0.187±0.021
Honey	1.74±0.038[a]	1.19±0.064[b]	0.884±0.023	0.156±0.023
Lemon	1.54±0.040	1.31±0.046[b]	0.742±0.021[c]	0.205±0.020
Yoghurt	0.859±0.16[a]	0.957±0.070	0.918±0.017[c]	0.0871±0.0074[d]
Banana	1.72±0.13	0.725±0.054[b]	0.720±0.032[c]	0.116±0.00054[d]
P	$p<0.05^a$	$p<0.0^{5b}$	$p<0.05^c$	$p<0.05^d$

Legend: Mean values for each solution are reported (n=3 technical replicates, n=1 biological replicate), with ± denoting the standard deviation. Significance levels are as follows: $p<0.05^a$: Significant difference compared to the control hexanal content. $p<0.05^b$: Significant difference compared to the control inosinic acid content. $p<0.05^c$: Significant difference compared to the control alanine content. $p<0.05^d$: Significant difference compared to the control glutamine content.

honey-marinated deer meat (0.156 mg g^{-1}) was slightly lower than that in the control (p=0.16). Yoghurt-marinated (0.0871 mg g^{-1}) and banana-marinated (0.0116 mg g^{-1}) deer meat contained significantly lower glutamine levels than did the control (p=0.016, p=0.028, respectively).

4. Discussion

This study examined the effects of different marinating solutions on the physicochemical properties of deer meat, specifically focusing on pH, water retention, texture, and biochemical composition.

4.1. Physical properties of deer meat after marination

4.1.1. pH

The pH of deer meat marinated in the different food ingredient solutions was highest in the control (water-only). The initial pH of the marinating solutions were 4.78 for honey, 2.44 for lemon, 5.57 for banana, and 4.22 for yoghurt. Therefore, the pH of the marinated deer meat was lower than that of the control, as it was influenced by the pH of the marinating solution. In addition, the pH of the deer meat immersed in each marinade was higher than that of the marinating solution. The pH of raw deer meat has been reported to be between 5.6 and 5.8 (Shimada et al., 2022), and in this study it was 6.11, which is close to this value. Since the pH of the meat itself was higher than that of the marinating solution, the pH of the marinating meat was higher than that of the marinating solution, particularly in the case of honey, lemon, and yogurt.

Furthermore, the pH was consistently higher after heating than before heating across all groups of marinated deer meat. In cheese, heating has been reported to decompose amino acids to produce ammonia (*Buňka et al.*, 2004). Ammonia production increases pH, and in this study, an increase in pH was observed after heating in all experimental groups. This suggests that thermal denaturation contributed to the pH increase, regardless of the marinating solution. The pH increases due to heating were approximately 0.4 for the control, lemon-, banana-, and yoghurt-marinated meat, while honey induced a slightly higher pH increase of approximately 0.5. As the pH of acacia honey has been reported to increase by 0.1 after heat treatment at 90 °C (*Sulaiman and Sarbon*, 2022), the use of honey in the marinade could have contributed intrinsically to the more pronounced rise in pH after heating compared to the other treatments.

4.1.2. Water holding capacity

The water retention properties of deer meat marinated in honey and lemon were higher than those of the control. Immersing pork meat in a solution of honey and water was also shown to improve its water-holding capacity, with increasing honey concentrations leading to nearly 75% water retention at 50% honey concentration (*Shimizu and Nakamura*, 2001). A similar trend was observed in the current study, where deer meat marinated in 50% honey retained 78.7% water. *Hu et al.* (2016) further demonstrated that adding glucose to chicken meat improved its water retention. Additionally, in kefiran gel, the addition of 50% fructose increased water retention from approximately 45% to up to 100% (*Zavala et al.*, 2015). This suggests that the sugar component of honey influenced the water retention capacity in the current study.

Similarly, improved water retention in chicken meat marinated in lemon juice has been reported (*Unal et al.*, 2022), which aligns with the current findings. The lowest water retention in meat is typically observed at pH 5.5, near the isoelectric point of meat proteins (*Abe et al.*, 2018). The pH of the lemon-treated meat was 3.53, sufficiently distant from the isoelectric point, which may have contributed to its enhanced water retention.

Conversely, both yoghurt- and banana-marinated deer meat exhibited slightly lower water retention levels than that of the control. *Masoumi et al.* (2022) showed that yoghurt lowers pH, thereby enhancing water retention in chicken. However, in the current study, the pH of deer meat marinated in yoghurt (5.29) and banana (5.63) remained close to the isoelectric point of meat, which likely played a role in the lower water retention of these two groups compared to the control.

4.1.3. Breaking strength

The breaking strength of deer meat marinated in honey was not significantly different to that of the control. In chicken meat, the addition of 10, 20, and 30% honey solution has been reported to increase water retention and tenderness, with a corresponding increase in honey concentration (*Hashim et al.*, 1999). In contrast, more respondents answered that pork marinated in a 50% honey mixture was tougher than that in 30–40% honey (*Shimizu and Nakamura*, 2001), possibly because honey caused caramelisation, which toughened the meat surface after heating. Honey caramelisation also occurred in the current study.

Meat marinated in lemon, yoghurt, and banana exhibited lower breaking strength than that of the control. Similar results have been reported in beef, where the meat softened as water retention improved (*Mega et al.*, 1979). In the current study, the low pH measured after lemon marination could have improved water retention, thereby resulting in lower rupture strength. Lactic acid in marinades has been associated with the softening of pork, sheep, and rabbit meat (*Simitzis et al.*, 2021). As lactic acid is present in yoghurt, a similar effect was anticipated in this study.

Treatment of chicken meat with ficin, one of the proteolytic enzymes found in banana peels, has demonstrated a softening effect (*Güven et al.*, 2021). Our findings align with these results, suggesting that ficin contained in banana peels reduced the breaking strength of the deer meat.

4.1.4. Moisture content

Moisture content was higher in deer meat marinated in honey and lemon than that in the control. As fructose and glucose are major components of honey, and lemon shifts the pH away from the isoelectric point of deer meat, both these factors likely contributed to higher water retention and subsequent moisture holding. Higher water retention has been linked to higher moisture content in pork (*Jankowiak et al.*, 2021). Although lemon-marinated deer meat exhibited higher water retention than the honey-marinated in this study, the moisture content after heating was lower in lemon-marinated deer meat than that in honey-marinated meat (66.3 vs. 72.0%, respectively). In honey, water retention is primarily enhanced by sugar, whereas in lemon juice, it is predominantly influenced by pH-induced changes in the isoelectric point. *Terazawa et al.* (2014) compared the moisture content of ground beef marinated in unglazed soy sauce, mirin, and soy sauce, then cooked in teriyaki sauce, finding that the teriyaki group retained more moisture due to the caramelisation of sugar. In the current study, the caramelisation of sugar contained in the honey is thought to have contributed to the higher moisture content observed in the honey-marinated deer meat than in the lemon-marinated meat.

Conversely, the moisture content of deer meat marinated in yoghurt and banana was lower than that of the control. This reduction can be attributed to water loss due to heating, which decreased the water retention properties as the pH remained close to the meat's isoelectric point (approximately 5.5). Similarly, banana marination produced a lower moisture content than did the control, a phenomenon also observed with yoghurt-marinated meat, both of which are attributable to the lower water content after heating.

4.2. Chemical composition of deer meat after marination

4.2.1. Hexanal

The hexanal content in deer meat marinated in honey and banana was higher than that in the control. Honey has been reported to contain hexanal as a volatile component, although its content varies depending on the nectar source (*Zhu et al.*, 2022). Similarly, as bananas have been reported to contain hexanal as a major volatile component (*Mukherjee et al.*, 2022), the higher hexanal levels observed in the meats marinated in honey and banana compared to the control can be attributed to the presence of hexanal in these marinating solutions.

Deer meat marinated in lemon showed no significant change in hexanal content compared to the control. Hexanal is produced by lipid oxidation, a process that involves metal ions (*Koyanagi*, 2013). Lipid oxidation can be inhibited by mitigating the action of metal ions via chelation (*Todokoro et al.*, 2021). As citric acid in lemons possesses chelating properties (*Akatsuka et al.*, 2015), it likely inhibits hexanal formation. However, chelation does not remove preexisting hexanal, which explains why no change was observed in the lemon-marinated meat.

The amount of hexanal in deer meat marinated in yoghurt was lower than that in the control. Yoghurt contains casein, a protein that has been reported to adsorb hexanal in deer meat (*Kogiso and Kanego*, 2015). Thus, casein in yoghurt may have contributed to the removal of hexanal in this study.

4.2.2. Inosinic acid

The inosinic acid content in banana-marinated deer meat was lower than that in the control meat. Previous studies have reported a decrease in inosinic acid levels with increasing bacterial counts. For instance, when beef was stored at 5 °C for 8 days, the number of total viable bacteria increased from approximately 4 log CFU g^{-1} to 8 log CFU g^{-1}, while the amount of inosinic acid decreased from 0.3 μmol g^{-1} to 0.02 μmol g^{-1} (*Parris et al.*, 1983). Similarly, when sterilised chicken meat was inoculated with *Staphylococcus* spp. and Enterobacteriaceae isolated from raw chicken meat and incubated at 35 °C for 48 h, the *Staphylococcus* count increased. While the amount of inosinic acid in chicken without bacterial inoculation decreased slightly, inosinic acid levels were reported to disappear within 48 h in inoculated meat (*Hayashi and Nakata*, 2003). Given that Enterobacteriaceae have been detected in bananas (*Issouffou et al.*, 2018) and that *Staphylococcus* spp. is commonly found on human skin and other surfaces, these bacteria may have been present in the bananas. Moreover, bacterial growth has been observed in the epidermis and pulp of bananas after being cut, with an increase from 0 $\log_{10}$ CFU g^{-1} to 7 $\log_{10}$ CFU g^{-1} in the pulp within two days (*Abe et al.*, 2012). This evidence suggests that inosinic acid may have been degraded by the bacteria present in bananas.

Conversely, honey- and lemon-marinated deer meat contained higher levels of inosinic acid than that in the control meat. Inosinic acid-degrading enzymes degrade inosinic acid over time, and its levels can be maintained by suppressing enzyme activity. *Seki and Kikuchi* (2022) reported that honey inhibits inosinic acid-degrading enzymes in chub mackerel, suggesting that honey in the current study similarly inhibited these enzymes. In addition, inosinic acid-degrading enzymes in various fish species have different optimum pH values (*Tomioka and Endo*, 1984). As honey and lemon create an acidic environment, enzyme activity in deer meat could have been suppressed, thereby preserving inosinic acid. This collectively suggests that honey and lemon may have supported the retention of inosinic acid in the marinated deer meat.

4.2.3. Alanine and glutamine

Honey contains gluconic acid, which has been reported to inhibit myosin degradation in squid (*Kuwahara et al.*, 2004). As myosin is a protein, inhibiting its degradation would prevent the production of amino acids. However, honey itself contains 3.43–27.0 mg/100 g alanine (*Quintas et al.*, 2021). Thus, while gluconic acid-induced proteolysis inhibition may have prevented the formation of amino acids, the alanine naturally present in honey may have offset this effect, resulting in the honey-marinated meat having a similar amount of alanine as the control.

The alanine content in deer meat marinated in lemon and banana was lower than that in the control. The addition of citric acid to squid inhibits the activity of metalloproteinase, an endogenous protease, and suppresses alanine production (*Geng et al.*, 2018). Similarly, the citric acid in lemons could have inhibited deer meat protease activity in this study, thereby inhibiting alanine production. Moreover, bananas contain starch, and amino acids are involved in starch gelatinisation. Alanine is reported to bind to starch, albeit relatively weakly (*Ito et al.*, 2006), suggesting that heating could have facilitated the binding of alanine to starch, thereby resulting in less free alanine in the banana-marinated meat than in the control.

In contrast, the amount of alanine in deer meat marinated in yoghurt was higher than that in the control. In fermented sausages, the addition of lactic acid bacteria resulted in protein degradation and higher alanine content (*Kato*, 1991). Various proteolytic enzymes are present in meat, each requiring different conditions for their activation and inhibition. In this study, yoghurt likely promoted the activity of proteolytic enzymes that produce alanine, which may have caused the higher alanine content of yoghurt-marinated meat. The glutamine content in deer meat marinated with honey and banana was lower than that of the control. The addition of gluconic acid to squid inhibits degradation (*Kuwahara et al.*, 2004). Given the high gluconic acid levels in honey, this compound could have inhibited protein degradation in the current study. Similarly to alanine, the starch in bananas likely interacted with amino acids in deer meat during banana marination, which likely reduced glutamine content. Although the amount of glutamine in lemon-marinated deer meat was higher than that in the control, the difference was not significant, suggesting that lemon had no substantial effect on glutamine levels. However, deer meat marinated in yoghurt had significantly lower glutamine levels than that did the control. Yoghurt contains a type of lactic acid bacteria that produce high levels of gamma-aminobutyric acid (GABA). *Ohmori et al.* (2018) reported that when yoghurt containing these bacteria was mixed with sake, the L-glutamic acid in the sake was broken down by the lactic acid bacteria, leading to increased GABA levels. As glutamine serves as a precursor for glutamic acid, a similar phenomenon may have occurred in this study, resulting in the depletion of glutamine in the yoghurt-marinated deer meat.

4.3. Limitations

This study has some limitations that warrant discussion. A primary concern is the lack of precise information regarding sample storage conditions; specifically, details on the duration and temperature that deer meat samples were frozen at was not available from the supplier.

Additionally, specific data on the deer species, exact hunting location, or the hunting season could not be obtained. While these details would significantly enrich the study's ecological context and reproducibility, they simply were not provided by the third-party supplier. Despite these gaps regarding the meat's origin, this study's conclusions remain solid given the available information.

Finally, many of the proposed mechanistic explanations in this study rely on findings from studies involving other types of meat, such as chicken, pork, beef, squid, and fish. While they offer plausible hypotheses, the specific physiological and biochemical responses of deer meat might differ. As these mechanisms could not be confirmed directly with individual deer meat samples, the direct applicability of these external findings to deer meat should be viewed with caution.

5. Conclusion

This study examined the effects of honey, lemon juice, yoghurt, and banana marination on deer meat quality. Regardless of the marinating solution used, the pH increased with heat. Both honey and lemon treatments resulted in high water retention, while lemon-marinated deer meat exhibited the lowest breaking strength compared with the other groups. Marination in yoghurt resulted in the lowest odour intensity, whereas lemon marination yielded the highest inosinic acid levels. Glutamine and alanine levels were the highest in yoghurt-marinated meat. Overall, the results indicate that among the marinating solutions tested, lemon marination offers the most significant improvements to the quality of deer meat.

With the growing population, food shortages are a significant concern. Consequently, in addition to major livestock meats, the utilisation of meat from wild deer and boar is expected to increase in the future. This study investigated methods to enhance the palatability of deer meat. Future research will focus on assessing quality changes and conducting sensory evaluations of processed deer meat to further expand its culinary applications.

Uticaj rastvora marinade na kvalitet mesa divljači jelena

Hiroko Seki

INFORMACIJE O RADU

Ključne reči:
Meso jelenske divljači
Kvalitet mesa
Mariniranje limunom
Sposobnost zadržavanja vode
Jogurt
Smanjenje mirisa.

APSTRAKT

Meso divljači jelena se izdvaja od mesa domaćih životinja zbog svog karakterističnog mirisa i žilavosti. Heksanal, primarno supstanca koja uzrokuje neprijatan miris, može se smanjiti adsorpcijom kazeina ili helacijom metalnih jona. Poboljšanje teksture može se postići povećanjem sposobnosti zadržavanja vode i korišćenjem proteolitičkih enzima. U ovom radu istraživan je uticaj mariniranja na kvalitet mesa divljači jelena korišćenjem limuna, meda, banane i jogurta, koji imaju potencijalna svojstva dezodoracije i omekšavanja. Meso divljači jelena je marinirano 12 sati u svakom rastvoru marinade, a zatim zagrejano. Nakon kuvanja, mereni su pH, sadržaj vlage, čvrstoća, miris i komponente ukusa mesa. Rezultati su pokazali da se pH povećao u svim uzorcima nakon pečenja, sposobnost zadržavanja vode je bila najveća u mesu mariniranom limunom i medom, a čvrstoća se smanjila u uzorcima tretiranim limunom, jogurtom i bananom. Jogurt je bio najefikasniji u smanjenju mirisa, dok se upotrebom limuna i jogurta povećao sadržaj inozinske kiseline i alanina. Na kraju, ovi rezultati ukazuju da je limun najefikasniji sastojak hrane za poboljšanje kvaliteta mesa jelenske divljači.

Disclosure statement: No potential conflict of interest was reporting by author.

Funding: This work was supported by the Tokyo University of Technology Graduate Research Fund. No specific additional grants were received from public, commercial, or not-for-profit funding agencies for this research.

Acknowledgments: I would like to thank Mr. Tadashi Fukui and Ms. Yuko Ichino from the School of Bioscience and Biotechnology, Tokyo University of Technology, for their valuable support during the experiments and manuscript preparation.

References

Abe, K., Sasamoto, M., Kaetsu, K., & Achiwa, N. (2012). Effect of electrolyzed acidic water treatment on the physiological and chemical properties and microorganisms of ethylene-treated banana sections. *Food Preservation Science*, 38(6), 321–328. https://doi.org/10.5891/jafps.38.321.

Abe, M., Sawayama, S., & Akita, O. (2018). Effects of soaking pork in shio-koji before cooking. *Journal of Cookery Science of Japan*, 51(3), 142–150. https://doi.org/10.11402/cookeryscience.51.142.

Akatsuka, M., Tamamura, S., Igarashi, T., & Kaneko, K. (2015). Characterization of organic substances and metal ions extracted from lignite by chelating and reducing agents. *Journal of MMIJ*, 131(7), 459–464. https://doi.org/10.2473/journalofmmij.131.459.

Buňka, F., Hrabě, J., & Kráčmar, S. (2004). The effect of sterilisation on amino acid contents in processed cheese. *International Dairy Journal*, 14(9), 829–831. https://doi.org/10.1016/j.idairyj.2004.02.008.

Fujino, S., Matoba, T., & Hasegawa, K. (1991). Changes in green beany flavor and texture in soybean sprouts during thermal cooking. *Science of Cookery*, 24(3), 193–197. http://doi.org/10.11402/cookeryscience1968.24.3_193.

Fujiwara, T., Watase, T., Matsui, S., Aihara, K., Sano, A., & Ichikawa, Y. (2018). Comparison of meat quality characteristics for Sika deer (*Carvus nippon*) obtained by different capturing methods. *The Japanese Journal of Zootechnical Science*, 89(2), 219–226. https://doi.org/10.2508/chikusan.89.219.

Geng, J., Takahashi, K., Kaido, T., Kasukawa, M., Okazaki, E., & Osako, K. (2018). The effect of organic salts on the browning of dried squid products processed by air-drying. *Food Chemistry*, 269, 212–219. https://doi.org/10.1016/j.foodchem.2018.06.129.

Güven, S. Y., Karakaya, M., & Babağlu, A. S. (2021). Proximate compositions, fatty acids and mineral contents of chicken and turkey gizzards, and textural properties after tenderization with proteolytic enzymes. *Journal of Food Processing and Preservation*, 45(10), e15775. https://doi.org/10.1111/jfpp.15775.

Hashim, I. B., McWatters, K. H., & Hung, Y. C. (1999). Marination method and honey level affect physical and sensory characteristics of roasted chicken. *Journal of Food Science*, 64(1), 163–166. https://doi.org/10.1111/j.1365-2621.1999.tb09883.x.

Hayashi, M., & Nakata, K. (2003). Effect of contaminating bacteria on the inosinic acid content of chicken meat. *Journal of Home Economics of Japan*, 54(6), 441–448. https://doi.org/10.11428/jhej1987.54.441.

Hu, H., Bai, X., Wen, A., Shah, A. A., Dai, S., Ren, Q., Wang, S., He, S., & Wang, L. (2016). Assessment of interactions between glutamine and glucose on meat quality, AMPK, and glutamine concentrations in pectoralis major meat of broilers under acute heat stress. *Journal of Applied Poultry Research*, 25(3), 370–378. https://doi.org/10.3382/japr/pfw021.

Issouffou, C., Suwansri, S., Salaipeth, L., Domig, K. J., & Hwanhlem, N. (2018). Synergistic effect of essential oils and enterocin KT2W2G on the growth of spoilage microorganisms isolated from spoiled banana peel. *Food Control*, 89, 260–269. https://doi.org/10.1016/j.foodcont.2018.02.019.

Ito, A., Hattori, M., Yoshida, T., Watanabe, A., Sato, R., & Takahashi, K. (2006). Regulatory effect of amino acids on the pasting behavior of potato starch is attributable to its binding to the starch chain. *Journal of Agricultural and Food Chemistry*, 54(26), 10191–10196. https://doi.org/10.1021/jf061823w.

Jankowiak, H., Cebulska, A., & Bocian, M. (2021). The relationship between acidification (pH) and meat quality traits of polish white breed pigs. *European Food Research and Technology*, 247(11), 2813–2820. https://doi.org/10.1007/s00217-021-03837-4.

Kato, T. (1991). Preparation of fermented sausage by lactic acid bacteria. *Journal of Food Science and Technology*, 38(11), 1063–1069. https://doi.org/10.3136/nskkk1962.38.1063.

Kogiso, K., & Kaneko, S. (2015). The aroma characteristics and food processing of venison from Nagano. *Journal of Nagano Prefectural College*, 69, 13–19. https://u-nagano.repo.nii.ac.jp/record/1196/files/kentan6902%E3%80%80%E5%B0%8F%E6%9C%A8%E6%9B%BD.pdf.

Koyanagi, A. (2013). Development of wine for cooking which controls the off-flavor of meat. *Journal of the Brewing Society of Japan*, 108(12), 890–893. https://doi.org/10.6013/jbrewsocjapan.108.890.

Kuwahara, K., Osako, K., & Konno, K. (2004). Improved gel formation of Japanese common squid muscle as a result of suppression of autolysis by some organic salt. *Nippon Suisan Gakkaishi*, 70(6), 922–927. https://doi.org/10.2331/suisan.70.922.

Masoumi, B., Abbasi, A., Mazloomi, S. M., & Shaghaghian, S. (2022). Investigating the effect of probiotics as natural preservatives on the microbial and physicochemical properties of yogurt-marinated chicken fillets. *Journal of Food Quality*, 2022(1), 5625114. https://doi.org/10.1155/2022/5625114.

Mega, A., Fujiki, S., & Arakawa, N. (1979). The effect of marinading on tenderness in meat cooking. *Journal of Home Economics of Japan*, 30(7), 618–621. https://doi.org/10.11428/jhej1951.30.618.

Mukherjee, S., Goswami, A., Mandal, D., & Mitra, A. (2022). Variation in postharvest fruit aroma volatiles among two popular banana cv. Malbhog and cv. Vaibalhla of northeastern region in India. *Plant Physiology Reports*, 27(2), 225–233. https://doi.org/10.1007/s40502-022-00655-y.

Naito, M., Yamada, C., & Izumi, H. (2019). Composition of cow's milk proteins with processing. *Journal of the Japanese Society for Food Science and Technology*, 66(6), 195–200. https://doi.org/10.3136/nskkk.66.195.

Ohmori, T., Tahara, M., & Ohshima, T. (2018). Mechanism of gamma-aminobutyric acid (GABA) production by a lactic acid bacterium in yogurt-sake. *Process Biochemistry*, 74, 21–27. https://doi.org/10.1016/j.procbio.2018.08.030.

Parris, N., Palumbo, S. A., & Montiville, T. J. (1983). Evaluation of inosine monophosphate and hypoxanthine as indicators of bacterial growth in stored red meat. *Journal of Food Protection*, 46(7), 614–617. https://doi.org/10.4315/0362-028X-46.7.614.

Quintas, P. Y., Keunchkarian, S., Romero, L., Canizo, B. V., Wuilloud, R. G., & Castells, C. B. (2021). Determination of amino acid content and its enantiomeric composition in honey samples from Mendoza, Argentina. *Journal of Food Processing and Preservation*, 45(12), e15966. https://doi.org/10.1111/jfpp.15966.

Seki, H. (2021). Quality changes in the adductor muscle of Ezo giant scallop *Mizuhopecten yessoensis* (Jay, 1857) during refrigerated storage. *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology*, 16(3), 110–118. https://doi.org/10.15578/squalen.585.

Seki, H. (2024). Developing flowcharts for hazard analysis in seafood retail: Critical control point verification. *Journal of Food Quality and Hazards Control*, 11(3), 166–176. http://dx.doi.org/10.18502/jfqhc.11.3.16588.

Seki, H., & Kikuchi, M. (2022). Effect of honey on the maintenance of taste components in the Chub Mackerel *Scomber japonicus* (Houttuyn, 1782). *Journal of Food and Nutritional Health*, 3(1), 1–5. https://doi.org/10.47275/2692-5222-115.

Shimada, K., Usagawa, J., Imano, M., Han, K. H., Fukushima, M., & Sekikawa, M. (2022). Estimation of aging period of Ezo-shika deer (*Cervus nippon* yesoenis) meat required for tenderization. *Hokkaido Journal of Livestock and Grassland Science*, 10(1), 17–24. https://doi.org/10.32253/hlgs.10.1_17.

Shimizu, M., & Nakamura, M. (2001). Cooking with honey, its history and theory. *Honeybee Science*, 22(4), 175–180. https://agris.fao.org/search/en/providers/122558/records/647242f3e17b74d2224f2515.

Simitzis, P., Zikou, F., Progoulakis, D., Theodorou, G., & Politis, I. (2021). A note on the effects of yoghurt acid whey marination on the tenderness and oxidative stability of different meat types. *Foods*, 10(11), 2557. https://doi.org/10.3390/foods10112557.

Sulaiman, N. H. I., & Sarbon, N. M. (2022). Physicochemical, antioxidant and antimicrobial properties of selected Malaysian honey as treated at different temperature: A comparative study. *Journal of Apicultural Research*, 61(4), 567–575. https://doi.org/10.1080/00218839.2020.1846295.

Terazawa, Y., Koga, T., & Saito, M. (2014). Changes in the properties and amount of available lysine of ground beef during grilling. *Journal of the Japanese Society for Food Science and Technology*, 61(12), 599–604. https://doi.org/10.3136/nskkk.61.599.

Todokoro, T., Kashihara, H., Fukuda, K., Tsutsumi, H., Hata, Y., & Ishida, H. (2021). Inhibition of lipid oxidation and hexanal production in cooked meats by microbial iron chelator deferriferrichrysin from rice wine. *Journal of Food Processing and Preservation*, 45(11), e15943. https://doi.org/10.1111/jfpp.15943.

Tomioka, K., & Endo, K. (1984). K value-Increasing Rates and IMP-degrading activities in various fish muscle. *Nippon Suisan Gakkaishi*, 50(5), 889–892. https://doi.org/10.2331/suisan.50.889.

Tsuchihashi, H. (2022). Study on lactic acid bacteria (LAB) isolated from raw milk in Japan: What is the difference between yogurt made with LAB derived from raw milk in Japan and conventional yogurt starter? *Kagaku to Seibutu*, 60(7), 334–345. https://doi.org/10.1271/kagakutoseibutsu.60.334.

Unal, K., Alagöz, E., Çelik, I., & Sarıçoban, C. (2022). Marination with citric acid, lemon, and grapefruit affects the sensory, textural, and microstructure characteristics of poultry meat. *British Poultry Science*, 63(1), 31–38. https://doi.org/10.1080/00071668.2021.1963674.

Yamazaki, S., Mizutani, T., & Kato, K. (2024). Influence of the aging process on the qualities of venison. *Research reports of Nagano Prefecture General Industrial Technology Center*, 19, 210–214. https://www.gitc.pref.nagano.lg.jp/reports/pdf/R6/R06F17_F21.pdf.

Yoshimura, M., Ooya, H., Fujimura, T., Watanabe, T., & Yokoyama, M. (2011). Effects of added grain Koji on the physical properties and palatability of sika deer meat product. *Journal of the Japanese Society for Food Science and Technology*, 58(11), 517–524. https://doi.org/10.3136/nskkk.58.517.

Zavala, L., Roberti, P., Piermaria, J. A., & Abraham, A. G. (2015). Gelling ability of kefiran in the presence of sucrose and fructose and physicochemical characterization of the resulting cryogels. *Journal of Food Science and Technology*, 52(8), 5039–5047. https://doi.org/10.1007/s13197-014-1577-2.

Zhu, M., Sun, J., Zhao, H., Wu, F., Xue, X., Wu, L., & Cao, W. (2022). Volatile compounds of five types of unifloral honey in Northwest China: Correlation with aroma and floral origin based on HS-SPME/GC-MS combined with chemometrics. *Food Chemistry*, 384, 132461. https://doi.org/10.1016/j.foodchem.2022.132461.

Authors info

Hiroko Seki, https://orcid.org/0000-0003-2426-7554

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 664.975.232.039.7
664.59:582.773
COBISS.SR-ID: 176277513
https://doi.org/10.18485/meattech.2025.66.2.6

Original scientific paper

Application of senduduk (*Melastoma malabathricum*) leaf powder as a natural antioxidant in beef sausages: Role of particle size on product quality

Suharyanto Suharyanto[1], Warnoto Warnoto[1], Rizky Aprilianti Ossa[1], Ade Yusnaini[1] and Hajrawati Hajrawati[2]*

[1] Department of Animal Science, Faculty of Agriculture, University of Bengkulu, Bengkulu. Indonesia. 38371A.
[2] Department of Animal Production Faculty of Animal Science, Hasanuddin University, Makassar, South Sulawesi, Indonesia.

ARTICLE INFO

Keywords:
Melastoma malabathricum
Beef sausage
Particle size
Antioxidant
Sensory quality
Natural preservative

ABSTRACT

This study evaluated the effects of *Melastoma malabathricum* (senduduk) leaf powder with different particle sizes (30, 40, and 50 mesh) on the quality of beef sausages. Sausages containing 0.75% senduduk powder were compared with a control and a butylated hydroxytoluene (BHT)-treated group. Parameters analyzed included microbial load, lipid oxidation (TBA), pH, cooking loss, moisture, water holding capacity (WHC), emulsion stability, elasticity, tenderness, and sensory properties. BHT showed superior antimicrobial and antioxidant activity, significantly lowering TPC and TBA values. Although senduduk powder did not significantly affect microbial counts, the 50-mesh size improved oxidative stability, WHC, elasticity, and aroma. However, it did not impact tenderness, color, or meaty taste. Overall acceptability of senduduk sausages was lower than BHT and control, possibly due to unfamiliar herbal flavors. These results suggest that while senduduk leaf powder has potential as a natural antioxidant, low inclusion levels limit its effectiveness, and further optimization is required for performance comparable to synthetic antioxidants.

1. Introduction

Lipid oxidation and microbial spoilage remain major challenges in the preservation of emulsified meat products such as sausages. These deteriorative processes compromise not only the shelf-life and safety, but also the sensory and nutritional quality of meat products (*Domínguez et al*., 2019). To mitigate these issues, synthetic antioxidants like butylated hydroxytoluene (BHT) are widely employed due to their proven efficacy in inhibiting oxidative degradation and microbial growth (*Zahid et al.*, 2019). However, growing consumer awareness and regulatory concerns about the potential health risks associated with synthetic additives have driven research toward natural alternatives.

Plant-based antioxidants derived from herbs, fruits, and leaves are gaining popularity as functional ingredients in meat systems due to their abundance of bioactive compounds, such as polyphenols, flavonoids, and tannins. These compounds exhibit antioxidant and antimicrobial activities by scavenging free radicals, chelating metal ions, and disrupting microbial cell membranes (*Rasheed et al*., 2024; Tiwari et al., 2023). Among these, *Melastoma malabathricum*—commonly known as senduduk—has emerged as a promising candidate due to its rich phytochemical profile and broad spectrum of biological activities.

Numerous studies have documented the medicinal properties of *M. malabathricum*, including antioxidant, antimicrobial, anti-inflammatory, and wound-healing activities (*Isnaini et al*., 2023; *Tiwari et al.*, 2023). Its leaves contain significant amounts of phenolic acids (e.g., gallic and ellagic acids), flavonoids (e.g., quercetin and kaempferol), and tannins, which contribute to its radical-scavenging ability and

***Corresponding author:** Suharyanto Suharyanto, *suharyanto@unib.ac.id*

Paper received: May 2nd 2025. Paper accepted 21st 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

microbial inhibition (*He et al.*, 2022; *Tiwari et al.*, 2023; *Hasan et al.*, 2024). In food-related applications, aqueous and ethanolic extracts of senduduk leaf have demonstrated strong ferric-reducing and DPPH-scavenging activity, suggesting potential as natural antioxidants in lipid-rich systems (*Zhang et al.*, 2024). However, the direct incorporation of senduduk leaf powder into meat matrices, particularly in emulsion-type sausages, remains largely unexplored.

In addition, the role of particle size in enhancing the functional efficacy of plant powders is increasingly recognized. Particle size reduction can improve the surface area, dispersion, and release kinetics of bioactive compounds, thus enhancing their interaction with proteins and lipids in the meat matrix (*Duguma et al.*, 2023; *Liang et al.*, 2024). Finer particles can facilitate improved oxidative stability, water-binding, and textural attributes due to more uniform incorporation and increased bioavailability of phenolic constituents (*Agamou et al.*, 2024; *Dacanal*, 2024).

This study aims to evaluate the effects of *M. malabathricum* (senduduk) leaf powder with different particle sizes (30, 40, and 50 mesh) on the microbiological, physicochemical, and sensory properties of beef sausages. In addition to natural treatments, a comparison with synthetic BHT and a negative control was conducted. Key quality indicators assessed were total plate count (TPC), thiobarbituric acid (TBA) values, pH, cooking loss, water holding capacity (WHC), emulsion stability, elasticity, instrumental tenderness, and sensory attributes. This investigation not only explores the applicability of *M. malabathricum* as a natural additive, but also provides novel insights into the role of particle size optimization in enhancing its performance in meat products.

2. Materials and Methods

2.1. Powder preparation from leaves

The *Melastoma malabathricum* leaves were collected from shrubs in Bengkulu City. The leaves used were the third leaves from the shoot, in intact condition. The leaves were cleaned from dust and other impurities, then air-dried for 72 hours. Afterward, they were oven-dried at 60 °C for 5 hours. The dried leaves were then blended or ground, then sieved sequentially using a 50-mesh sieve; the residue was further sieved with a 40-mesh sieve, and the remaining portion was sieved with a 30-mesh sieve. The fractions obtained from each mesh size were used as treatments.

2.2. Sausage's preparation and treatment application

Bali beef from the thigh was used for sausage production. The meat was separated from connective tissue and fat, cut into smaller pieces, and then ground. After grinding, salt, one-third of the ice crystals, and the treatment powder were added. Vegetable oil, seasonings, *Melastoma malabathricum* leaf powder/BHT, and another one-third of the ice crystals were

Table 1. Sausage formula and *Melastoma malabathricum* leaf powder treatments per batch

Ingredients	Treatments				
	Control	Butylated hydroxytoluene	30M	40M	50M
Meat (g)	400.0	400.0	400.0	400.0	400.0
Vegetable oil (g)	80.0	80.0	80.0	80.0	80.0
Skim milk powder (g)	24.0	24.0	24.0	24.0	24.0
Tapioca flour (g)	60.0	60.0	60.0	60.0	60.0
Ice crystal (g)	140.0	140.0	140.0	140.0	140.0
Salt (g)	8.0	8.0	8.0	8.0	8.0
Garlic powder (g)	7.0	7.0	7.0	7.0	7.0
Pepper powder (g)	3.0	3.0	3.0	3.0	3.0
Nutmeg powder (g)	1.6	1.6	1.6	1.6	1.6
BHT (g)	-	0.12	-	-	-
M. malabathricum leaf powder (g)	-	-	3.0	3.0	3.0
Total (g)	**723.6**	**724.0**	**726.6**	**726.6**	**726.6**

subsequently incorporated while mixing for several minutes. Skim milk powder and tapioca flour, along with the remaining one-third of the ice crystals, were then added until a homogeneous mixture was obtained. The treatments applied are shown in Table 1. The batter was allowed to rest for 10 minutes, stuffed into non-edible polyamide food-grade casings with a diameter of 16 mm, and steamed at 65 °C for 45 minutes.

2.3. Total plate count (TPC)

The total microbial count was determined using the plate count method, following the procedure of BSN (2008). A total of 25 g of sausage sample was aseptically homogenized in 225 mL of sterile buffered peptone water (BPW) as the initial dilution. Serial dilutions of 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} were then prepared by transferring 1 mL from the previous dilution to 9 mL of sterile BPW. From each dilution, 1 mL was transferred into separate sterile petri dishes, followed by the addition of 15–20 mL of sterile plate count agar (PCA). After the agar solidified, the plates were incubated at 37°C for 24–48 hours. Colony-forming units (cfu) were then counted.

2.4. Thiobarbituric acids (TBA)

TBA assay was adapted from the method published by *Tarladgis et al.* (1960). A total of 10 g of sausage was homogenized with 50 mL of distilled water for 2 minutes. The mixture was transferred into a distillation flask, and 47.5 mL of distilled water was added. Subsequently, 2.5 mL of 4 M HCl was added until the pH reached 1.5, along with boiling chips and an antifoam agent. Distillation was performed under high heat to collect 50 mL of distillate within 10 minutes. The distillate was stirred, and 5 mL was transferred into a test tube and mixed with 5 mL of TBA reagent. The mixture was heated in a boiling water bath for 35 minutes. A blank was prepared using 5 mL of distilled water and 5 mL of TBA reagent. After cooling for 10 minutes, the absorbance was measured at 528 nm, using the blank as a reference. The TBA value was calculated as mg of malondialdehyde per kg of sample using the equation: TBA = 7.8 × D.

2.5. pH value

The pH of the sausage was determined by homogenizing 1 gram of sausage with 9 mL of distilled water. The mixture was stirred until homogeneous, and the pH was measured using a calibrated pH meter.

2.6. Cooking loss

Cooking loss was calculated using the difference in weight before and after steaming. The weight of the batter was recorded before stuffing, and the weight of the sausage was measured after steaming, draining, and cooling to room temperature (with the casing removed). Cooking loss was expressed as a percentage using the following formula:

Cooking loss (%) = [(weight of batter – weight of sausage) / weight of batter] × 100

2.7. Moisture content

Moisture content was determined using the oven-drying method (AOAC, 2005). A 2 g sample of sausage was dried in an oven at 105 °C until a constant weight was achieved. Moisture content was calculated using the following formula:

Moisture content (%) = [(initial weight – weight after drying) / initial weight] × 100

2.8. Water Holding Capacity (WHC)

Water holding capacity (WHC) was determined using the centrifugation method (Jung & Joo, 2013) with slight modification. A 5 g portion of homogenized sausage sample was placed into a centrifuge tube and mixed with 10 mL of distilled water. The mixture was incubated at 30 °C for 30 minutes. After incubation, the mixture was centrifuged at 3000 rpm for 30 minutes. The supernatant was discarded, and the remaining pellet was re-incubated at 30 °C for 10 minutes. After the second incubation, the supernatant was again discarded. WHC was calculated using the following formula:

WHC (%) = [weight of sausage after supernatant removal / weight of sausage with 10 mL added water] × 100

2.9. Emulsion Stability

The measurement of emulsion stability adopted *Seo et al.* (2016) with minor modification. A 7.5 g sample was placed into a centrifuge tube and heated in a water bath at 70 °C for 30 minutes. The sample was then centrifuged at 1000 rpm for 10 minutes. The released supernatant was collected and weighed. This liquid was then dried in an oven at 105 °C for 16 hours. The residue remaining after drying was weighed and recorded as the fat content. The water content was calculated as the difference between the weight of the liquid and the fat content.

Emulsion stability is indicated by the amount of released water. The lower the amount of released water, the higher the emulsion stability.

The following formulas were used:

Released liquid (%) = (weight of released liquid / weight of sample) × 100

Released water (%) = (weight of water / weight of sample) × 100

2.10. Folding Test

The folding test was conducted based on the method described by Lanier (1992). The evaluation was performed by 25 semi-trained panelists selected from undergraduate students of the Animal Science Study Program, Faculty of Agriculture, University of Bengkulu, who had completed the Advanced Animal Product Technology course. A central section of the sausage was sliced into pieces measuring 3 mm in thickness and 2.5 cm in length. Each slice was folded using the index finger and thumb, and panelists assigned scores based on the degree of cracking observed during folding. A score of 5 was given if the sausage showed no cracking when folded, 4 if there was no cracking when folded into a half-circle, 3 if slight cracking occurred at the fold in the half-circle position, 2 if cracking appeared rapidly when folded into a half-circle, and 1 if cracking occurred immediately when the fingers applied pressure to fold the sample.

2.11. Tenderness

The measurement of sausage tenderness was performed using a universal penetrometer. The penetrometer was prepared by ensuring the indicator needle was at the zero position. A weight was then added to the plunger head of the needle rod. The load (g) was calculated by summing the weight of the weight, plunger head, and the needle. The sample was placed directly under the needle, and the pressure lever was pressed for 10 seconds. The indicator needle scale, which shows the depth of needle penetration into the sample (mm), was then read. Each measurement result was converted to the unit of mm g^{-1} s^{-1}.

2.12. Sensorial characteristics

The sensory characteristics were assessed by adapting *Meilgaard et al.* (1999) with slight modification. Sausages were evaluated by 25 semi-trained panelists selected from fifth-semester students of the Department of Animal Science, Faculty of Agriculture, University of Bengkulu. The panelists were given adequate briefing and instructions regarding the sensory evaluation procedures and organoleptic attributes to be assessed. The evaluated attributes included color (very dull – very bright), odor (very fishy – not fishy), texture (very coarse – smooth), tenderness (not tender – very tender), and overall acceptability (dislike very much – like very much).

Each evaluation was conducted using a linear scale, with the left end indicating the most negative perception and the right end indicating the most positive. A 7 cm horizontal line was used for each attribute. Panelists marked their personal responses on the line, and the distance (in cm) from the left end to the mark was measured as the hedonic and quality score. Each sample was coded with a three-digit random number, and evaluations between samples were interspersed with palate cleansing using plain water.

2.13. Statistical Analysis

The obtained data were analyzed using analysis of variance (ANOVA). For variables that showed significant differences among treatments, further analysis was conducted using Duncan's Multiple Range Test (DMRT). A confidence level of 95% was used in all statistical evaluations.

3. Results and Discussion

3.1. Total Plate Count (TPC)

TPCs of beef sausages ranged from 3.63 to 4.16 log cfu g^{-1} (Table 2). A significantly lower ($P < 0.05$) TPC was observed in the BHT group (3.63 log cfu g^{-1}) compared to the control (4.16 log cfu g^{-1}), confirming the well-documented antimicrobial efficacy of synthetic antioxidants through membrane disruption and enzyme inhibition (*Osorio-Olivares et al*., 2024).

While sausages treated with senduduk leaf powder (30M, 40M, 50M) showed no statistically significantly lower TPC compared to the control, slightly lower TPCs were noted in the 40M (3.97 log cfu g^{-1}) and 50M (4.02 log cfu g^{-1}) groups relative to 30M (4.14 log cfu g^{-1}). These findings suggest that smaller particle sizes could enhance antimicrobial efficacy, likely due to their greater surface area, facilitating greater release and bioavailability of phenolic compounds (*Khoo et al*., 2017; *Prasedya et al*., 2021; *Zhang et al*., 2024).

Table 2. Total plate count (TPC), thiobarbituric acid (TBA) value, and pH of beef sausages with senduduk leaf powder, butylated hydroxytoluene (BHT), and control treatments.

Variables	Treatments				
	Control	BHT	30M	40M	50M
TPC (log cfu g^{-1})	4.16±0.12^{a}	3.63±0.24^{b}	4.14±0.08^{a}	3.97±0.37^{ab}	4.02±0.28^{a}
TBA (mg Kg^{-1})	0.07±0.02	0.03±0.05	0.05±0.03	0.05±0.03	0.04±0.02
pH	6.00±0.28^{a}	5.70±0.26^{ab}	5.40±0.12^{b}	5.46±0.19^{b}	5.43±0.33^{b}

Legend: Means in the same row with different superscript letters differ significantly (P < 0.05). 30M, 40M, 50M = particle size of senduduk leaf powder in mesh.

Polyphenols exhibit antimicrobial activity via multiple mechanisms, including membrane disruption, inhibition of DNA and protein synthesis, metal ion chelation, oxidative stress induction, and interference with quorum sensing (*Rasheed et al*., 2024). However, the relatively modest TPC reductions in senduduk treatments suggest that a 0.75% inclusion level may be insufficient to exert a strong antimicrobial effect, potentially due to limited release or thermal degradation of active compounds during processing. These results indicate that higher concentrations or alternative delivery methods could be required to optimize the antimicrobial potential of senduduk leaf powder in meat matrices.

3.2. Thiobarbituric Acid (TBA)

Lipid oxidation levels, determined by the TBA assay, ranged from 0.03 to 0.07 mg MDA kg^{-1} (Table 2). As expected, the BHT treatment exhibited the lowest TBA value (0.03 mg kg^{-1}), confirming its high oxidative stability. Among the treatments with senduduk leaf powder, the 50M group showed the lowest TBA value (0.04 mg kg^{-1}), followed by 30M and 40M (both at 0.05 mg kg^{-1}). Although the differences were not statistically significant, the data suggest a trend toward improved oxidative stability with decreasing particle size.

The enhanced antioxidant potential of finer particles may be attributed to their increased surface area, which facilitates the release and diffusion of bioactive compounds. Senduduk leaf is known to be rich in phenolic acids and flavonoids (*Hipol et al*., 2023), which function as hydrogen donors, scavenging lipid peroxyl radicals and inhibiting the propagation phase of lipid oxidation (*Tiwari et al*., 2023). The lower TBA values observed in the 50M group suggest a more efficient antioxidant activity, likely due to greater availability and mobility of phenolic constituents.

These findings are consistent with previous studies indicating that smaller particle sizes enhance antioxidant efficacy in meat systems. *Duguma et al*. (2023) reported that finely ground herbal extracts provided more uniform and effective oxidative protection. Similarly, *Agamou et al.* (2024) and *Zhang et al.* (2024) demonstrated that particle size reduction increases total phenolic content and antioxidant capacity due to cell wall disruption and improved compound release. *Liang et al*. (2024) further emphasized that grinding enhances the bioavailability of antioxidant compounds by mechanically breaking plant cell matrices.

Nevertheless, despite the observed trend, the antioxidant efficacy of senduduk leaf powder remained inferior to that of BHT, possibly due to lower concentration or stability of active compounds during processing. These results suggest that while particle size reduction improves the functional performance of natural antioxidants, optimizing the concentration and protection of phenolics during thermal treatment remains essential for maximizing oxidative stability in meat products.

3.3. pH Values

The pH of the sausages ranged from 5.40 (30M) to 6.00 (control), showing significant differences (P < 0.05) between 30M/40M/50M and the control (Table 2). The lower pH in the senduduk groups compared with the control could be attributed to the acidic nature of phenolic compounds in senduduk powder. These compounds can contribute to a decrease in pH by interacting with meat proteins and other components, leading to a more acidic environment (*Suharyanto et al.*, 2020) by donating hydrogen ions, resulting in increased acidity (*Suharyanto et al.*, 2022).

However, the pH of sausage obtained from the addition of senduduk leaf powder with particle sizes of 30 mesh to 50 mesh was similar. This is likely due to comparable particle surface areas and phenolic compound release within this narrow particle size range. The minor variation in particle size did not significantly alter the quantity and efficacy of phenolic compounds interacting with the meat matrix, resulting in uniform pH levels across treatments (*Novelli et al.*, 2014). It is possible that further reduction in particle size could result in a significant decrease in pH.

3.4. Cooking Loss

Cooking loss did not differ significantly among treatments ($P > 0.05$), ranging from 1.06% to 1.87% (Table 3), indicating that 0.75% addition of senduduk leaf powder with differing particle sizes or BHT had limited impact on moisture and fat loss during heating. Cooking loss reflects emulsion stability and is governed by the integrity of protein-water-fat interactions during thermal processing (*Mazumder et al.*, 2023; *Kawata et al.*, 2023; *Faridah et al.*, 2023). Although antioxidants can enhance structural stability by mitigating protein oxidation (*Oh et al.*, 2024), their effect could be negligible at low inclusion levels. This is consistent with previous findings where low-dose herbal antioxidants (<1%) did not alter cooking loss despite improving WHC and oxidative stability (*Bellucci et al.*, 2022; *Adeyemi et al.*, 2025). In this study, improved WHC in some treatments did not translate into lower cooking loss, likely due to the limited influence of internal water-binding changes on fluid release during cooking at low additive concentrations. Thus, higher inclusion levels or alternative strategies could be required to achieve significant improvements in cooking yield.

3.5. Moisture Content

The moisture content among treatments (control, BHT, 30M, 40M, and 50M) showed no significant differences ($P > 0.05$), with values ranging from 61.80% to 63.59% (Table 3). This observation shows that the addition of senduduk leaf powder at the 0.75% concentration and different particle sizes (30, 40, and 50 mesh) did not substantially alter the overall moisture content in beef sausage.

Moisture content in processed meat is mainly governed by initial water addition, ingredient water-binding capacity, and processing conditions (*Kim et al.*, 2022). In this study, the low-level addition (0.75%) of senduduk leaf powder did not significantly affect total moisture content, despite notably enhancing WHC. This indicates that senduduk leaf powder primarily modifies protein-water interactions, thus improving water retention, rather than altering overall moisture content. These findings are consistent with previous reports, which suggest that small herbal additions typically influence functional properties, like WHC and protein-water interactions, rather than directly affecting moisture levels (*Choe et al.*, 2011; *Zhang et al.*, 2013).

Table 3. Physicochemical properties of beef sausages with senduduk leaf powder, butylated hydroxytoluene (BHT), and control treatments.

Variables	Treatments				
	Control	BHT	30M	40M	50M
Cooking Loss (%)	1.06±0.71	1.37±0.52	1.87±1.48	1.68±0.68	1.77±1.01
WHC (%)	$78.16±0.88^{c}$	$87.14±1.04^{a}$	$64.30±0.83^{e}$	$76.03±1.03^{d}$	$85.17±0.99^{b}$
Moisture Content (%)	63.22±2.13	61.80±1.31	63.36±2.64	62.57±1.87	63.59±2.49
Fluid Release (%)	0.34±0.22	0.10±0.06	0.17±0.06	0.18±0.06	0.11±0.08
Folding Test	$2.44±1.12^{bc}$	$2.40±0.96^{bc}$	$1.92±0.76^{c}$	$2.68 ± 0.85^{b}$	$3.52±1.00^{a}$
Tenderness ($mm\ g^{-1}\ s^{-1}$)	0.48±0.22	0.55±0.10	0.46±0.06	0.45±0.11	0.45±0.15

Legend: Means in the same row with different superscript letters differ significantly ($P < 0.05$). 30M, 40M, 50M = particle size of senduduk leaf powder in mesh.

3.6. Water Holding Capacity (WHC)

The WHC showed significant differences among treatments ($P < 0.05$), with BHT-treated sausages exhibiting the highest WHC (87.14%), followed by sausages containing senduduk leaf powder with finer particle sizes (50M; 85.17%) (Table 3). The significant differences in WHC suggest that both the nature of additives and particle size significantly influenced water-protein interactions and consequently affected the ability of the product to retain moisture.

The greater WHC in sausages with BHT likely result from BHT's antioxidant activity, which prevents protein oxidation and maintains protein integrity, thereby preserving their water-binding functionality (*Boateng et al.*, 2022). Protein oxidation negatively alters protein structure, reducing WHC (*Liu et al.*, 2022a; *Liu et al.*, 2022b). Additionally, WHC improved with decreasing particle size of senduduk leaf powder (from 30M to 50M), as finer particles enhance extraction and dispersion of bioactive compounds such as flavonoids and tannins. These compounds interact effectively with meat proteins, stabilizing the emulsion and improving water-binding capacity (*Dacanal*, 2024). Thus, both antioxidant properties and optimal particle size enhance WHC by preserving protein integrity and strengthening protein-water interactions.

3.7. Emulsion Stability

The effects of adding senduduk leaf powder of differing particle sizes on the emulsion stability of sausages are presented in Table 3. Emulsion stability, as indicated by fluid release after physical agitation (vortexing), showed numerical differences among treatments, although these were not statistically significant ($P > 0.05$). Specifically, fluid release values were lowest in sausages containing synthetic antioxidant BHT (0.10 ± 0.06%), followed closely by sausages formulated with the smallest particle size of senduduk leaf powder (50 mesh) at 0.11 ± 0.08%. Sausages with 30 mesh and 40 mesh senduduk powders exhibited slightly higher fluid releases of 0.17 ± 0.06% and 0.18 ± 0.06%, respectively, whereas the control without antioxidants demonstrated the highest fluid release at 0.34 ± 0.22%.

The numerical reduction in fluid release with senduduk leaf powder and BHT could be associated with improved emulsion formation due to the presence of phenolic compounds in plant powders, which interact with meat proteins and lipids to stabilize the matrix (*Jung et al.*, 2022). Finer particles, such as those in the 50 mesh treatment, likely dispersed more effectively, enhancing these interactions (*Albert et al.*, 2019). However, the lack of significant differences suggests that the 0.75% concentration of senduduk leaf powder was insufficient to produce a measurable stabilizing effect. *Lee et al.* (2020) similarly reported no improvement in emulsion stability at low concentrations of plant-derived antioxidants. Measurement variability could also have contributed to the non-significant findings.

3.8. Folding Test

The effects of incorporating senduduk leaf powder with varying particle sizes on sausage elasticity, as measured by folding test scores, are presented in Table 3. A significant effect was observed among treatments ($P < 0.05$). The 50M treatment, containing 0.75% senduduk leaf powder at 50 mesh, yielded the highest folding score (3.52 ± 1.00), indicating superior elasticity compared to all other treatments. Conversely, the lowest elasticity was observed in the 30M group (1.92 ± 0.76), suggesting that larger particle sizes might interfere with the uniform distribution and interaction of bioactive compounds with meat proteins. The 40M treatment showed intermediate elasticity (2.68 ± 0.85), while the control (2.44 ± 1.12) and BHT (2.40 ± 0.96) groups did not differ significantly and demonstrated moderate elasticity.

The improved elasticity observed in the 50M treatment is likely due to the increased surface area of finer particles, which enhances their dispersion and integration within the meat matrix. This facilitates stronger interactions between phenolic compounds and myofibrillar proteins, supporting a more cohesive protein gel network. These findings are consistent with *Suharyanto et al.* (2025), who reported that finer plant powders improve protein binding and water retention in meat products. Conversely, the coarser particles in the 30M treatment may have led to incomplete incorporation into the protein matrix, reducing cohesiveness and gel strength, as similarly noted by *Santhi et al.* (2017). Folding scores of BHT-treated sausages were comparable to the control, indicating that BHT had minimal impact on elasticity. This suggests that the physical form and matrix interaction of antioxidants play a critical role in texture, beyond their chemical properties alone.

3.9. Tenderness

No significant differences were observed in sausage tenderness among treatments ($P > 0.05$), with values ranging from 0.45 to 0.55 mm g^{-1} s^{-1} (Table 3). The addition of 0.75% senduduk leaf powder, regardless of particle size, did not influence texture compared to the control or BHT-treated sausages.

These findings suggest that the concentration used may have been too low to induce structural changes in the meat matrix. Previous studies have similarly reported limited effects of low-level plant-based antioxidants on textural parameters in emulsified meat products (*Lee et al.*, 2020). Additionally, differences in particle size (30–50 mesh) may not have been large enough to alter the dispersion or interaction of the powder with meat proteins.

It is also possible that the bioactive compounds in senduduk powder were insufficiently available to influence myofibrillar protein interactions, a key determinant of meat tenderness. The instrumental method used may also lack sensitivity to detect subtle differences in gel firmness at such low additive levels.

Further research with higher inclusion levels or functional extracts of senduduk leaf, as well as more detailed rheological assessments, are warranted to fully understand its potential impact on textural quality.

3.10. Sensory Properties

The sensory evaluation showed no significant differences ($P > 0.05$) in color, texture, tenderness, or meaty flavor of the sausages, but significant differences ($P < 0.05$) were observed in aroma and overall acceptance (Table 4). Lightness scores ranged from 4.80 to 5.56 and did not differ significantly. Adding 0.75% senduduk leaf powder with different particle sizes had little effect on color, likely due to its low pigment content, similar to findings in sausages with low levels of natural antioxidants (Lee et al., 2020).

Aroma scores differed significantly ($P < 0.05$), with BHT (5.50) and 50M (5.53) scoring higher than 30M (4.88), while the control and 40M were intermediate. Finer senduduk powder (50 mesh) likely interacted better with volatile compounds, reducing off-odors, aided by phenolic compounds (*Lee et al.*, 2020). Lower aroma scores in 30M could be due to poor dispersion within the meat matrix.

Although texture scores did not differ significantly, BHT and control groups scored higher (5.50 and 5.27, respectively) than 30M and 40M (4.48 and 4.67, respectively). Coarser particles could have disrupted the emulsion structure, affecting mouthfeel. Uniform particle size is important for maintaining good texture in emulsified products (*Santhi et al.*, 2017). Tenderness scores (5.21–5.84) also showed no significant differences, with all sausages rated moderately tender, supporting instrumental results and confirming that low levels of natural antioxidants do not affect tenderness (*Lee et al.*, 2020). Meaty flavor perception was similar across treatments, although the control and BHT (6.16 and 6.18, respectively) scored slightly higher than senduduk groups. This suggests that senduduk powder at 0.75% does not enhance or impair meat flavor, consistent with earlier studies (*Domínguez et al.*, 2019).

Significant differences ($P < 0.05$) were observed in overall acceptance. BHT-treated sausages had the highest score (6.24), followed by the control (5.78), while senduduk treatments were lower (5.14–5.47). Although 50M improved aroma and elasticity, overall acceptability was not significantly enhanced, possibly due to combined effects

Table 4. Sensory properties of beef sausages with senduduk leaf powder, butylated hydroxytoluene (BHT), and control treatments.

Variables	Treatments				
	Control	**BHT**	**30M**	**40M**	**50M**
Color (Lightness)	5.56 ± 1.32	5.44 ± 1.32	4.84 ± 1.19	4.80 ± 1.35	5.17 ± 1.31
Odor (fishy-unfishy)	5.43 ± 0.92^{ab}	5.50 ± 0.97^{a}	4.88 ± 1.12^{b}	5.06 ± 0.73^{ab}	5.53 ± 0.91^{a}
Texture	5.27 ± 1.19	5.50 ± 1.00	4.48 ± 1.13	4.67 ± 0.90	5.07 ± 1.26
Tenderness	5.38 ± 1.20	5.84 ± 1.24	5.45 ± 1.16	5.23 ± 1.27	5.21 ± 1.63
Meaty Taste	6.16 ± 1.08	6.18 ± 1.04	5.75 ± 1.04	5.60 ± 1.40	5.82 ±1.42
Acceptance	5.78 ± 1.09^{ab}	6.24 ± 1.04^{a}	5.47 ± 1.02^{b}	5.14 ± 1.18^{b}	5.29 ± 0.99^{b}

Legend: Means in the same row with different superscript letters differ significantly ($P < 0.05$). 30M, 40M, 50M = particle size of senduduk leaf powder in mesh.

of color, texture, or unfamiliar herbal notes. Overall liking depends on a balance of multiple sensory traits (*Fiorentini et al*., 2020).

4. Conclusion

This study demonstrates that adding 0.75% senduduk (*Melastoma malabathricum*) leaf powder to beef sausages had limited effects on microbiological, chemical, physical, and sensory qualities. Finer particles (50 mesh) slightly improved the WHC, emulsion stability, and elasticity without significantly affecting moisture, tenderness, or cooking loss. Sensory evaluation showed better odor and overall acceptance with finer powder, although other attributes remained largely unchanged. Senduduk leaf powder shows potential as a natural antioxidant, but further optimization of concentration, particle size, and processing is needed to match the efficacy of synthetic antioxidants like BHT.

Primena praha lista biljke senduduk (*Melastoma malabathricum*) kao prirodnog antioksidansa u goveđim kobasicama: Uloga veličine čestica u kvalitetu proizvoda

Suharyanto Suharyanto, Warnoto Warnoto, Rizky Aprilianti Ossa, Ade Yusnaini i Hajrawati Hajrawati

INFORMACIJE O RADU

Ključne reči:
Melastoma malabathricum
Goveđe kobasice
Veličina čestica
Antioksidans
Senzorski kvalitet
Prirodni konzervans

APSTRAKT

U ovoj studiji ispitivan je uticaj praha lista biljke Melastoma malabathricum (senduduk) različitih veličina čestica (30, 40 i 50 meš) na kvalitet goveđih kobasica. Kobasice koje su sadržale 0,75% praha senduduka upoređene su sa kontrolnom grupom i grupom tretiranom butiliranim hidroksitoluolom (BHT). Analizirani parametri obuhvatali su mikrobiološko opterećenje, oksidaciju lipida (TBA), pH vrednost, gubitak pri kuvanju, sadržaj vlage, sposobnost zadržavanja vode (WHC), stabilnost emulzije, elastičnost, mekoću i senzorna svojstva. BHT je pokazao superiorno antimikrobno i antioksidativno delovanje, značajno smanjujući ukupni broj mikroorganizama (TPC) i vrednosti TBA. Iako prah senduduka nije značajno uticao na broj mikroorganizama, veličina čestica od 50 meš poboljšala je oksidativnu stabilnost, WHC, elastičnost i aromu. Međutim, nije zabeležen uticaj na mekoću, boju ili mesnati ukus. Ukupna prihvatljivost kobasica sa dodatkom senduduka bila je niža u poređenju sa BHT i kontrolnom grupom, verovatno usled prisustva nepoznatih biljnih aroma. Dobijeni rezultati ukazuju na to da prah lista senduduka poseduje potencijal kao prirodni antioksidans, ali njegova ograničena efikasnost pri niskim koncentracijama zahteva dodatnu optimizaciju kako bi se postigla uporediva svojstva sa sintetičkim antioksidansima.

Disclosure statement: No potential conflict of interest was reported by the authors.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements: The authors sincerely thank the Head of the Department of Animal Science and the Head of the Animal Science Laboratory, Faculty of Agriculture, University of Bengkulu, for their support and for providing the facilities for this research.

References

Adeyemi, K. D., Olatunji, O. S., Atolani, O., Ishola, H., Shittu, R.M., Okukpe, K. M. ... & Kazeem, M. O. (2025). Cholesterol oxides and quality attributes of NaCl-substituted low-fat chicken sausages prepared with different antioxidants. *Heliyon* 11(2), e41796.

Agamou, A., Djeukeu, A.W., Assiene, O. D. S., Zra, T., Obono Ndong, T. L., Mbango Eke, P., Mboube Ngongang, O., Keubing Feudjio, S. R. & Fongnzossie, E. (2024). Influence of particle size fraction and bioactive compound contents on the biological activities of *Solanum torvum* L. leaf powder extracts. *Journal of Experimental Biology and Agricultural Sciences* 12(2), 203–217.

Albert, C., Beladjine, M., Tsapis, N., Fattal, E., Agnely, F. & Huang, N. (2019). Pickering emulsions: Preparation processes, key parameters governing their properties and potential for pharmaceutical applications. *Journal of Controlled Release* 309, 302–332.

AOAC, (2005). Official methods of analysis of AOAC International (18th ed.). Association of Official Analytical Chemists.

Bellucci, E. R. B., Dos Santos, J. M., Carvalho, L. T., Borgonovi, T. F., & Lorenzo, J. M. & da Silva-Barretto, A.C. (2022). Açaí extract powder as natural antioxidant on pork patties during the refrigerated storage. *Meat Science* 184, 108667.

Boateng, E. F., Yang, Z. & Zhang, W. (2022). Effects of kiwifruit peel extract and its antioxidant potential on the quality characteristics of beef sausage. *Antioxidants* 11(8), 1441.

Choe, J. H., Jang, A., Lee, E. S., Choi, J. H., Choi, Y. S., Han, D. J. ... & Kim, C. J. (2011). Oxidative and color stability of cooked ground pork containing lotus leaf (*Nelumbo nucifera*) and barley leaf (*Hordeum vulgare*) powder during refrigerated storage. *Meat Science* 87(1), 12–18.

Dacanal, G. C. (2024). Particle size and morphology in food science and technology: a review. *International Journal of Food Science and Technology* 59(10), 6821–6833.

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W. & Lorenzo, J. M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants* 8(10), 429.

Duguma, H. T., Zhang, L., Ofoedu, C. E., Chacha, J. S. & Agunbiade, A. O. (2023). Potentials of superfine grinding in quality modification of food powders. *CyTA-Journal of Food* 21(1), 530–541.

Faridah, M. R., Yusoff, M. M., Rozzamri, A., Ibadullah, W. Z. W., Hairi, A. N. A., Daud, N. H. A. ... & Ismail-Fitry, M. R. (2023). Effect of palm-based shortenings of various melting ranges as animal fat replacers on the physicochemical properties and emulsion stability of chicken meat emulsion. *Foods* 12(3), 597.

Fiorentini, M., Kinchla, A. J. & Nolden, A. A. (2020). Role of sensory evaluation in consumer acceptance of plant-based meat analogs and meat extenders: A scoping review. *Foods* 9(9), 1334.

Hasan, N. A., Wazir, N. N., Samsudin, M. Y., Sanizam, M. M. S. M., Ahmad, N. M., Hisham, N. A. B. ... & Masdek, N. R. N. (2024). Evaluation of phytoactive contents and antibacterial activities of green synthesised cerium oxide nanoparticles using *Melastoma* sp. leaf extract as the capping agent. *Heliyon* 10(14), e34558.

He, R. J., Wang, Y. F., Yang, B. Y., Liu, Z. B., Li, D. P., Zou, B. Q. & Huang, Y. L. (2022). Structural characterization and assessment of anti-inflammatory activities of polyphenols and depsidone derivatives from *Melastoma malabathricum* subsp. normale. *Molecules* 27(5),1521.

Hipol, R. L., Wayas, H., Hipol, R., Bacuyag, F. M., Cabanlong, J., Daquigan, M. & Pladio, L. (2023). Phytochemical content, thin layer chromatographic profile, and pharmacologic activities of the Philippine native *Melastoma malabathricum* Linn. from Benguet. *Science, Engineering and Health Studies* 23050012–23050012.

Isnaini, Oktaviyanti, I. K. & Budiarti, L. Y. (2023). Antibacterial and wound healing activity of ethanolic extract *Melastoma malabathricum* L. *Research Journal of Pharmacy and Technology* 16(5), 2210–2214.

Jung, D. Y., Lee, H. J., Shin, D. J., Kim, C. H. & Jo, C. (2022). Mechanism of improving emulsion stability of emulsion-type sausage with oyster mushroom (*Pleurotus ostreatus*) powder as a phosphate replacement. *Meat Science* 194, 108993.

Jung, E. & Joo, N. (2013). Roselle (*Hibiscus sabdariffa* L.) and soybean oil effects on quality characteristics of pork patties studied by response surface methodology. *Meat Science* 94, 391–401.

Kawata, K., Giotto, F.M., de Mello, A.S., Kingery, T. & Silva, L.H. (2023). Effect of Beef Silver Skin (Epimysium) Levels on Meat Emulsion Stability, Quality Attributes, and Texture Parameters. *Foods* 12(20), 3775.

Khoo, H. E., Azlan, A., Tang, S. T. & Lim, S. M. (2017). Anthocyanidins and anthocyanins: Colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food & Nutrition Research* 61(1), 1361779.

Kim, D. H., Kim, Y. J., Shin, D. M., Lee, J. H. & Han, S. G. (2022). Drying characteristics and physicochemical properties of semi-dried restructured sausage depend on initial moisture content. *Food Science of Animal Resources* 42(3), 411.

Lanier, T.C. (1992). Measurement of surimi composition and functional properties. In Lanier, T.C. & Lee, C.M. (Eds.), Surimi Technology. Marcel Dekker, pp. 123–163.

Lee, S. Y., Lee, D. Y., Kim, O. Y., Kang, H. J., Kim, H. S. & Hur, S. J. (2020). Overview of studies on the use of natural antioxidative materials in meat products. *Food Science of Animal Resources* 40(6), 863–880.

Liang, K., Liang, S. & Zhu, H. (2024). The physicochemical characteristics and phenolic bioaccessibility of defatted millet bran powder prepared using superfine grinding. *LWT- Food Science and Technology* 201, 116173.

Liu, J., Liu, D., Zheng, A. & Ma, Q. (2022a). Haem-mediated protein oxidation affects water-holding capacity of beef during refrigerated storage. *Food Chemistry* X 14, 100304.

Liu, Y., Zhang, L., Gao, S., Bao, Y., Tan, Y., Luo, Y. ... & Hong, H. (2022b). Effect of protein oxidation in meat and exudates on the water holding capacity in bighead carp (*Hypophthalmichthys nobilis*) subjected to frozen storage. *Food Chemistry* 370, 131079.

Mazumder, M. A. R., Sujintonniti, N., Chaum, P., Ketnawa, S. & Rawdkuen, S. (2023). Developments of plant-based emulsion-type sausage by using grey oyster mushrooms and chickpeas. *Foods* 12(8), 1564.

Meilgaard, M. C., Carr, B. T. & Civille, G. V. (1999). Sensory evaluation techniques. CRC Press.

BSN National Standardization Agency of Indonesia. (2008). Methods for testing microbial contamination in meat, eggs, milk, and their processed products (SNI 2897:2008). National Standardization Agency of Indonesia.

Novelli, E., Fasolato, L., Cardazzo, B., Carraro, L., Taticchi, A. & Balzan, S. (2014). Addition of phenols compounds to meat dough intended for salami manufacture and its antioxidant effect. *Italian Journal of Food Safety* 3(3), 1704.

Oh, Y. N., Choi, H. Y., Kim, Y. B., Hong, S. G. & Kim, H. Y. (2024). Effect of paprika powder on the antioxidant capacity of emulsion-type sausages. *Food Science of Animal Resources* 44(5), 1126.

Osorio-Olivares, M.E., Vásquez-Martínez, Y., Díaz, K., Canelo, J., Taborga, L. & Espinoza-Catalán, L. (2024). Antibacterial and antioxidant activity of synthetic polyoxygenated flavonoids. *International Journal of Molecular Sciences* 25(11), 5999.

Rasheed, H. A., Rehman, A., Karim, A., Al-Asmari, F., Cui, H. & Lin, L. (2024). A comprehensive insight into plant-derived extracts/bioactives: Exploring their antimicrobial mechanisms and potential for high-performance food applications. *Food Bioscience* 104035.

Santhi, D., Kalaikannan, A. & Sureshkumar, S. (2017). Factors influencing meat emulsion properties and product texture: A review. *Critical Reviews in Food Science and Nutrition* 57(10), 2021–2027.

Seo, J. K., Yum, H. W., Kim, G. D., Jeong, J. Y., & Yang, H. S. (2016). Properties of frankfurter-type sausages with pork back-fat replaced with bovine heart surimi-like materials. *Korean Journal for Food Science of Animal Resources* 36(4), 523.

Suharyanto, Nuraini, H., Suryati, T., Arief, I. I. & Sajuthi, D. (2022). Antioxidant, antimicrobial and physicochemical properties of beef sausages enriched with an aqueous extract of Senduduk (*Melastoma malabathricum* L.) leaf. *International Journal of Food Studies* 11(2), 320–334.

Suharyanto, S., Nuraini, H., Suryati, T., Arief, I. I. & Sajuthi, D. (2020). Aqueous leaf extract of Senduduk (*Melastoma malabathricum* L.) could improve the physicochemical properties of beef sausage dough. *Jurnal Ilmu dan Teknologi Hasil Ternak* 15(2), 86–96.

Suharyanto, S., Warnoto, W., Banjarnahor, T.L., Timoti, I. & Hajrawati, H. (2025). Improving beef meatball properties by adding senduduk (*Melastoma malabathricum* L.) leaf powder. *International Journal of Agricultural Technology* 21(1), 299–316.

Tarladgis, B. G., Watts, B. M., Younathan, M. T. & Dugan, L. R. (1960). A distillation method for the quantitative determination of malonaldehyde in rancid foods. *Journal of the American Oil Chemists' Society* 37(1), 44–48.

Tiwari, M., Barooah, M. S. & Bhuyan, D. (2023). Phytochemical and bioactive potentialities of *Melastoma malabathricum*. In Recent Frontiers of Phytochemicals. Elsevier, pp. 601–615.

Zhang, W., Xiao, S. & Ahn, D. U. (2013). Protein oxidation: Basic principles and implications for meat quality. *Critical Reviews in Food Science and Nutrition* 53(11), 1191–1201.

Zhang, Z., Chen, Y., Wang, S., Tong, Z., Luan, F., Jiang, B. ... & Xu, Z. (2024). Effect of particle size on physical properties, dissolution, in vitro antioxidant activity, and in vivo hepatoprotective properties of *Tetrastigma hemsleyanum* Diels et Gilg powders. *Pharmaceutics* 16(11), 1352.

Authors info

Suharyanto Suharyanto, https://orcid.org/0000-0002-0114-3690
Warnoto Warnoto, https://orcid.org/0009-0007-8429-3267
Rizky Aprilianti Ossa, https://orcid.org/0009-0005-7570-2079
Ade Yusnaini, https://orcid.org/0009-0006-1745-0069
Hajrawati Hajrawati, https://orcid.org/0000-0001-7096-2502

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.5.028:636.2(594)
637.056:582.546.2(594)
COBISS.SR-ID: 176283657
https://doi.org/10.18485/meattech.2025.66.2.7

Original Scientific Paper

The effect of using different bamboo on the characteristics of sui wu'u fermented meat from Bajawa, Nusa Tenggara Timur

Sulmiyati Sulmiyati[1*], *Gemini Ermiani Mercurina Malelak*[1] and *Bastari Sabtu*[1]

[1] Universitas Nusa Cendana, Faculty of Animal Science, Marine, and Fisheries, Jl. Adi Sucipto, Penfui Kupang, 85001, Nusa Tenggara Timur, Indonesia

ARTICLE INFO

Keywords:
Beef
Food
Preservatives
Traditional
Quality

ABSTRACT

This research aimed to analyze the characteristics of beef sui wu'u prepared by storing the meat product in different types of bamboo. The research design used four treatments with five storage replications: P1: green betung bamboo (Dendrocalamus asper), P2: brown betung bamboo (Dendrocalamus asper), P3: talang bamboo (Schizoztachyum brachcladum), P4: gombong bamboo (Gigantocloa verticallata). The research showed that the different types of bamboo storage had a significant effect (P<0.05) on the physical characteristics of beef sui wu'u in terms of yield, final pH, water holding capacity and hardness. Among the chemical characteristics, using different types of bamboo had a significant effect (P<0.05) on the water and protein content of beef sui wu'u. The organoleptic characteristics showed the different types of bamboo storage container had a significant effect (P<0.05) on colour, aroma, texture and overall acceptability, but for the colour dimensions, L *, a*, b*, Cab, hab, Y, X, Z, x, y, Wi, Ti, and Tw, there were no significant effects (P>0.05). The microbiological characteristics of the sui wu'u for all types of bamboo used were within the standard limits fermented meat products. The use of different types of bamboo influences the characteristics of beef sui wu'u in terms of physical, chemical, colour dimensions, organoleptic characteristics and microbiology. The use of containers made from brown betung bamboo (Dendrocalamus asper) produces better beef sui wu'u than the other bamboo types. Nonetheless, the use of talang bamboo and gombong bamboo can also be recommended in the process of making sui wu'u, but the final beef product had different characteristics from the sui wu'u stored in brown betung bamboo, and was especially different from sui wu'u stored in talang bamboo.

1. Introduction

Traditional meat fermentation utilizes the activity of bacteria or enzymes that occur during the fermentation process, where bacterial or enzyme activity is obtained from the raw materials used in the meat fermentation process or from the type of container used during the process of fermentation. The fermented meat product traditional found in East Nusa Tenggara, Indonesia, is sui wu'u. The name sui wu'u, according to the local Flores people, is derived from sui (meat) and wu'u (corn flour). Although sui is the general word for all types of meat, it can specifically refer to beef. A similar, related product is called hui wu'u when based on pork (hui in the local language). Therefore, the product's name depends on the meat used, but regardless, this product is fermented meat coated with salt and corn flour and then stored in bamboo containers, locally called tuku. According to (*Rubak, Lalel, & Sanam,* 2023), sui wu'u is a product produced by the people of Bajawa, East Nusa Tenggara, using

***Corresponding author:** *sulmiyati@staf.undana.ac.id*

Paper received: January 23rd 2025. Paper accepted July 29th 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

preservation by traditional methods, i.e., by coating the meat with salt then storing it in bamboo (tuku) for six months. *Febrianti et al.* (2021) the type of bamboo used is betung (aka petung) bamboo (*Dendrocalamus asper*), which contains bioactive compounds, such as phenolics, flavonoids, lignans, tannins. Research conducted by (*Chee et al.,* 2020) showed that *D. asper* contains phenolics and flavonoids (total phenolic content measured via Folin-Ciocalteu), has antioxidant activity measurable using the DPPH method, as well as enzymatic activity, such as inhibiting α-amylase and α-glucosidase. In addition, *Lactococcus lactis* was isolated from sui wu'u (*Rubak*, *Lalel*, *Sanam*, *et al*., 2023).

The characteristics of fermented meat products are their specific taste, texture and long shelf-life, all a result of both natural fermentation or from added cultured microorganisms (*Zhong et al*., 2021). Various fermented meat products are traditionally produced across Asia, the principles of which are almost the same as sui wu'u (*Wang et al.,* 2022*; Zhong et al.,* 2021; 2022)*,* including a local product from Hunan and Guizhou, China, with added rice flour and salt. Apart from that, the same principle applies to Cangkuk fermented meat product and this processed product comes from Kuantan Singingi, Riau, Indonesia, and has added betung bamboo shoots, rice and salt (*Mirdhayati,* 2022). Furthermore *Endo et al.* (2014), a type of fermented processed product, Jinhua ham, is a fermented traditional product from Jinhua, China, a pork product coated with salt and stored for two months. Nham is a fermented pork product from Thailand, where the meat contains added rice, garlic, 2% salt (w/v), pepper, chilli, nitrate and is fermented for 3–4 days. Sai-krok-prieo and Mum are fermented sausages originating from Thailand that contain sugar, pepper, chilli, salt and are fermented for 2–3 days. Nem Chua is a processed fermented meat product from Vietnam where lean meat and skin are mixed with additives and chilies and fermented for 3–4 days. Urutan, a fermented sausages product from Bali, Indonesia contains lean meat mixed with chili, sugar, and salt. *Olatunde et al.* (2023)*,* various fermented meat products are popular, namely Arjia from India, Yak Kargyong from Himalayan regions, Chartaysha, Kargyong, and Suka Ko Masu from India, Nem Chua from Vietnam, Sai-Krok-Prieo from Thailand and Tocin from the Philippines. According to *Bamidele et al.* (2023), many fermented meat products originate from Africa, namely Soudjouk/Sucuk, Boubnita, Pastirma, Afo-nnama, Beirta, Miriss, Dodery, Gueddid, and Khilii/Khlia.

Relatively few studies have been conducted on the characteristics of sui wu'u. *Naju et al.* (2022) showed that the use of different corn flours does not influence the organoleptic characteristics of the sui wu'u produced, and 0.5 kg of flour is optimal to preserve 250 g of landrace pork stored for one month using betung bamboo. *Febrianti et al.* (2021) found that using 0.5 kg of corn flour in 250 g of meat and 6% (w/w) salt, with storage for 1 month, did not affect the pH value, water holding capacity, cooking loss, or total lactic acid bacteria. Research into the physiochemical, microbiological and organoleptic characteristics after six months of storage by (*Rubak, Lalel, & Sanam,* 2023), using the ratio of meat (60%): corn flour (30%): salt (5%), showed the sui wu'u contained essential nutrients for the human body and was safe for consumption. According to *Di Gioia* (2015)*,* the quality and manufacturing consistency of fermented processed products is greatly influenced by many factors, namely the raw materials used, which must be fresh and have low contamination, the consistent presence of fermentative microorganisms, application of strict sanitation, and proper control of time, temperature and humidity during fermentation. Furthermore *Bamidele et al.* (2023) stated that some fermented meat products can be classified as shelf-stable meat. Several variables that contribute to the stability of microbial populations in fermented meat products are low pH, high growth rate of lactic acid bacteria, low water activity, long drying time, and the added salt and seasonings. The previous research results were the basis for initial data on the formula used to make sui wu'u in the current study. This study aimed to analyze the characteristics of beef sui wu'u stored in different types of bamboo (tuku) in terms of physical, chemical, colour, organoleptic, and microbiological characteristics.

2. Materials and Methods

2.1 Sui wu'u preparation

Traditional sui wu'u preparation was previously described in detail (*Febrianti et al.,* 2021; *Naju et al.,* 2022)· Briefly, 250 g of beef was cut into dimensions of 5 cm × 6 cm × 0.5 cm. Dry corn crumble (500 g, i.e., 200% of the weight of beef) were coarsely ground into corn crumble. The cut beef was coated with 6% (w/w) salt, left to rest for 5 minutes, then completely coated with corn crumble (w/w). Corn crumble was layered into the bamboo (tuku). The first, followed by a layer of coated meat; thereafter, alternate layers of corn crumble and coated beef were added, with corn crumble as the final layer. After that, covered with bamboo and stored for 30 days at room temperature (27–29 °C).

2.2 Research Design

The study was a completely randomized design with four treatments, each with five replications. Treatments were the four different types of bamboo, P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*), P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

2.3 Physical Characteristics

Water holding capacity (WHC) was measured using the Hamm method (*Soeparno,* 1994); 0.3 g of sui wu'u was placed on Whatman 42 filter paper and then pressed using two glass plates (modified press equipment) with a weight of 35 kg for 5 minutes. The area of the flattened meat was drawn on the filter paper and then entered into the formula (equations 1, 2, 3). Cooking loss (CL) (*Kong et al*., 2023; *Lu et al*., 2022; *Zhang et al*., 2023) was measured by weighing 5 g of sui wu'u into a polythene plastic bag and heating in a water bath at 80 °C. Then, the cooked meat was cooled to 25 °C and held for 15 minutes before being dried and weighed and entered into the formula (equation 4) to yield the cooking loss. The pH was measured using a previously published method (*Hiemori-Kondo et al.,* 2022). Sui wu'u was homogenized with twice its weight of distilled water, and the pH of the homogenized solution was measured using a pH meter (Ezdo PH5011, China). Hardness was measured (*Zhang et al.,* 2023) using a texture analyzer (Brookfield CT3 4500, USA). Colours *L, *a, *b were measured using a colour meter (Color Meter TES 135A, Republic of China, Taiwan) with standards *L (brightness), *a (redness), and *b (yellowness).

$$\text{milimigrans } H_2O = \frac{\text{we area (cm}^2) - 8.0}{0.0948} = x \qquad \text{Eq 1}$$

$$\text{wet area level} = \frac{X}{\text{sample weight (g)}} = x100\% \qquad \text{Eq 2}$$

$$\text{wet holding capacity} = \text{\% water content} - \text{\% wet area level} \qquad \text{Eq 3}$$

$$\text{Cooking Loss (\%)} = \frac{W - Wo}{W} = x100\% \qquad \text{Eq 4}$$

Information, w = weight of meat,
Wo = wight of meat after cookint

2.4 Chemical Characteristics

Contents of water, protein, fat, and carbohydrates in the sui wu'u were measured according to commonly used methods (*AOAC*, 2005).

2.5 Organoleptic Characteristics

Organoleptic quality of the sui wu'u was measured using 25 semi-trained panellists. Organoleptic testing used a hedonic quality test on a scale of 1–5 to look at colour, aroma, taste, texture and level of liking. The hedonic quality scale is shown in Table 1.

2.6. Microbiological Characteristics

Total plate count (TPC) and counts of *Escherichia coli*, and *Staphylococcus aureus* were conducted by standard methods (*National Standardization Agency of Indonesia,* 2008).

Table 1. Sui wu'u organoleptic quality hedonic scale

Parameter	Hedonic quality score				
	1	2	3	4	5
Colour	Pale red	Red	Slightly reddish brown	Quite brownish red	Brownish red
Aroma	Aroma off	Does not have the typical sui w'u aroma	Has a slight typical sui wu'u aroma	Has a quite typical sui wu'u aroma	Has a typical sui wu'u aroma
Taste	Tasty off	Not sour	Slightly sour	Quite sour	Sour
Texture	Not solid	Slightly not solid	Slightly solid	Quite solid	Solid
Acceptance	Do not like	Slightly do not like	Slightly like	Quite like	Like

2.7 Data analysis

Data on physical characteristics, i.e., yield, pH of meat, final pH, percentage of lactic acid, water holding capacity, cooking loss, colour characteristics of sui wu'u (L*, a*, b*, Cab, hab values, Y, X, Z, x, y, Wi, Yi, Tw), as well as chemical characteristics (water, protein, fat and carbohydrate) were analyzed by one-way ANOVA, and if an effect was measured, Duncan's test was used. Organoleptic characteristics (colour, aroma, taste, texture and level of acceptance) were analyzed using Kruskall-Wallis, and if they were influential, with Mann-Whitney analysis. Microbiological characteristics (TPC, *E coli*, and *S. aureus* counts) were analyzed descriptively. Data were tabulated using Microsoft Excel and analysed using SPPS version 29 software. Data were presented as mean SD (P<0.05).

3. Results and Discussion

3.1 Physical Characteristics

The measured physical characteristics of beef sui wu'u were yield, pH of fresh beef, final pH of the sui wu'u product, percentage of lactic acid, water holding capacity, cooking loss, and hardness. Different types of bamboo (tuku) influenced the physical characteristics of the beef sui wu'u produced after being stored for 30 days. The physical characteristics of beef sui wu'u produced using the different types of bamboo are shown in Table 2.

The sui wu'u yield value was in the range of 49.34±9.19 (talang bamboo) to 65.49±5.04% (green betung bamboo). The initial pH of the beef used was in the range 5.58±0.086 to 5.61±0.145, which was within the normal range. After storage for 30 days, the final pH of beef sui wu'u was in the range of 5.32±0.346 (green betung bamboo) to 6.95±0.934 (talang bamboo). The percentage of lactic acid in the sui wu'u was in the range 0.378±0.293% (talang bamboo) to 0.678±0.146% (green betung bamboo). The water holding capacity of sui wu'u was in the range 18.01±2.08% (talang bamboo) to 28.79±1.79% (brown betung bamboo). The cooking loss was in the range 23.31±5.98% to 25.94±7.48%. The hardness was in the range of 119.30±39.06 g (green betung bamboo) to 368.40±262.77 g (talang bamboo) (Table 2). The statistical analysis showed that the physical characteristics of sui wu'u were influenced by the type of bamboo used. Namely, using different types of bamboo had significant effects (P<0.05) on yield, pH, water holding capacity, and hardness, but no significant effects (P>0.05) on lactic acid content or cooking loss.

Green betung bamboo produced a higher yield of sui wu'u compared to the use of other types of bamboo. This is likely because green betung bamboo has the characteristic texture of young bamboo and has a high-water content. The use of talang bamboo produced the lowest yield compared to the use of other types of bamboo. This is perhaps because talang bamboo is thinner than the other bamboos, so the better air circulation caused the sui wu'u in talang bamboo to be drier than that in the other bamboo types. Also, the water content reduces during storage, which logically is affected by the thin talang bamboo allowing more water reduction than the other bamboos used. The yield of sui wu'u produced was significantly affected (P<0.05) by the characteristics of the bamboo used, as bamboo contains water, cellulose,

Table 2. Physical characteristics of beef sui wu'u prepared using different types of bamboo

Parameter	P1	P2	P3	P4	P-Value
Yield (%)	55.97±3.79^{a}	65.50±5.04^{b}	49.34±9.19^{a}	56.67±4.29^{a}	0.005
pH fresh beef	5.58±0.086	5.61±0.179	5.58±0.126	5.61±0.145	0.964
pH sui wu'u	5.46±0.377^{a}	5.32±0.346^{a}	6.95±0.934^{b}	5.67±0.467^{a}	0.002
Lactic acid percentage(%)	0.414±0.117	0.678±0.146	0.378±0.293	0.564±0.081	0.060
Water Holding Capacity (%)	28.79±1.79^{b}	27.73±2.25^{b}	18.01±2.08^{a}	27.98±0.678^{b}	0.000
Cooking Loss (%)	25.05±6.10	25.94±7.48	25.25±5.92	23.31±5.98	0.927
Hardness (g)	147.60±28.82^{a}	119.30±39.06^{a}	368.40±262.77^{b}	229.80±70.52^{ab}	0.049

P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

^{a,b} Different superscript letters in a row indicate values are significantly different (P<0.05) lignin and hemicellulose. Previous research (*Han et al.,* 2023) reported that the characteristics of structural bamboo segments, including their hierarchy, the vascular pattern bundle distribution, and fibre morphology have significant differences from multipore vascular bundles and irregular fibre morphology in the case of moso bamboo. Besides that, every type of bamboo has a specific structure, pore, porosity, chemical components and contents. According to *Subekti et al.* (2015), the chemical composition of bamboo is different for each species, so in betung bamboo, the chemical composition is 51.20% cellulose, 24.51% lignin and 0.32% nitrogen. *Zhang et al.* (2018)*; Zhang et al.* (2019)*,* bamboo is hygroscopic, which allows the processes of absorption and desorption of water from the environment when the relative humidity changes, thus effecting changes in bamboo's water content; the cellulose, hemicellulose, and lignin play roles in this.

The pH range of the meat used to produce sui wu'u was normal (*Puolanne et al.,* 2001), as the normal post-rigor pH of beef ranges from 5.60 to 6.48. According to *Wyrwisz et al.* (2019), the pH of beef *longissimus lumborum* is pH 5.51 to 5.68. During 30 days of storage, the pH of the meat decreased, except for sui wu'u in talang bamboo and gombong bamboo—the pH of these products increased. This shows that the characteristics of the bamboo used influences the final pH of the sui wu'u produced. Differences could also be due to the high activity of lactic acid bacteria during the storage process in brown and green betung bamboo, causing the lower final pH of sui wu'u from these tuku. According to *Zhong et al.* (2021), during the fermentation stage, the pH decrease from the initial pH of fresh beef to the final pH of sui wu'u provides the advantage of inhibiting the growth of several harmful bacteria and ensuring the quality of fermented meat. Furthermore *Chelule et al.* (2010)*,* the decreasing pH from fermentation to below about pH 5 could be detrimental to the fermenting microorganisms, so usually the pH of fermented product remains at a pH somewhat below 5. According to *Sun et al.* (2016)*,* the decrease in pH was greater in sausages inoculated with lactic acid bacteria. According to *Puolanne et al.* (2001), effect the combination of salt and pH is important for regulation of salt use and meat pH to reach a high enough level of water holding capacity. However, the pH of sui wu'u produced using containers made from talang bamboo and gombong bamboo had a higher pH compared to the initial pH of the fresh meat. According to *Feiner* (2006)*,* pH influences colour, shelf life, taste, microbiological stability, yield and texture of meat and meat products. The pH value of meat and meat product (raw fermented Salami) is around 4.6 and 6.4. Meat of pH >6.4 becomes damaged due to enzyme activity that produces large amounts of by-products from metabolism, unpleasant odours, and discolouration.

The lactic acid content was inversely correlated with the final pH of sui wu'u, where the higher the final pH, the lower the lactic acid content, and vice versa. According to *Wang et al.* (2022), fermentation reduces the pH drastically and the lactic acid content is negatively correlated, so the lactic acid content increases in line with decreasing pH. Sui wu'u is stored in talang bamboo had a lower percentage of lactic acid compared to other types of product. This is influenced by the lactic acid bacteria conversion of glycogen into lactic acid, as was indicated by the carbohydrate content of sui wu'u fermented in talang bamboo being numerically higher than in sui wu'u from other bamboo containers (Table 4). The low percentage of lactic acid could be influenced by the physical characteristics of talang bamboo, i.e., it is a thin bamboo, so outside air can likely more easily enter the internal bamboo spaces, thus giving the sui wu'u its characteristics.

The characteristics of the bamboo used influenced the sui wu'u water holding capacity, sui wu'u stored in talang bamboo had lower water holding capacity than product from the other types of bamboo. An increase in meat pH will increase the impression of juiciness and the water holding capacity and will decrease the cooking loss in sheep muscles linearly (*Soeparno,* 1994). *Apple & Yancey* (2013) reported positive and negative charges of muscle myofibril are in equal proportions at its isoelectric point, so the charged parts are attracted to each other, thereby reducing the amount of water that can be attracted to the myofibril. If the pH is below the isoelectric point, it causes an excess of positive charge, but if the pH is above the isoelectric point, there is an excess of negative charge, resulting in a greater attraction to water. According to *Puolanne et al.* (2001)*,* salt is also involved in the ability to hold water, so water holding capacity is affected by the pH of the raw material. However, if meat is combined with NaCl, this combination is expected to keep the high pH so the water holding capacity remains high. However, this was in contrast to our results, where the high pH (pH=6.948) in sui wu'u stored in talang bamboo had a lower water holding capacity that other products with lower pH but higher water holding capacity. Other research *Puolanne & Peltonen* (2013) studied the combination of pH and salt content in dry sausages during fermentation and drying, where at the beginning of fermentation, the ability to bind water was close to optimal. Then, simultaneously with a decrease in pH and an increase in ionic content, water holding capacity can end up above the optimal point so that it is possible to bind the particles cohesively, and this can have an impact on the resulting texture. The gel formed by the coagulation of dissolved proteins will stabilize the structural cohesiveness and low water-holding capacity during the fermentation process.

The use of different bamboos did not affect the cooking loss. Cooking loss is influenced by pH and water-holding capacity. According to *Torley et al.* (2000) cooking loss is influenced by a significant interaction between cooking temperature, and ionic strength, pH, and trypolyphosphate. The high hardness value of sui wu'u was influenced by the characteristics of the bamboo used. Sui wu'u stored in talang bamboo had different characteristics compared to product from betung bamboo. Furthermore, the hardness of sui wu'u was also closely related to the water content. The sui wu'u produced using talang bamboo containers was drier compared to sui wu'u from other types of bamboo. Similar effects were also obtained by (*Wang et al.,* 2023), in that shear force was related to hardness and was influenced by the loss of water content as a result of the length of drying. Accordingly *Hu et al.* (2022)*; Van Wezemael et al.* (2014), there is a relationship between water content and the level of hardness. Furthermore *Hu et al.* (2021) reported that hardness is influenced by water content and water activity. Apart from that, the level of hardness is influenced by the decrease in water content and pH of dry fermented sausages (*Bozkurt & Bayram,* 2006).

3.2 Colour Dimension Characteristics

The use of different bamboo types did not influence the colour characteristics of beef sui wu'u (Table 3). Treatment P3 (sui wu'u produced in Talang bamboo), with respect to L*, tended to be darker and with respect to a* tended to be redder than the other bamboo types, but differences were statistically insignificant (P>0.05) Physically, the results show that beef sui wu'u had a pale red colour unless using a talang bamboo container.

Colour characteristics of beef sui wu'u can be measured using the CIELAB method (*Warris,* 2000)*,* this method develops through changing colours into imaginary primaries X, Y, and Z. The values X, Y, and Z are tristimulus that describe colours as points in space. The tristimulus value is used to calculate three coordinates L*, a*, and b*. L* is the component or value of lightness, while a* indicates red-greenish colour and b* indicates yellow-bluish colour. The

Table 3. Colour characteristics of beef sui wu'u prepared using different types of bamboo

Parameter	P1	P2	P3	P4	p-Value
L*	24.02±12.73	24.06±9.74	21.342±5.729	24.003±19.066	0.982
a*	19.59±16.18	29.76±43.47	33.755±28.945	24.512±42.805	0.923
b*	−37.56±30.36	−31.631±37.022	−36.786±35.995	−39.326±42.161	0.989
Cab*	62.80±41.25	53.388±49.488	59.710±30.280	66.454±37.665	0.962
hab	269.06±73.58	244.646±123.248	247.150±115.150	242.212±99.041	0.975
Y	7.22±9.15	4.834±2.499	3.635±1.397	8.841±14.244	0.774
x	0.254±0.107	0.304±0.090	0.283±0.108	0.251±0.130	0.847
y	0.186±0.092	0.224±0.121	0.190±0.134	0.190±0.159	0.963
X	8.13±8.33	6.716±1.601	5.769±1.196	10.172±12.154	0.803
Z	14.58±8.10	12.726±8.703	12.920±8.534	18.841±16.002	0.794
Wi	372.40±224.36	265.444±261.140	339.440±301.112	408.026±277.570	0.855
Yi	−272.064±224.18	61.122±197.306	−220.796±233.416	−188.060±190.574	0.102
Tw	−20.043±69.62	−46.418±63.925	−16.786±80.381	−14.446±79.160	0.893

P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

L*, a*, b* values influence Wi, Yi, and Tw assessments. The low L* in sui wu'u was likely influenced by a browning reaction which is characterized by the formation of a dark colour. According to *Bozkurt & Bayram* (2006) the dark colour in fermented meat is formed as a result of the formation of nitrosomyoglobin, which plays a role the desired darker colour formation and is influenced by a decrease in water content. This indicates that fermented meat products will be a darker colour than the meat used to produce them. The positive a* value indicated similar red colours of the different sui wu'u products, although talang bamboo tended to produce a redder sui wu'u colour than the others (Figure 1). This was likely a result of salt reactions during fermentation. According to *Chelule et al.* (2010)*,* stable haemoglobin S-nitroso, which is marked by a bright red colour, forms as a result of the reaction of nitrite with myoglobin during roasting, fermentation or cooking processes. Furthermore, according to (*Hu et al.,* 2021*,* 2022), the red colour is formed as a result of the formation of nitrosomyoglobin occurring due to the decrease in pH. The b* values measured reflected that some blueness was noticeable in our sui wu'u. This is different from other research (*Hu et al.,* 2022)*,* where fermented sausage reflects a yellow colour. This is caused by a decrease in pH. The formation of yellow pigment is a reaction between lipid oxidation products and amines in the phospholipid group or amines in proteins.

3.3 Chemical Characteristics

The chemical characteristics of beef sui wu'u using different bamboo types are shown in Table 3. The statistical analysis showed that the use of different types of bamboo produced significant effects ($P<0.05$) on the water and protein content of the sui wu'u. However, bamboo type did not significantly affect ($P>0.05$) the carbohydrate or fat content of the sui wu'u. During fermentation, the chemical content is indicated to be changed by lactic acid bacteria, which can be natu rally found in the bamboo used. Research conducted by (*Rubak, Lalel, Sanam, et al.,* 2023), discovered the lactic acid bacteria, *Lactococcus lactis* isolated from sui wu'u.

The water content of beef sui wu'u was in the range 41.47±8.14% (talang bamboo) to 58.81±2.90% (green betung bamboo). The protein content of beef sui wu'u was in the range of 26.99±2.50% to 37.72±1.50%, seen in product from green betung bamboo and talang bamboo, respectively. The carbohydrate content of beef sui wu'u was in the range of 6.56 ± 1.57% to 11.65 ± 7.04%, seen in product from gombong bamboo, and talang bamboo, respectively. The fat content of the sui wu'u was in the range of 1.13± 0.31% (brown betung bamboo) to 1.99 ± 0.812% (green betung bamboo) (Table 4).

The characteristics of the bamboo used as a container in making sui wu'u influences the chemical content of the product, where the use of talang bamboo

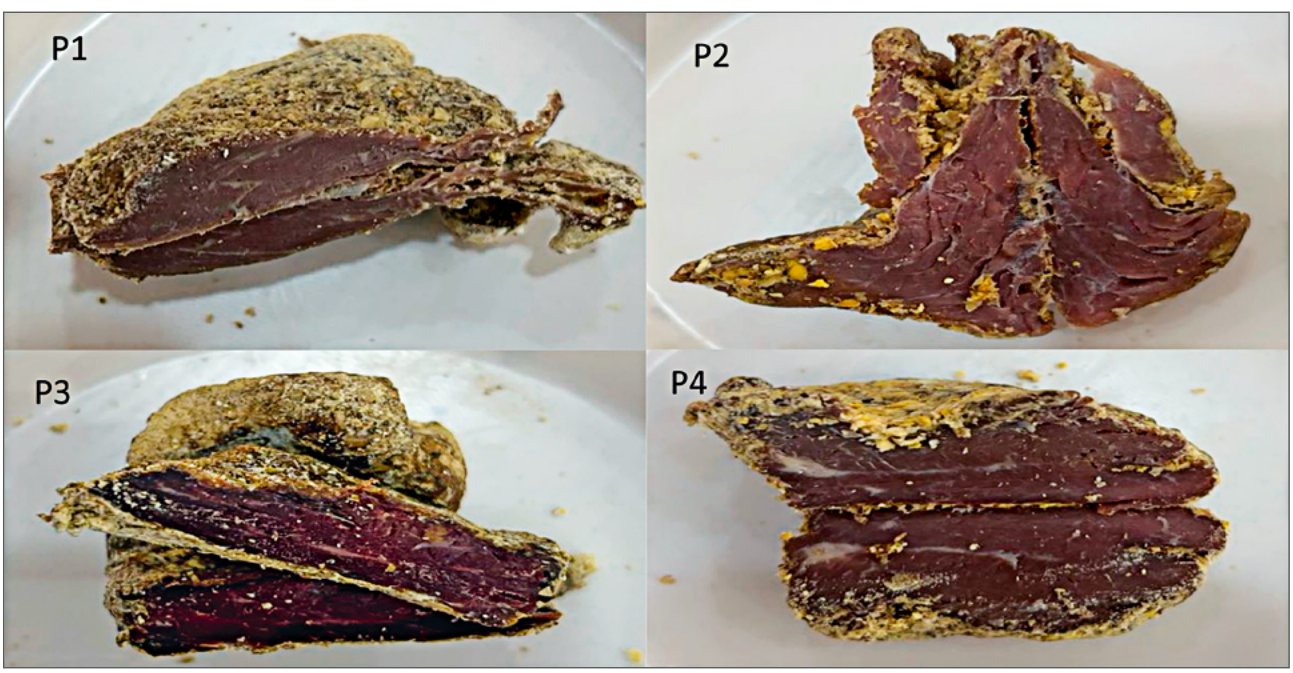

Figure 1. Beef sui wu'u prepared using different types of bamboo. P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

Table 4. Chemical characteristics of beef sui wu'u prepared using different types of bamboo

Parameter	P1	P2	P3	P4	P-Value
Water (%)	54.04±4.09^{b}	58.81±2.90^{b}	41.47±8.14^{a}	54.54±2.49^{b}	<0.001
Protein (%)	30.70±3.82^{b}	26.99±2.50^{a}	37.72±1.50^{c}	32.66±1.95^{b}	<0.001
Carbohydrate (%)	9.63±1.86	8.65±1.86	11.65±7.04	6.56±1.57	0.247
Fat (%)	1.13±0.314	1.99±0.81	1.84±0.594	1.57±0.498	0.143

P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

^{a,b,c} Different superscript letters in a row indicate values are significantly different (P<0.05)

results in lower water content and greater protein content. According to *Subekti et al.* (2015), each type of bamboo has different chemical components. Furthermore, according to (*Han et al.,* 2023)*,* bamboo species have different morphologies and structures. The water and protein content of the sui wu'u produced in the current study was higher, but the fat content was lower compared to research by (*Rubak, Lalel, & Sanam,* 2023), where the water, protein and fat content of pork sui wu'u stored in betung bamboo for 6 months was 6.11±0.09, 24.29±0.21 and 59.68±0.07, respectively. This difference is influenced by the type of meat used and storage time. The decrease in water content is also influenced by the activity of microorganisms. According to *Zhong et al.* (2021)*,* during fermentation there will be a decrease in water content, which can be beneficial for inhibiting pathogen microorganisms. The use of water by microorganisms and the addition of salt, the precipitation of water was facilitated, resulting in a decrease in water content during fermentation.

3.4 Organoleptic Characteristics

The change in chemical components in beef due to fermentation will affect the organoleptic characteristics of beef sui wu'u. The scores for the organoleptic characteristics of beef sui wu'u using different types of bamboo are shown in Table 5. The statistical analysis showed that the use of different types of bamboo had significant effects (P<0.05) on the colour, aroma, texture and overall acceptance of beef sui wu'u, but showed an insignificant effect (P>0.05) on the taste of beef sui wu'u.

Sui wu'u colour scores ranged from 3.51±1.64 to 4.01±1.32, while aroma scores ranged from 2.50±1.26 to 3.31±1.30. The sui wu'u texture scores ranges from 2.57±1.34–4.03±1.11. The taste scores of sui wu'u ranged from 3.64±1.07 to 3.81±1.06, and overall acceptance scores of sui wu'u were from 3.23±0.899 to 3.60±0.916 (Table 5).

Sui wu'u stored in talang bamboo tended to have a lower aroma score compared to the products from the other bamboos, indicating the aroma produced differs in the talang bamboo product. The difference in the aroma of sui wu'u using talang bamboo (compared with the aroma of the other products) could have been caused by the higher pH as a result of the activity of by-products produced during fermentation. According to *Feiner* (2006)*,* if the pH is around 6.4, meat can be damaged due to enzyme activity, producing large amounts of by-products from metabolism, unpleasant odours and discolouration. The beef sui wu'u produced in all the bamboo containers had quite a sour taste. This indicates that during storage in bamboo,

Table 5. Organoleptic characteristics of beef sui wu'u prepared using different types of bamboo

Parameter	–	P2	P3	P4	P-Value
Colour	3.51±1.64^{a}	3.64±1.30	3.63±1.42^{a}	4.01±1.32^{b}	0.035
Aroma	2.59±1.38^{ab}	3.31±1.30^{c}	2.50±1.26^{a}	2.86±1.44^{b}	0.000
Taste	3.81±1.06	3.71±1.01	3.64±1.07	3.65±1.02	0.487
Texture	2.57±1.36^{a}	3.06±1.44^{b}	4.03±1.11^{c}	3.99±1.18^{c}	0.000
Acceptance	3.60±0.916^{b}	3.35±0.927^{a}	3.23±0.899^{a}	3.38±0.905^{ab}	0.036

P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*).

^{a,b,c} Different superscript letters in a row indicate values are significantly different (P<0.05) the expected fermentation processes occurred, characterised by a sour taste. The sui wu'u texture scoring showed that products made from talang and gombong bamboo containers were different from those produced using betung bamboo. This is closely related to the water content of sui wu'u, as the sui wu'u content of beef using containers made of talang bamboo had a lower water content compared to other types of bamboo (Table 4), and besides that, could also be influenced by the characteristics of the bamboo type. The overall acceptance assessed by the panellists showed they had a specific level of acceptance for each bamboo container used, and each sui wu'u produced from different types of bamboo had its own characteristics that were liked by the panellists. The degradation of protein and fat components by natural microorganisms found in bamboo and beef during the fermentation process, likely influences the characteristics of the aroma and taste of fermented sui wu'u. According to *Zhong et al.* (2021), microorganisms degrade both protein and fat during long fermentation processes to produce small molecules of peptides, amino acids fatty acids, etc., and the appropriate degradation process helps form a fermented meat taste.

The use of different types of bamboo influences the characteristics of beef sui wu'u in terms of colour, aroma, texture, and level of acceptance. The use of containers made from brown betung bamboo provided better organoleptic characteristics of beef sui wu'u compared with the other bamboo types studied.

3.5 Microbiological Characteristics

The microbiological characteristics of the beef sui wu'u produced using different types of bamboo are shown in Table 6. These results indicate that the sui wu'u produced was within the standard limits for *E. coli* and *S. aureus* contamination. The TPC of beef sui wu'u produced was in the range of 1.10×10^9 CFU/g to 2.80×10^9 CFU/g. Sui wu'u from gombong bamboo showed a higher TPC compared to the other treatments. Based on SNI 7388:2009 standards (*National Standardization Agency of Indonesia,* 2009), the TPC of processed whole or cut meat product should be below 1×10^5 CFU/g. The higher TPC in our sui wu'u was likely not caused by the presence of pathogenic bacteria, but could be due to the presence of lactic acid bacteria which played a role in the fermentation process. The TPCs from our current research were higher than in research conducted by (*Rubak, Lalel, & Sanam,* 2023), i.e., the TPC of pork sui wu'u stored in betung bamboo for approx. 6 months was 4.4×10^5 CFU/g. (*Rubak*, *Lalel*, *Sanam*, *et al*., 2023) isolated *Lactococcus lactis* from sui wu'u, and reported that the total lactic acid bacteria count in pork sui wu'u is around 3.7×10^3 CFU/g.

According to (*BPOM: Food and Drug Supervisory Agency)* (*Food and Drug Supervisory Agency,* 2019), the maximum number of *E. coli* in meat and fermented processed meat products without heat treatment is around 10^3 CFU/g. *E. coli* was not detected in the beef sui wu'u in our study, regardless of the type of bamboo used. *S. aureus* contamination in the sui wu'u was 1.00×10^3 CFU/g for all types of bamboo used, which did not exceed the permitted level in SNI 7388:2009 standard (*National Standardization Agency of Indonesia,* 2009). According to (*BPOM: Food and Drug Supervisory Agency)* (*Food and Drug Supervisory Agency*, 2019), a maximum of 10^4 CFU/g of *S. aureus* is permitted in meat, processed meat products and fermented meat without heat treatment.

Most fermented products can experience contamination by spoilage bacteria, expressed during storage. Several types of pathogenic bacteria are commonly found in fresh meat, such as *Campylobacter, E. coli serotype* O157:H7, and *Salmonella*, while *L. monocytogenes* and antibiotic-resistant bacteria, such as *Campylobacter* and *Salmonella* (*Dixon*

Table 6. Microbiological characteristics of beef sui wu'u prepared using different types of bamboo

Parameter	BPOM PP BPOM No. 13/2019 Fermented processed meat product	P1	P2	P3	P4
TPC (CFU/g)	-	1.20×10^9	1.50×10^9	1.10×10^9	2.80×10^9
Escherichia coli (CFU/g)	10^3 CFU/g	-	-	-	-
Staphylococcus aureus (CFU/g)	10^4 CFU/g	1.00×10^3	1.00×10^3	1.00×10^3	1.00×10^3

P1: brown betung bamboo (*Dendrocalamus asper*), P2: green betung bamboo (*Dendrocalamus asper*) P3: talang bamboo (*Schizoztachyum brachcladum*), P4: gombong bamboo (*Gigantocloa verticallata*). - : not found *et al.,* 2023) can also occur. According to *Ramos et al.* (2023)*, S. aureus* and its toxins cannot be avoided with certainty in alkaline foods because its spores can survive. However, according to *Dong et al*. (2024)· a decrease in pH not only affects organoleptic properties but can play a role in suppressing pathogens and spoilage microorganisms during fermentation and the final safety of the product. The sui wu'u produced, in terms of microbiological characteristics, was not influenced by the type of bamboo used, as can be seen from the microbiological profile.

Overall, beef sui wu'u produced in all four types of bamboo had acceptable levels of *E. coli* and *S. aureus* that were within the maximum permitted levels. Therefore, beef sui wu'u produced using the different bamboo types and stored for 30 days would be safe to consume with regard to these pathogens.

4. Conclusion

The use of different types of bamboo container influences the characteristics of beef sui wu'u in terms of physical, chemical, colour, organoleptic and microbiological aspects. The use of containers made from brown betung bamboo (*Dendrocalamus asper*) produces better beef sui wu'u. However, the individual use of talang and gombong bamboos can also be appropriate in the process of making sui wu'u, although compared with the sui wu'u stored in brown betung bamboo, the final products will have different characteristics in terms of physical, chemical and organoleptic aspects. Microbiological characteristics met the standards and showed the products were safe for consumption with respect to *S. aureus* and *E. coli* levels.

Uticaj korišćenja različitih vrsta bambusa na karakteristike fermentisanog mesa sui wu'u iz Bajave, Istočna Nusa Tenggara

Sulmiyati Sulmiyati, Gemini Ermiani Mercurina Malelak i Bastari Sabtu

INFORMACIJE O RADU

Ključne reči:
Govedina
Hrana
Konzervansi
Tradicionalno
Kvalitet

APSTRAKT

Ovo istraživanje imalo je za cilj analizu karakteristika goveđeg sui wu'u, pripremljenog čuvanjem proizvoda od mesa u različitim vrstama bambusa. Eksperimentalni dizajn obuhvatio je četiri tretmana sa po pet ponavljanja skladištenja: P1 – zeleni betung bambus (Dendrocalamus asper), P2 – smeđi betung bambus (Dendrocalamus asper), P3 – talang bambus (Schizostachyum brachycladum) i P4 – gombong bambus (Gigantochloa verticillata). Rezultati istraživanja pokazali su da je vrsta bambusa imala značajan uticaj (P<0,05) na fizičke karakteristike sui wu'u, uključujući randman, konačnu pH vrednost, sposobnost vezivanja vode i tvrdoću mesa. Kada je reč o hemijskim osobinama, korišćenje različitih bambusa značajno je uticalo (P<0,05) na sadržaj vode i proteina. Organoleptičke analize pokazale su da je vrsta bambusove ambalaže značajno uticala (P<0,05) na boju, aromu, teksturu i ukupnu prihvatljivost proizvoda. Međutim, kada su u pitanju dimenzije boje (L*, a*, b*, C_ab, h_ab, Y, X, Z, x, y, W_i, T_i i T_w), nije uočen statistički značajan uticaj (P>0,05). Mikrobiološke karakteristike sui wu'u kod svih korišćenih vrsta bambusa bile su u granicama standarda za fermentisane proizvode od mesa. Upotreba različitih vrsta bambusa utiče na fizičke, hemijske, organoleptičke i mikrobiološke karakteristike sui wu'u, dok razlike u dimenzijama boje nisu bile značajne. Najbolji kvalitet sui wu'u postignut je korišćenjem smeđeg betung bambusa (Dendrocalamus asper), ali se i talang i gombong bambus mogu preporučiti u procesu proizvodnje, iako gotov proizvod pokazuje različite karakteristike, naročito u poređenju sa sui wu'u skladištenim u talang bambusu.

Disclosure Statement: No potential conflict of interest was reported by authors.

Funding: This research was implemented with DIPA funding from the Institute for Research and Community Service, Universitas Nusa Cendana on the basic research in college excellence Scheme (Penelitian Dasar Unggulan Perguruan Tinggi) Number 133/UN15.22/LT/2024, dated 18 March 2024.

References

AOAC. (2005). *Official Methods of Analysis (18 Edn)*. Association of Official Analytical Chemist Inc. Mayland.

Apple, J. K., & Yancey, J. W. S. (2013). Water-Holding Capacity of Meat. *The Science of Meat Quality*, 119–145. https://doi.org/10.1002/9781118530726.ch7.

Bamidele, O. P., Adeyanju, A. A., Wokadala, O. C., & Mlambo, V. (2023). African fermented fish and meat-based products. In *Indigenous Fermented Foods for the Tropics*. INC. https://doi.org/10.1016/b978-0-323-98341-9.00025-6

Bozkurt, H., & Bayram, M. (2006). Colour and textural attributes of sucuk during ripening. *Meat Science*, 73(2), 344–350. https://doi.org/https://doi.org/10.1016/j.meatsci.2006.01.001.

Chee, K. K., Yen, N. T., Fook, Y. C., & Sit, N. W. (2020). Nutritional compositions, biological activities, and phytochemical contents of the edible bamboo shoot, Dendrocalamus asper, from Malaysia. *International Food Research Journal*, 27(3), 546–556.

Chelule, P. K., Mokoena, M. P., & Gqaleni, N. (2010). Advantages of traditional lactic acid bacteria fermentation of food in Africa. *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology. A. Mendez-Vilas (Ed.)*, 1160–1167.

Di Gioia, D. (2015). Safety of Fermented Meat. In *Regulating Safety of Traditional and Ethnic Foods*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-800605-4.00007-4.

Dixon, M., James, M., Leathers, R., & Smithers, G. W. (2023). Safety of Food and Beverages: Meat and Meat Products. In *Reference Module in Food Science* (Second Edi, Vol. 3). Elsevier. https://doi.org/10.1016/b978-0-12-822521-9.00229-x.

Dong, K., Wang, Q., Li, X., Li, X., An, F., Luo, Z., Wang, J., Zeng, Q., Shang, P., Liu, Z., & Huang, Q. (2024). An effective means to improve the flavor quality of traditional fermented sour meat: The salt reduction strategy. *LWT*, 209(August), 116726. https://doi.org/10.1016/j.lwt.2024.116726.

Endo, A., Irisawa, T., Dicks, L., & Tanasupawat, S. (2014). Fermented Foods: Fermentations of East and Southeast Asia. In *Encyclopedia of Food Microbiology: Second Edition* (Second Edi, Vol. 1). Elsevier. https://doi.org/10.1016/B978-0-12-384730-0.00119-1.

Febrianti, E., Miwada, I., & Lindawati, S. (2021). Physical and total quality of sui wu'u total acid bacteria preserved with corn flour (*Amylum maydis*). *Journal Peternakan Tropika*, 9(2), 404–415.

Feiner, G. (2006). Definitions of terms used in meat science and technology. *Meat Products Handbook*, 46–71. https://doi.org/10.1533/9781845691721.1.46.

Food and Drug Supervisory Agency, (2019). *Peraturan Badan Pengawas Obat dan Makanann Nomor 13 Tahun 2019* tentang Batas Maksimal Cemaran Mikroba dalam Pangan Olahan. Food and Drug Supervisory Agency. Jakarta.

Han, S., Li, X., Ye, H., Ou, X., & Wang, G. (2023). Three-dimensional visualization structural characteristics and performance of discontinuous coarse fiber bamboo nodes. *Journal of Materials Research and Technology*, 26, 8181–8191. https://doi.org/10.1016/j.jmrt.2023.09.142.

Hiemori-Kondo, M., Ueta, R., & Nagao, K. (2022). Improving deer meat palatability by treatment with ginger and fermented foods: A deer meat heating study. *International Journal of Gastronomy and Food Science*, 29(July), 100577. https://doi.org/10.1016/j.ijgfs.2022.100577.

Hu, Y., Li, Y., Li, X., Zhang, H., Chen, Q., & Kong, B. (2022). Application of lactic acid bacteria for improving the quality of reduced-salt dry fermented sausage: Texture, color, and flavor profiles. *LWT*, 154(2022), 112723. https://doi.org/https://doi.org/10.1016/j.lwt.2021.112723.

Hu, Y., Li, Y., Zhu, J., Kong, B., Liu, Q., & Chen, Q. (2021). Improving the taste profile of reduced-salt dry sausage by inoculating different lactic acid bacteria. *Food Research International*, 145, 110391. https://doi.org/https://doi.org/10.1016/j.foodres.2021.110391.

Kong, L., Liu, C., Tang, H., Yu, P., Wen, R., Peng, X., Xu, X., & Yu, X. (2023). Hygroscopicity and antioxidant activity of whey protein hydrolysate and its ability to improve the water holding capacity of pork patties during freeze−thaw cycles. *LWT-Food Science and Technology*, 182(2023), 114784. https://doi.org/10.1016/j.lwt.2023.114784.

Lu, J., Wang, Y., Chen, B., Xie, Y., Nie, W., Zhou, H., & Xu, B. (2022). Effect of pigskin gelatin hydrolysate on the porcine meat quality during freezing. *Meat Science*, 192, 108907. https://doi.org/10.1016/j.meatsci.2022.108907.

Mirdhayati, I. (2022). The chemical, microbiological, and sensory characteristics of cangkuk: a fermented beef meat from Kuantan Singingi, Riau Province. *Jurnal Ilmiah Peternakan Terpadu*, 10(1), 1–17. https://jurnal.fp.unila.ac.id/index.php/JIPT.

National Standardization Agency of Indonesia, (2008). *SNI 2897:2008, Methods for testing microbial contamination in meat, eggs and milk and their processed products*. National Standardization Agency. Jakarta.

National Standardization Agency of Indonesia, (2009). SNI 7388 : 2009 Maximum limit of microbial contamination in food. National Standardization Agency. Jakarta.

Naju, F., Miwada, I., & Lindawati, S. (2022). organoleptic quality of landrace pork preserved by traditional preservation method (sui wu'u) from East Nusa Tenggara. *Majalah Ilmiah Peternakan*, 25(1), 40–45. https://ojs.unud.ac.id/index.php/mip.

Olatunde, O. O., Bandara, N., Olukomaiya, O. O., Fadimu, G. J., Olajide, A. M., Owolabi, I. O., Coker, O. J., Ajayi, F. F., Akinmosin, B. O., Kupoluyi, A. O., Ademola, O. M., & Petchkongkaew, A. (2023). Asian fermented fish and meat-based products. In *Indigenous Fermented Foods for the Tropics*. INC. https://doi.org/10.1016/b978-0-323-98341-9.00004-9.

Puolanne, E. J., Ruusunen, M. H., & Vainionpää, J. I. (2001). Combined effects of NaCl and raw meat pH on water-holding in cooked sausage with and without added phosphate. *Meat Science*, 58(1), 1–7. https://doi.org/10.1016/S0309-1740(00)00123-6.

Puolanne, E., & Peltonen, J. (2013). The effects of high salt and low pH on the water-holding of meat. *Meat Science*, 93(2), 167–170. https://doi.org/10.1016/j.meatsci.2012.08.015.

Ramos, C. L., Bressani, A. P., Batista, N. N., Martinez, S. J., Dias, D. R., & Schwan, R. F. (2023). Indigenous fermented foods: nutritional and safety aspects. *Current Opinion in Food Science*, 53, 101075. https://doi.org/10.1016/j.cofs.2023.101075.

Rubak, Y. T., Lalel, H. J. D., & Sanam, M. U. E. (2023). Physicochemical, microbiological, and sensory characteristics of "Sui Wu'u" traditional pork products from Bajawa, West Flores, Indonesia. *Veterinary World*, 16(5), 1165–1175. https://doi.org/10.14202/vetworld.2023.1165-1175.

Rubak, Y. T., Lalel, H. J. D., Sanam, M. U. E., & Nalle, R. P. (2023). Probiotic Characteristics of Lactic Acid Bacteria Isolated From Sui Wu'u: A Traditional Food From Bajawa, West Flores, Indonesia. *Current Research in Nutrition and Food Science*, 11(3), 1074–1086. https://doi.org/10.12944/CRNFSJ.11.3.13.

Soeparno, (1994). *Ilmu dan Teknologi Daging (Meat Science and Technology)*. Gadjah Mada University Press. Yogyakarta.

Subekti, N., Yoshimura, T., Rokhman, F., & Mastur, Z. (2015). Potential for Subterranean Termite Attack against Five Bamboo Species in Correlation with Chemical Components. *Procedia Environmental Sciences*, 28(SustaiN 2014), 783–788. https://doi.org/10.1016/j.proenv.2015.07.092.

Sun, Q., Chen, Q., Li, F., Zheng, D., & Kong, B. (2016). Biogenic amine inhibition and quality protection of Harbin dry sausages by inoculation with Staphylococcus xylosus and Lactobacillus plantarum. *Food Control*, 68, 358–366. https://doi.org/https://doi.org/10.1016/j.foodcont.2016.04.021.

Torley, P. J., D'Arcy, B. R., & Trout, G. R. (2000). The effect of ionic strength, polyphosphates type, pH, cooking temperature and preblending on the functional properties of normal and pale, soft, exudative (PSE) pork. *Meat Science*, 55(4), 451–462. https://doi.org/10.1016/S0309-1740(00)00004-8.

Van Wezemael, L., De Smet, S., Ueland, Ø., & Verbeke, W. (2014). Relationships between sensory evaluations of beef tenderness, shear force measurements and consumer characteristics. *Meat Science*, 97(3), 310–315. https://doi.org/https://doi.org/10.1016/j.meatsci.2013.07.029.

Wang, H., Sui, Y., Liu, J., Kong, B., Li, H., Qin, L., & Chen, Q. (2023). Food Chemistry: X Analysis and comparison of the quality and flavour of traditional and conventional dry sausages collected from northeast China. *Food Chemistry: X*, 20(July), 100979. https://doi.org/10.1016/j.fochx.2023.100979.

Wang, Q., Li, X., Xue, B., Wu, Y., Song, H., Luo, Z., Shang, P., Liu, Z., & Huang, Q. (2022). Low-salt fermentation improves flavor and quality of sour meat: Microbiology and metabolomics. *LWT*, 171(November), 114157. https://doi.org/10.1016/j.lwt.2022.114157.

Warris, P. D. (2000). *Meat Science an Introductory Text*. CABI Publishing.

Wyrwisz, J., Moczkowska, M., Kurek, M. A., Karp, S., Atanasov, A. G., & Wierzbicka, A. (2019). Evaluation of WBSF, color, cooking loss of Longissimus lumborum muscle with fiber optic near-infrared spectroscopy (FT-NIR), depending on aging time. *Molecules*, 24(4), 1–11. https://doi.org/10.3390/molecules24040757.

Zhang, H., Tang, D., Yang, H., Liu, X., Cheng, J., Wang, X., Zou, J., & Lin, Y. (2023). Effects of high hydrostatic pressure assisted enzymatic tenderization on goose meat texture and myofibril protein. *LWT-Food Science and Technology*, 184(2023), 114845. https://doi.org/10.1016/j.lwt.2023.114845.

Zhang, X., Li, J., Yu, Y., & Wang, H. (2018). Investigating the water vapor sorption behavior of bamboo with two sorption models. *Journal of Materials Science*, 53(11), 8241–8249. https://doi.org/10.1007/s10853-018-2166-y.

Zhang, Y., Huang, X., Yu, Y., & Yu, W. (2019). Effects of internal structure and chemical compositions on the hygroscopic property of bamboo fiber reinforced composites. *Applied Surface Science*, 492(April), 936–943. https://doi.org/10.1016/j.apsusc.2019.05.279.

Zhong, A., Chen, W., Duan, Y., Li, K., Tang, X., Tian, X., Wu, Z., Li, Z., Wang, Y., & Wang, C. (2021). The potential correlation between microbial communities and flavors in traditional fermented sour meat. *LWT*, 149(2021), 111873. https://doi.org/10.1016/j.lwt.2021.111873.

Zhong, A., Chen, W., Hu, L., Wu, Z., Xiao, Y., Li, K., Li, Z., Wang, Y., & Wang, C. (2022). Characterisation of key volatile compounds in fermented sour meat after fungi growth inhibition. *LWT*, 165(February), 113662. https://doi.org/10.1016/j.lwt.2022.113662.

Authors info

Sulmiyati Sulmiyati, https://orcid.org/0000-0001-9988-1896
Gemini Ermiani Mercurina Malelak, https://orcid.org/0000-0002-3371-7900
Bastari Sabtu, https://orcid.org/0009-0007-9591-8904

Guidelines for the Authors

"Meat Technology" (ISSN 0494-9846) is a scientific journal publishes:

- Original scientific papers (papers which present previously unpublished results of authors' own investigations using scientific methodology);
- Review papers (papers which include original, detailed and critical overview of a research problem or an area to which the author has significantly contributed, as evidenced by auto citations);
- Brief or preliminary papers (full-format original scientific papers or of preliminary character);
- Reviews (of books, scientific conferences etc.)

Eligible for publishing are those papers, which have not been previously published, presented or considered for publication in another journal, except as abstracts presented at scientific conferences. The first author is both responsible for meeting these criteria and for obtaining agreement to publish from all of the co-authors.

Authors of papers are obliged to respect scientific and ethical principles and rules when preparing and publishing articles in accordance with international standards.

Procedure

Papers are subject to anonymous reviews (two at least), while the decision to accept the paper for publishing is reached by the editor-in-chief, together with subeditors and the members of the editorial board.

Accepted papers are subject to proofreading. The editorial board reserves the right to minor corrections of the manuscript. Where major corrections are necessary, the first author will be notified, and the paper sent for revision, with a set deadline. After all corrections, authors are requested to submit a „Statement authors" on mail danijelas@inmesbgd.com.

Language

Papers must be written on English (British English spelling).

Editing of the manuscripts

The paper should be edited in Microsoft Word software, using Times New Roman font, size 12 pt, paragraph spacing 1.5 and margins of 2 cm. Papers are submitted in electronic form by email:

- danijela.sarcevic@inmes.rs or
- meat.technology@inmes.rs, or via
- www.journalmeattechnology.com.

The text should be clear, concise, grammatically correct and should contain the following sections:

The title (lowercase, bold, font size 14 pt). Below the title, names of the authors (first name, last name, lowercase, italic, font size 12 pt). Numbers following names in superscript refer to the authors' institution.

At the bottom of the first page, put affiliation according to the number in superscript, name and address of the institutions authors are employed in should be given (italic, font size 10 pt, the main words capitalized). In the new line, the name and e-mail of the corresponding author should be provided (font 12).

Abstract on English and Serbian should contain 150–250 words with key words (maximum 5, italic, font 12). The English abstract should be typed below the title and names of the authors, and om Serbian below the conclusion.

The original scientific paper should contain the following chapters: introduction, material and methods, results and discussion (combined or separate), conclusion, notes (optional) and references. Chapter names are typed in lowercase, font size 12, bold.

INTRODUCTION: should contain clear description of the investigated subject and aim of the research with the short citations of the relevant literature (not more than 10 years old);

MATERIAL AND METHODS: this chapter describes material and methods used and outlines the design of the experiment;

RESULTS AND DISCUSSION: The results should be processed by statistical methods appropriate to the experiment; they should be clear and concise using tables, graphs, photographs, illustrations and other. The same result should not be presented through both table and graph. Discussion should be related to presented results avoiding repetitions of already stated facts, using comparison of obtained results and relevant literature data related to similar group of products, comparable analytical method et sim.

When in the text, literature is cited by giving author's last name, last name with "and", if the cited literature is published by two authors, or, in the case of more than two authors by "et al." abbreviation after the surname of the first author (italic). Cited literature with the year of publishing should be in brackets.

Figures and illustrations are numerated with the same number as given in the text of the paper. Titles of the tables are written above the tables; titles of the graphs and illustrations are printed below (in lowercase). Tables, graphs and figures are submitted separately, in the appendix.

If tables, graphs or figures originate from other sources, the author is required to state the source of such data (author, year of publishing, journal etc.). Notes should be placed at the bottom of the page containing cited material.

The author should apply the International System of Units (SI system) and current regulation on measuring units and measuring instruments.

<u>CONCLUSION</u>: provides the review of the most important facts obtained during the research.

It is important for authors to send **Disclosure statement:** No potential conflict of interest was reported by authors.

Acknowledgement: should contain title and number of the project i.e. title of the program from which is the research carried out and described in the paper, as well as the name of the institution that funded the project or program and should be written after conclusion, before references.

<u>REFERENCES</u>: (Times New Roman 12 pts) should include recent international publications. If the original literature cited has not been available, the authors should quote the source used. The references should be numerated in alphabetical order and should be cited exactly the way they appear in the original publication. Sources, volume and issue numbers should be written in italic.

<u>Example:</u>

- Journals:

Givens, D. I., Kliem, K. E., Gibbs, R. A. (2006). The role of meat as a source of n3 polyunsaturated fatty acids in the human diet. *Meat Science*, 74 (1), 209–218.

- Books:

Bao, Y., Fenwick, R. (2004). Phytochemicals in Health and Disease, CRC Press, Los Angeles.

- Books with more chapters:

Marasas, W. F. O. (1996). Fumonisins: History, worldwide occurrence and impact. In Fumonisins in food, advances in experimental medicine and biology.Eds. L. S. Jackson, J. W. DeVries, L. B. Bullerman, Plenum Press, New York, pp. 118.

- PhD and MSc thesis:

Radeka, S. (2005). Grape mash maceration and varietal aroma of Malvazija istarska wine, PhD Thesis, Faculty of Agriculture, University of Zagreb, Croatia.

- Symposiums, Congresses:

Harvey, J. (1992). Changing waste protein from a waste disposal problem to a valuable feed protein source: a role for enzymes in processing offal, feathers and dead birds. Alltech's 8th Annual Symposium,Nichdasville, Kentucky, Proceedings, 109−119.

- Software:

STATISTICA (Data Analysis Software System) (2006). v.7.1., StatSoft, Inc., USA (www.statsoft.com).

- Websites:

Technical report on the Food Standards Agency project G010008 (2002). Evaluating the risks associated with using GMOs in human foods, University of Newcastle, UK (http://www.foodsafetynetwork.ca/gmo/gmnewcastlereport.pdf).

Each publication cited in the text must be listed in References. The citations in the text need to be arranged in the following way:

If there is only one author of the cited paper, the author's surname and the year of publication is stated in the brackets (*Thomas,* 2008). In case the same author has more publications in the same year, additional letters are added next to the year (*Thomas*, 2008a; *Thomas*, 2008b).

If there are two authors of the publication, surnames of authors and year of publication is written in the brackets (*Thomas and Fenwick*, 2008).

If there are three or more authors, the surname of the first author is stated in the brackets, followed by abbreviation "et al." and year of publication (*Thomas et al.*, 2008).

If more references are cited within the same brackets, citations should be done in chronological order.

Papers belonging to the category other than original scientific papers can contain chapters titled by choice of the author.

Papers are submitted by e-mail:

- danijela.sarcevic@inmes.rs,
- meat.technology@inmes.rs

or on

- www.journalmeattechnology.com

EDITORIAL BOARD

LIST OF REVIEWERS

As an Editor in chief of scientific journal "Meat Technology", I would like to express my gratitude to professors, scientists and researchers for their contribution of reviewing in our journal. In this volume we present the list of reviewers.

Antonella Dalle Zotte, University of Padova, Department of Animal Medicine, Production and Health, Padova, Italy

Mohammed Gagaoua, PEGASE, INRAE, Institut Agro, Saint-Gilles, France

Rubén Domínguez Valencia, Meat Technology Center, San Cibrao das Viñas — Ourense, Spain

Oxana Kuznecova, V. M. Gorbatov Federal Research Center of Food System Moscow, Russia

Irina Tchernukha, V. M. Gorbatov Federal Research Center of Food System Moscow, Russia

Iva Steinhauserova, University of Veterinary and Pharmaceutical Sciences, Brno, Faculty of Veterinary Hygiene and Ecology, Brno, Czech

Tomas Alter, Free University Berlin, Faculty of Veterinary Medicine, Berlin, Germany

Sabine Leroy, Nacional Institute for Agricultural Research, Research Center Klermon-Feran, France

Meltem Serdaroğlu, Ege University, Engineering Faculty, Food Engineering Department, Izmir, Turkey

Lazo Pendovski, Ss Cyril and Methodius University in Skopje, Faculty of Veterinary Medicine, Skopje, Republic of North Macedonia Republic

Muhamed Smajlović, University in Sarajevo, Faculty of Veterinary Medicine, Bosnia and Herzegovina

Tomaž Polak, University in Ljubljana, Faculty of Biotechnology, Ljubljana, Republic of Slovenia

Željko Sladojević, Veterinary Institute „Dr Vaso Butozan", Banja Luka, Bosnia and Herzegovina

Snježana Mandić, University in Banja Luka, Technological Faculty, Banja Luka, Republic of Srpska

Milenko Šarić, University in Banja Luka, Faculty of Agriculture, Banja Luka, Republic of Srpska

Meho Bašić, University in Tuzla, Faculty of Technological Sciences, Bosnia nad Herzegovina

Goce Cilev, University St. Kliment Ohridski, Veterinary Faculty, Bitola, Republic of North Macedonia

Urška Jamnikar Ciglenečki, University in Ljubljana, Faculty of Veterinary Medicine, Ljubljana, Republic of Slovenia

Lea Demšar, University in Ljubljana, Faculty of Biotechnology, Ljubljana, Republic of Slovenia

Urška Henigman, University in Ljubljana, Faculty of Biotechnology, Ljubljana, Republic of Slovenia

Sheryl Avery, Scientific & Editorial English Services, Hamliton, New Zeland

Olgica Cerić, Food and Drug Administration – FDA, Veterinary Laboratory Investigation and Response Network, New Hampshire, USA

Luca Cocolin, Universitá degli Studi di Torino, Faculty of Agriculture, Department of Agricultural, Forest and Food Sciences, Torin, Italy

Galia Zamaratskia, Swedish University of Agricultural Sciences, Uppsala, Sweden

Antonia Ricci, National Laboratory for Salmonella, Departman for Food Safety, Risk Analysis/OIE Referential Laboratory for Salmonella, Padua, Italy

Ilija Đekić, University in Belgrade, Faculty of Agriculture, Belgrade, Republic of Serbia

Breda Jakovac-Strajn, University in Ljubljana, Faculty of Veterinary Medicine, Ljubljana, Republic of Slovenia

Rebeka Garsija, Animal Plant Health Agency, Dartford, United Kingdom

Vladimira Pistenkova, Faculty of Veterinary Hygiene and Ecology, Brno Czech Republic

Andrej Kirbiš, University in Ljubljana, Faculty of Veterinary Medicine, Ljubljana, Republic of Slovenia

Zlatko Jusufhodžić, Veterinary Institute Bihać, Bihać, Bosnia and Herzegovina

Marija Bošković Cabrol, University of Padua, Marie Skłodowska-Curie Postdoctoral Researcher, Padua, Italy

Biljana Pećanac, Public Institution Veterinary Institute of the Republic od Srpska „Dr Vaso Butozan", Banja Luka, Republic of Srpska

Anne Leskoviz, Ecole Nationale Superieure Agronomique de Tolouse, Toulouse, France

Martin Bouwknegt, Nacional Institute for Public Health and Environment, Eindhoven, Netherlands

Jacques-Antonie Hennekinne, Laboratory for Food Safety, ANSES – Agency National Securite Sanitarie de l' Alimentation, de l'Environnment et du Travial, Maisons-Alfort, France

Branko Velebit, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Ivan Nastasijević, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Aurelija Spirić, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Lidija Perić, University in Novi sad, Faculty of Agriculture, Novi Sad, Republic of Srbia

Marija Jokanović, University in Novi Sad, Faculty of Technological Sciences, Novi Sad, Republic of Serbia

Jelena Petrović, Scientific Institute of Veterinary medicine, Novi Sad, republic of Serbia

Zorica Jugović-Knežević, University in Belgrade, Faculty of Technological Science, Belgrade, Republic of Serbia

Nataša Kilibarda, University Singidunum, Belgrade, Republic of Serbia

Svetlana Stanišić, University Singidunum, Belgrade, Republic of Serbia

Zorica Bašić, Military Medical Academy, Institute of Hygiene, Belgrade, Republic of Serbia

Milka Popović, University in Novi Sad, Faculty of Medical Sciences, Novi Sad, Republic of Serbia

Ksenija Nešić, Scientific Veterinary Institute – Belgrade, Belgrade, Republic of Serbia

Stamen Radulović, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Vesna Janković, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Saša Janković, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Mirjana Lukić, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Mitrović Radmila, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Rašeta Mladen, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Dejana Trbović, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Jelena Ćirić, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Dragan Milićević, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Milan Ž. Baltić, University in Belgrade, Faculty of Veterinary Medicine, Blgrade, Republic of Serbia

Radoslava Savić-Radovanović, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Milica Laudanović, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Nikola Čobanović, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Nikola Stanišić, Inovation center AVEBE U.A., Groningen, Holandija

Silvana Stajković, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Dragoljub Jovanović, University in Belgrade, Faculty of Veterinary Medicine, Belgrade, Republic of Serbia

Dragana Ljubojević-Pelić, Veterinary Institute Novi Sad, Novi Sad, Republic of Serbia

Milan Milijašević, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Drago Nedić, Veterinary Institute „Vaso Butozan“ Banja Luka, Republic of Srpska

Nevena Maksimović, Institute for Animal Husbandry, Belgrade, Republic of Serbia

Jelena Jovanović, Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

Marija Dokmanović-Starčević, Army of Serbia, Belgrade, Republic of Serbia

Radomir Savić, University in Belgrade, Faculty of Agriculture Sciences, Belgrade, Republic of Serbia

Slađana Šobajić, University in Belgrade, Faculty of Farmaceutical Science, Belgrade, Republic of Serbia

Slaviša Stajić, University in Belgrade, Faculty of Agriculture, Belgrade, Republic of Serbia

Mukadderat Gokmena, Balikesir University, Faculty of Veterinary medicine, Department of Food Hygiene and Technology, Balikesir, Turkey

Weizheng Sun, South China University of Technology, China

Danka Spirić, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Stefan Simunović, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Jasna Kureljušić, Scientific Institute of Veterinary Medicine of Serbia, Department of food and feed safety, Belgrade, Serbia

Slobodan Knežević, Scientific Veterinary Institute Novi Sad, Belgrade, Serbia

Aleksandra Silovska Nikolova, Ss. Cyril and Methodius University in Skopje, Faculty of Agricultural Sciences and Food, Skopje, Republic of North Macedonia

Aleksandra Martinović, University of Donja Gorica, Faculty of Food Technology Food Safety and Ecology, Pdgorica, Montenegro

Svetlana Grdović, Faculty of Veterinary Medicine University in Belgrade, Belgrade, Serbia

Ana Gavrilović, University of Zagreb Faculty of Agriculture, Zagreb, Croatia

Marija Bošković Cabrol, University of Padua, DAFNAE, Italy

Mirko Prodanov, UKIM – Faculty for Veterinary Medicine in Skopje, Skopje, Republic of North Macedonia

Slavica Vesković Moračanin, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Kazimir Matović, Veterinary Specialized Institute Kraljevo, Kraljevo, Serbia

Martin Šlachta, Global Change Research Institute CAS, Czechia

Željko Gottstein, Faculty of Veterinary Medicine, University of Zagreb, Zagreb, Croatia

Nemanja Zdravković, Scientific Institute of Veterinary Medicine of Serbia, Belgrade, Serbia

Branka Borović, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Biljana Pećanac, Veterinary Institute of the Republika Srpska Dr. Vaso Butozan, Banja Luka, Bosnia and Herzegovina

Berker Nacak, Uşak University, Türkiye

Milica Glišić, Faculty of Veterinary Medicine, University of Belgrade, Belgrade, Serbia

Slobodan Lilić, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Marko Pajić, Scientific Veterinary Institute of “Novi Sad”, Novi Sad, Serbia

Dragana Ljubojević Pelić, Scientific Veterinary Institute of “Novi Sad”, Novi Sad, Serbia

Hülya Serpil Kavuşan, Ege University, Engineering Faculty, Food Engineering Department, Izmir, Turkey

Nikola Betić, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Nino Terjung, German Institute of Food Technologies (DIL), Quakenbrück, Germany

Sara Simunović, Institute of Meat Hygiene and Technology, Belgrade, Serbia

Damir Pavliček, Croatian Veterinary Institute, Veterinary Institute Križevci, Croatia

Mila Arapcheska, University “St. Kliment Ohridski” – Bitola, Faculty of Biotechnical Sciences - Bitola, Macedonia

Anna Bero, “V.M. Gorbatov Federal Research Center for Food Systems” Russian Academy of Sciences, Moscow, Russia

Predrag Ikonić, Institute of Food Technology in Novi Sad, University of Novi Sad, Novi Sad, Serbia

Slaviša Stajić, University of Belgrade, Faculty of Agriculture, Belgrade, Serbia

Branko Suvajdžić, University of Belgrade, Faculty of Veterinary Medicine, Department of Food Hygiene and Technology, Belgrade, Serbia

Andrea Radalj, University of Belgrade, Faculty of Veterinary Medicine, Belgrade, Serbia

Marko Dmitrić, Department of Food Safety, Veterinary Specialized Institute Kraljevo, Serbia

Jelena Babić Milijašević, Institute of Meat Hygiene and Technology, Belgrade, Serbia


Ludi za Poli
kako ko voli!
poli
SINCE
1974
ORIGINAL
madaboutpoli.com


Ravno
100%
DOMAĆE
Kažu: „Kod vas je sve ravno."
A nama srce zaigra kad vidimo kakva je Vojvodina!
Ravnica puna žita, vrednih ljudi, pravih domaćina.
Ravna – pa se brzo stigne od farme do prodavnice.
Zato je kod nas uvek sveže – ravno 100% domaće!
I ukusno, kao sve što dolazi iz Vojvodine.
Prava mešavina ljubavi i duge tradicije.
Matijević
INDUSTRIJA MESA NOVI SAD
Iz ravnice, ravno do vas
WWW.MATIJEVIC.RS

carnex

PAŠTETA

ALPSKA

Carnex sa ponosom predstavlja novitet u svom asortimanu - Alpsku paštetu, pažljivo kreiranu da spoji kvalitet, inovaciju i gurmanski užitak!

Kao lider na tržištu, Carnex ostaje veran potrošačima i osluškujući njihove potrebe uvodi nove proizvode prateći savremene trendove. U skladu sa tim, dobro poznati ukus Carnex Alpske kobasice sada se može pronaći i u pašteti! Alpska pašteta predstavlja proizvod stvoren za ljubitelje intenzivnih ukusa i visokih hranljivih vrednosti. Zahvaljujući bogatstvu proteina i kremastoj strukturi postaje idealan izbor za sve generacije.

Sa dolaskom proleća, Carnex nas je podsetio da se u omiljenim zalogajima najlepše uživa u prirodi. Zahvaljujući praktičnom pakovanju i bogatom ukusu, Alpska pašteta se savršeno uklapa u savremeni način života, pružajući brz, ali kvalitetan obrok u svakoj prilici. Carnex i ove godine inspiriše ljubitelje dobrog ukusa da zajedno sa najbližima stvaraju nezaboravne trenutke, jer uživanje u hrani nije samo potreba, već način da se povežemo i delimo lepe trenutke. Bilo da je reč o porodičnom izletu ili pauzi u pokretu, Alpska pašteta unosi toplinu i uživanje u svaki zalogaj, podsećajući da su upravo ti mali momenti oni koji se najduže pamte.

BOGATO PROTEINIMA

INTENZIVAN UKUS

ZA PRAVE GURMANE

PROBAJTE NOVI UKUS ALPSKE PAŠTETE!


YUHOR
Još od 1902.
Neka te kvalitet vodi
Neka te kvalitet vodi
YUHOR
Još od 1902.
ČAJNA
KOBASICA
TRADICIONALNA RECEPTURA
DIMLJENO NA BUKOVOM DRVETU
BEZ GLUTENA
73% SVINJSKOG MESA
BEZ GLUTENA
BEZ GLUTENA
OTVORITI OVDE

Neoplanta
Delikates

POBEDNIČKA KOBASICA

SA SIROM

*Potrošači izabrali putem aplikacije „Napravi kobasicu po svom ukusu“

Meat

Your smart way to meet today's demands and shape the future of meat

Biosolutions offer you natural, science-driven answers that can support flavor development, increase safety and productivity.

Visit us on www.novonesis.com or
contact your local Novonesis partner

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

664.9

MEAT technology : scientific journal / editor in chief Vesna Z. Djordjevic. - Vol. 57, No. 1 (2016) - . - Belgrade : Institute of Meat Hygiene and Technology, 2016- (Beograd : Naučna KMD). - 30 cm

Dva puta godišnje. - Je nastavak:
Tehnologija mesa = ISSN 0494-9846
ISSN 2466-4812 = Meat technology (Belgrade)
COBISS.SR-ID 225196812