SCIENTIFIC JOURNAL

eISSN 2560-4294
UDK 664.9

meat technology

64 Vol.
03 No.
2023 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 2560-4294
UDK 664.9

meat technology
scientific journal

Meat Technology Vol. 64 No. 3 P. 73–144 Belgrade 2023

CONTENTS

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

UDK: 637.523.053
ID: 133291017
https://doi.org/10.18485/meattech.2023.64.3.1

Original scientific paper

Evaluation of 3D laser imaging as a method for determination of different geometrical parameters of fermented sausages

Stefan Simunović[1], Sara Simunović[1], Jelena Babić-Milijašević[1], Čaba Silađi[1], Saša Janković[1], Ilija Đekić[2] and Igor Tomašević[3,4]*

[1] *Institute of Meat Hygiene and Technology, Kaćanskog 13, 11000 Belgrade, Serbia*
[2] *Institute of Food Technology and Biochemistry, Faculty of Agriculture, University of Belgrade, 11080 Belgrade, Serbia*
[3] *Department of Animal Source Food Technology, University of Belgrade, Nemanjina 6, 11080 Belgrade, Serbia*
[4] *DIL German Institute of Food Technology, Quakenbrueck, 49610 Germany*

A R T I C L E I N F O

Keywords:
3D laser imaging
3D scanning
Volume
Surface
Shrinkage

A B S T R A C T

The aim of this study was to investigate the possibility of using 3D laser imaging in the analysis of geometrical parameters of fermented sausages during different stages of drying. Three samples of izletnička sausage ware taken for the analyses immediately after stuffing into casings and after 9, 18, 27 and 35 days of ripening. Volume of the sausage reduced significantly ($P < 0.05$) from the initial value of 377.93 cm^3 to 254.58 cm^3, while surface area reduced from 33.43 cm^2 to 27.06 cm^2. Weight loss showed strong negative correlations ($P < 0.01$) with both volume ($r = -0.99$) and surface area ($r = -0.82$), indicating the possibility of using 3D laser imaging in the estimation of weight loss. The relative error of volume estimation was between 1.9 % and 4.5 %. During the entire ripening period, a constant decrease in the volume to surface area ratio of izletnička sausage was observed. This decrease showed a strong negative correlation ($P < 0.01$; $r = -0.81$) with scores for wrinkly appearance obtained by a trained sensory panel. 3D laser imaging demonstrated a possibility for application in estimating the volume and surface area of fermented sausages.

1. Introduction

Food quality is specified by different regulations, and they mostly refer to chemical parameters that are determined using routine laboratory analyses (*Official Gazette of RS,* 2015). Apart from regulating chemical parameters of food, food quality regulations also refer to product color, texture and appearance, which are determined by sensory experts.

However, this type of quality determination depends on the subjective assessment of the sensory panellists, which could lead to a number of errors and false results. In addition, sensory analysis is laborious, time-consuming and limited by human factors. Therefore, development of fast, precise, accurate and automated methods for determination of sensory parameters is of interest to different parties involved, like producers, inspection bodies and laboratories.

In recent years, a great demand has arisen for additive free/clear label food (*Simunovic et al.,* 2020). In most cases, these products, often being of superior quality to those produced industrially, are produced by craft manufacturers. However, when using nothing but natural ingredients, it is difficult to achieve and maintain standardized production. Therefore, these products are usually more susceptible to quality defects, like rancidity, changes in color, texture and flavour and shorter shelf life. European regulations recognize some traditional

***Corresponding author:** Simunovic Stefan: *stefan.simunovic@inmes.rs*

Paper received November 11th 2023. Paper accepted November 22nd 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

food products and allow some exceptions in terms of compliance with hygienic requirements. According to *European Commission* (2004), food can be produced by traditional methods that have proven their safety, even if they do not comply with different food safety regulations. This is particularly important for small manufacturers of traditional products in Europe who cannot meet hygiene requirements for different reasons. These producers usually have financial difficulties meeting strict hygiene requirements. Additionally, full hygiene criteria compliance and abandoning the use of traditional materials could possibly affect specific sensory characteristics of the product.

In fermented sausage production, quality is usually determined by the use of higher quality ingredients, longer ripening period and higher meat to fat ratio in the sausage formulation. During the last decade, there has been a number of recommendations about dietary fat intake as a result of the negative health effects when such fat is consumed excessively (*Liu et al.*, 2017). This influenced the trend in consumption of low fat products and led to a number of fat-reduced products in the market. When it comes to fermented sausages, fat content was, in most cases, reduced by replacing part of the pork back fat with meat (*Gomez and Lorenzo,* 2013; *Lorenzo and Franco,* 2012). In addition to the increase in production price, fat reduction led to the formation of a wrinkly appearance or uneven surface of the sausage. The reason for this is to be found in the higher moisture content in meat compared to pork back fat, which consequently causes higher weight loss during drying than in the normal-fat sausages (*Mora-Gallego et al*., 2014). However, there is no study focusing on the sensory acceptability of fermented sausages with different levels of wrinkly appearance.

Recent advancements in the field of three-dimensional (3D) laser imaging have created new possibilities in the analysis of various food products. The study of *Vaskoska et al.* (2020) showed that 3D laser imaging could be used to estimate the volume of pork cuboids. In addition, those authors showed the possibility of predicting cooking loss by using the volume reduction obtained by the 3D imaging before and after cooking. Traditionally, the volume of irregularly shaped objects is measured by the water displacement method. When it comes to food, the main disadvantage of this method is its destructiveness due to water absorption by the sample. However, this method is reliable, accurate and fast and can be used to determine the relative error of new methods for volume estimation (*Zhang et al*., 2019). The study of *Uyar and Erdogdu* (2009) showed the possibility of estimating volume and surface area of pears, strawberries, bananas, apples and eggs. In addition, in the study of *Zhang et al*. (2019), the volume of potatoes, carrots and ginger root was measured by both the 3D scanner and water displacement methods. The relative error of 3D estimated volume ranged between 2.6% and 5.4%. In the study of *Goni et al*. (2007), the relative error of volume estimation by 3D scanner for Granny Smith apple, red delicious apple and fresh meat was −1.25%, −1.01% and −0.95%, respectively. On the other hand, the surface area of irregularly shaped objects is traditionally measured by the tape method (*Banks,* 1985). This method involves covering the entire surface of an object using tape cut into small strips. Afterwards, the strips are removed and the surface area of all strips is measured manually or by an area meter. This method is prone to human error and is time-consuming (*Zhang et al.*, 2016). However, *Zhang et al.* (2016) proposed a method for measuring the surface area of an egg based on 3D laser imaging. The authors found that the method had high accuracy when they compared the results of 3D estimated surface area with results obtained by manual measurement of small pieces of broken egg shell.

Non-destructiveness is an important characteristic of analytical methods, perhaps especially for those that tend to be used for product analysis during different stages of production. 3D laser imaging is capable of measuring different geometrical characteristics of objects without destruction of product structure (*Uyar and Erdogdu,* 2009). In recent years, numerous research studies aimed at 3D scanning applications in different industries. The reasons for the recent increase in the popularity of 3D technology are in the more competitive price of commercial scanners and the advancements in the field of 3D processing software. In addition, these scanners do not require staff to be trained to a high level, while processing of 3D data is facilitated by the multiple software products available.

The aim of this study was to investigate the possibility of using 3D laser imaging in the analysis of the geometrical parameters of fermented sausages during different stages of ripening. In addition, volume to surface ratio, as a possible indicator of sausages' wrinkly appearance, was compared to sensory panel estimation of wrinkly appearance in order to evaluate the correlation between these two parameters. The authors identified a knowledge gap in the determination of fermented sausages' geometrical characteristics during ripening as a consequence of the destructiveness of methods we have used in the past.

2. Materials and Methods

2.1 Sausage preparation and sampling

One batch of approximately 20 kg of izletnička sausage was produced using fresh pork ham (85%) and pork back fat (15%). One part of the pork ham was ground through an 8 mm plate, while frozen (−18 °C) pork back fat and the rest of the pork ham were cut in a bowl cutter KU 130 AC (Laska, Traun, Austria) and then mixed with the ground ham and spices. The spices were the following: salt, white pepper, coriander, nutmeg; starter cultures were also added at this stage. Meat batter was stuffed into collagen casings (Ø 55 mm) in units of approximately 20 mm in length using a filling machine VF616 (Handtmann, Biberach an der Riss, Germany). Sausages were transferred to a traditional smoking chamber where they were cold smoked during four days using commercial beech chips as previously described by *Simunovic et al.* (2020). Afterwards, sausages were transferred to a ripening chamber with controlled conditions where they were kept for 36 days. Three sausages for analysis were taken immediately after stuffing into casings, and after 9, 18, 27 and 36 days of ripening. Before each stage of the analysis, the weight of the sausages was firstly measured in order to calculate weight loss, which was expressed as a percentage of the sample initial weight. The sausages were then used for 3D laser imaging and sensory analysis, and then after each stage of the analysis, the same sausages were immediately returned to the ripening chamber for further drying.

2.2 3D laser imaging

The 3D shape of the sausages (Figure 1) was obtained using an EinScan-SP (Shining 3D Tech., Hangzhou, China) scanner. Sausages were placed on a rotation table and scanned in a dark room as recommended by the manufacturer. In order to obtain 3D data of the downwards facing surface on which the sausage was laid, sausages were rotated by 90 degrees and scanned again. All sausages were scanned using texture mode while adjusting the brightness depending on the color of each sample. The duration of one scan was approximately 40 min. Meshing of 3D scans was performed using EXScan S_v3.0.0.1 (Shining 3D Tech., Hangzhou, China) software as described by *Simunovic et al.* (2022). Relative error (%) of 3D estimated volume was measured during each stage using the water displacement method.

Figure 1. 3D model of izletnička sausage

2.3 Sensory analysis

The sensory panel for descriptive sensory analysis consisted of four women and four men. Panellists were trained during a one-month period according to ISO 8586:2012 (*ISO*, 2012). Analysis was performed at the start and at each ripening stage, when panellists were asked to rate the wrinkly appearance of the sausages using a 5-point Likert scale (i.e. 1 – no wrinkly appearance, 5 – very wrinkly appearance). Before analysis, fermented sausages with different levels of wrinkly appearance were presented to panellists.

2.4 Statistical analysis

Pearson correlation coefficients, mean values and standard deviations were all obtained using SPSS package (SPSS 23.0, Chicago, IL, USA). For statistical analysis of the obtained data, one-way analysis of variance (ANOVA) was performed. Tukey's post hoc test was used for comparison of mean values of the analyzed parameters, with statistical significance being set at $p<0.05$.

3. Results and Discussion

The relative error of 3D volume measurements ranged from 1.9 % to 4.5 %, depending on the processing stage. These values are similar to those found by *Zhang et al.* (2019) and *Simunovic et al.* (2022), but higher than those reported by *Goni et al.* (2007). Generally, there are four main groups of characteristics that have been analyzed in fermented sausages: physico-chemical, textural, sensory and microbiological. All of these were extensively analyzed in many types of sausages in the past.

However, there is a lack of scientific data regarding geometrical parameters of sausages. Fermented sausages undergo relatively long ripening and drying processes. During this period, they can lose from 20 % to 55% of their initial weight (*Brankovic Lazic et al*., 2019; *Wen et al*., 2019), depending on temperature and relative humidity conditions, drying time and formulation. The decrease of sausage moisture content results in volume reduction and affects sausage appearance. At the moment, there are no peer-reviewed, published data regarding volume determination of fermented sausages.

During ripening, the volume of izletnička sausage reduced significantly (P < 0.05) from the initial value of 377.93 cm^3 to 254.58 cm^3 (Table 1). Volume reduction showed a very strong negative correlation (P < 0.01) with weight loss (r = 0.99).

From this it can be concluded that moisture evaporation, which naturally occurs during the drying process, influenced the reduction in volume of the sausages. To support this statement, the most intense reduction in both volume and weight loss was observed between days 9 and 18 of ripening. The strong correlation between weight loss and volume indicates that volume measurements by 3D laser imaging could be used to estimate the weight loss of the sausage, which is often used as an indicator for the end of the drying process. In addition, weight loss is an important economic parameter since it directly affects production yield. *Simunović et al*. (2020) reported the strong negative correlation between weight loss and moisture content of Njeguška sausage, which leads to an assumption that 3D laser imaging could also be used to estimate sausage moisture content. As moisture content is considered a quality parameter of dry fermented sausages according to Serbian regulation on the quality of ground meat, meat preparations and meat products (*Official Gazette of RS, 2015*), application of 3D laser imaging could be used as a tool in the analysis of moisture content. Traditionally, moisture content is determined by drying the sample for several hours at temperatures around 105 °C. The analytical method involves homogenization of the sample, drying and cooling until the sample reaches constant mass. This means that the sample can be dried several times, primarily depending on its moisture content but also on nutritional value, texture and other factors. Because of that, the method is very time-consuming and it requires use of an oven and an analytical balance. On the contrary, analysis by means of 3D laser imaging usually lasts from 20 to 80 minutes depending on the required quality of the scan. In the study of *Uyar and Erdogdu* (2009), the reported scanning time for peach samples was around 2 hours. The reasons for the lower scanning duration in our study could be in our use of a different scanner and the more advanced PC configuration nowadays. However, during the 3D scanning procedure, the presence of an operator is only needed for the rotation of the sample by 90°, as already explained in the previous section.

Application of 3D scanning technology in the food sector could be particularly important for the meat industry where 3D imaging could be used as a tool to determine the end of drying processes. Currently, food business operators are responsible for determining the end of a drying process, so this proposed method could potentially prevent the occurrence of human error. However, in order to apply this method in industry, it is necessary to develop mathematical models for different types of fermented sausages. Different sausage formulations, casings and ripening conditions affect different drying dynamics, which would consequently require different models, not only for different types of sausages but also for different processing plants and ripening

Table 1. Change in geometrical and sensory parameters of izletnička sausage during ripening

	Processing time (days)				
	0	9	18	27	36
Volume (cm^3)	377.93±2.50^a	334.25±2.02^b	289.43±1.58^c	273.29±0.94^d	254.58±2.29^e
Surface (cm^2)	33.43±0.56^a	30.64±1.51^b	28.94±0.47^{bc}	28.34±0.61^{bcd}	27.06±1.36^{cd}
Weight loss (%)		9.66±0.00	21.11±0.00	26.51±0.00	31.36±0.00
Volume/Surface ratio	11.31±0.15^a	10.93±0.60^{ab}	10.00±0.20^{bc}	9.65±0.24^c	9.42±0.54^c
Wrinkly appearance score	1.67±0.50^a	2.12±0.64^a	3.62±0.52^b	3.88±0.35^b	4.12±0.35^b

$^{a\text{-}e}$ Values in the same row followed by different letters are significantly different (P<0.05).
Data represent the mean ± standard deviation (n = 3)

chambers. Furthermore, these models could potentially be used to control the temperature and relative humidity conditions in ripening chambers, while on-line analysis could also be possible by installation of scanners directly in drying chambers.

The surface area of izletnička sausage reduced significantly during drying from the initial value of 33.43 cm^2 to 27.06 cm^2. As was the case with volume, surface area reduction showed a negative correlation ($P < 0.01$) with weight loss ($r = -0.82$). As we previously explained, manual surface area measurements of irregular objects are time-consuming and prone to human error. Because of that, these measurements are not performed routinely in laboratories in spite of the fact that surface area could potentially be used in evaluation of different quality parameters of food. However, because of the uneven surface of the sausages it was not possible to measure the surface area by the tape method. In the study of *Zhang et al.* (2016), the relative error for surface area estimation of an egg by 3D laser imaging was between 0.38 % and 0.95 %. In our study, at the end of the ripening, the weight loss of izletnička sausage was 31.36 %, and this was similar to the weight loss found in sausages with reduced salt content (*Corral et al*., 2016), but lower than weight losses found in Cinta Senese and Harbin dry sausages (*Aqualini et al*., 2018; *Wen et al*., 2019). Generally, sausages with high weight loss tend to acquire a wrinkly appearance, as is usually the case with sausages produced by traditional means. On the other hand, industrial sausages are usually produced with the addition of different plant proteins that have a role of binding the water molecules. This means that relatively few water molecules are capable of evaporating during drying, which results in less weight loss than in traditional sausages, and this is of great importance for the cost-effectiveness of production.

Fermented sausages are produced using two main ingredients, meat and back fat. In order to prepare the batter, these ingredients are comminuted or ground, mixed and filled into casings. Because of the higher moisture content of meat compared to back fat, in the parts where meat is on the surface of the sausage, small depressions are formed. In other words, more moisture evaporates from meat parts, which results in the formation of these depressions. The result is the formation of an uneven surface on the sausage. This is more obvious the longer the drying period. In the study of *Mora-Gallego et al*. (2014), three different types of fermented sausages were produced, each containing different amounts of pork back fat. Those authors concluded that the batch produced with the highest amount of back fat was rounder than other batches. In other words, the lower the content of fat in the sausage, the more uneven is the sausage surface. High fat content slows the drying rate during ripening, which results in a lower amount of wrinkles compared to those produced with lower fat content (*Wirth*, 1988). The longer the ripening period, the higher the weight loss, and consequently, the wrinklier the sausage appearance. In this study, our sensory panel rated the wrinkly appearance of izletnička sausage as highest at the end of the drying. Izletnička sausage is characterized by a low fat content, so high scores for wrinkly appearance at the end of the ripening were expected. Our results showed a strong correlation between surface area and volume during ripening ($P < 0.0$; $r = 0.92$). However, a strong correlation between these two parameters was expected. The total reduction in volume of izletnička sausage was 32.64 % and was higher than the reduction of sausage surface area, which was 19.05 % of its initial value. Results showed a constant decrease in volume to surface ratio during the entire ripening period. This reduction was strongly related to scores for wrinkly appearance obtained by sensory panel. More precisely, these two parameters showed a strong negative correlation ($P < 0.0$; $r = -0.81$), which indicates that volume to surface area ratio could potentially be used to estimate the wrinkly appearance of sausages. The volume to surface area ratio of izletnička sausage reduced from the initial value of 11.31 to 9.42 at the end of the ripening period. The lower this ratio is, the wrinklier is the appearance of the sausage. However, there is a need for more detailed research about the possibility of using volume to surface ratio for the estimation of wrinkly appearance of fermented sausage.

4. Conclusion

Relative errors of volume and surface area estimation gave promising results for the application of 3D laser imaging in the analysis of fermented sausages. Apart from being affordable and easy to use, this method is non-destructive, and because of that, it can be fully applicable in analysis during different stages of the fermented sausage production process. The strong correlation between sensory scores for wrinkly appearance and volume to surface ratio indicate that this ratio could be used in the future for determination of wrinkly appearance. However, further research regarding the application of 3D laser imaging in food analysis should be conducted. More precisely, future research should be focused on characterization of geometrical parameters of other fermented sausages and development of mathematical models for determination of different quality parameters. In addition, it is necessary to conduct a study on the sensory acceptability of fermented sausages with different levels of wrinkly appearance and to determine the optimal level for each type of the sausage. A limitation of this research is that surface area was not able to be measured experimentally due to the uneven surface of the sausage.

Procena metode 3D laserskog snimanja za potrebe određivanje različitih geometrijskih parametara fermentisanih kobasica

Stefan Simunović, Sara Simunović, Jelena Babić-Milijašević, Čaba Silađi, Saša Janković, Ilija Đekić i Igor Tomašević

INFORMACIJE O RADU

Ključne reči:
3d lasersko skeniranje
Zapremina
Površina
Naboranost

APSTRAKT

Cilj rada bio je da se istraži mogućnost primene 3D laserskog skeniranja u analzi geometrijskih parametara fermentisanih kobasica tokom različitih faza procesa sušenja. Tri uzorka izletničke kobasice su ispitivana odmah nakon punjenja u omotače, nakon 9, 18, 27 i 35 dana zrenja. Zapremina kobasice se statistički značajno ($P < 0,05$) smanjila sa početne vrednosti od 377,93 cm^3 na 254,58 cm^3. Sa druge strane, površina izletničke kobasice se statistički značajno ($P < 0,05$) smanjila sa 33,43 cm^2 to 27,06 cm^2. Kalo sušenja pokazalo je jaku negativnu korelaciju ($P < 0,01$) sa zampreminom ($r = -0,99$) i površinom kobasice ($r = -0,82$), ukazujući na mogućnost primene 3D laserskog skeniranja u proceni kala sušenja. Relativna greška procene zapremine bila je od 2,1 do 8,1 %. Tokom sušenja, primećen je konstantan pad odnosa zapremine i mase sa početne vrednosti od 11,31 do 9,42 na kraju procesa. Ovaj pad je pokazao jaku negativnu korelaciju sa ocenama za naboranost površine dobijenih od strane obučenog senzornog panela. 3D lasersko skeniranje pokazalo je mogućnost primene u proceni zapremine i površine fermentisanih kobasica.

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

Funding: The study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract number 451-03-47/2023-01/200143) and Contract number — Grant No. 451-03-47/2023-01/200050 from 03.02.2023.

References

Banks, N. H. (1985). Surface area estimation of potato tubers. *Potato Research*, 28, 487–496.

Brankovic Lazic, I., Jovanovic, J., Simunovic, S., Raseta, M., Trbovic, D., Baltic, T. & Ciric, J. (2019). Evaluation of sensory and chemical parameters of fermented sausages. *Meat Technology,* 60 (2*)*, 84–90.

Corral, S., Salvador, A. & Flores, M. (2016). Effect of the use of entire male fat in the production of reduced salt fermented sausages. *Meat Science,* 116, 140–150.

European Commission No 852 (2004). Regulation No 852/2004 of the European parliament and of the council of 29 April 2004 on the hygiene of foodstuffs. *Official Journal of the European Union, L 139/1*.

Gómez, M. & Lorenzo, J. M. (2013). Effect of fat level on physicochemical, volatile compounds and sensory characteristics of dry-ripened "chorizo" from Celta pig breed. *Meat Science,* 95 (3), 658–666.

Goni, S., Purlis, E. & Salvadori, V. (2007). Three-dimensional reconstruction of irregular foodstuffs. *Journal of Food Engineering,* 82, 536–547.

ISO 8586 (2012). Sensory analysis — General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors.

Liu, A., Ford, N., Hu, F., Zelman, K., Mozaffarian, D. & Kris-Etherton, P. (2017). A healthy approach to dietary fats: understanding the science and taking action to reduce consumer confusion. *Nutrition Journal,* 16 (1), 1–15.

Lorenzo, J. M. & Franco, D. (2012). Fat effect on physico-chemical, microbial and textural changes through the manufactured of dry-cured foal sausage lipolysis, proteolysis and sensory properties. *Meat Science,* 92, 704–714.

Mora-Gallego, H., Serra, X., Dolors Guàrdia, M. & Arnau, J. (2014). Effect of reducing and replacing pork fat on the physicochemical, instrumental and sensory characteristics throughout storage time of small caliber non-acid fermented sausages with reduced sodium content. *Meat Science,* 97, 62–68.

Official Gazette of RS No 94. (2015). Regulation on the quality of ground meat, meat preparations and meat products.

Simunovic, S., Đorđević, V. Barba, F. J., Lorenzo, J. M., Rašeta, M., Janković, S. & Tomasevic, I. (2020). Characterisation of changes in physicochemical, textural and microbiological properties of Njeguška sausage during ripening. *Journal of Food Science and Technology,* 2020. doi: 10.1007/s13197-020-04862-z

Simunovic, S., Đorđević, V., Lakićević, B., Đekić, I., Lorenzo, J. M., Barba, F. J. & Tomasevic, I. (2022). Digital Evaluation of Nitrite-Reduced "Kulen" Fermented Sausage Quality. *Journal of Food Quality*, 2022, e2480746. doi: https://doi.org/ 10.1155/2022/2480746

Uyar, R. & Erdogdu, F. (2009). Potential use of 3-dimensional scanners for food process modeling. *Journal of Food Engineering,* 93, 337–343.

Vaskoska, R., Ha, M., Tran, H. T. T., Khoshelham, K., White, J. & Warner R. (2020). Evaluation of 3D laser scanning for estimation of heating-induced volume shrinkage and prediction of cooking loss of pork cuboids compared to manual measurements. *Food and Bioprocess Technology,* 2020. doi: 10.1007/s11947-020-02421-0

Wen, R., Hu, Y., Zhang, L., Wang, Y., Chen, Q. & Kong, B. (2019). Effect of NaCl substitutes on lipid and protein oxidation and flavor development of Harbin dry sausage. *Meat Science,* 156, 33–43.

Wirth, F. (1988). Technologies for making fat-reduced meat products. *Fleischwirtschaft*, 68, 1153–1156.

Zhang, R., Li, F., Tang, J., Koral, T. & Jiao, Y. (2019). Improved accuracy of radio frequency (RF) heating simulations using 3D scanning techniques for irregular-shape food. *LWT — Food Science and Technology*, 121, 108951.

Zhang, W., Wu, X., Qiu, Z. & He, Y. (2016). A novel method for measuring the volume and surface area of egg. *Journal of Food Engineering,* 170, 160–169.

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

UDK: 637.54.058
ID: 133248265
https://doi.org/10.18485/meattech.2023.64.3.2

Review paper

Poultry meat quality preservation by plant extracts: an overview

Ines Feknous[1], Djamal Ait Saada[1], Cerine Yasmine Boulahlib[2], Laura Alessandroni[3], Sendous Wadjila Souidi[4], Ouiza Ait Chabane[1] and Mohammed Gagaoua[5]*

[1] *Food Technology and Nutrition Laboratory (LTAN), Abdelhamid Ibn Badis University, 27000, Mostaganem, Algeria*
[2] *Université des Frères Mentouri Constantine, 25000, Constantine, Algeria*
[3] *Chemistry Interdisciplinary Project (CHIP), School of Pharmacy, University of Camerino, Via Madonna delle Carceri, 62032 Camerino, Italy*
[4] *Laboratory of Sciences and Technics of Animal Production, Abdelhamid Ibn Badis University, Mostaganem, 27000, Mostaganem, Algeria*
[5] *PEGASE, INRAE, Institut Agro, 35590 Saint-Gilles, France*

ARTICLE INFO

Keywords:
Chicken meat safety
Plant extracts
Shelf-life
Natural preservatives
Bioactive compounds
Meat preservation

ABSTRACT

Poultry meat is appreciated by consumers for its nutritional value, low fat content, versatility of use in various cuisines and affordable prices. However, its susceptibility to spoilage due to multiple pre-slaughter and processing factors poses challenges for the meat industry, especially in developing countries. To improve the safety of poultry products, synthetic preservatives like nitrites, butylated hydroxytoluene and sulphites are used. Currently, these additives/preservatives have, however, raised concerns about their impact on human health, prompting a shift from consumers toward natural alternatives, such as medicinal and aromatic plants. Therefore, this paper delves into the potential of plant extracts as natural preservatives for improving the quality and shelf-life of chicken meat and processed products. It provides an overview of the various plant extracts and essential oils that have demonstrated antimicrobial, antioxidant and enzyme inhibitory properties, without compromising the sensory attributes of the products. Different incorporation methods are discussed, including direct incorporation or marination in aqueous and/or alcoholic extracts, and the use of essential oils, including for *in vivo* animal feed supplementation. Overall, each method influences the final product quality differently. We further summarised the current knowledge about the mechanisms of action of the plant extracts tested, even though they are not fully elucidated. Despite the benefits of these compounds, some challenges have to be addressed, including standardising the composition of the extracts, harmonising the sensitivity of the bioactive compounds with the processing conditions, ensuring cost effectiveness and obtaining regulatory approvals for their use. The scaling up of production to meet industry demands also presents some technical challenges. Overall, the application of natural plant preservatives not only enhances chicken meat quality, but also could support the meat industry to align with the evolving consumer expectations for sustainable food products.

1. **Introduction**

Meat, the product of converting animal muscle into a culinary delight, holds immense importance in human diets and cultures worldwide. The transformation of muscle into meat through sophisticated post-mortem physical and biochemical changes that occur in early post-mortem and during ageing, confers the expected sensory qualities by consumers. In fact, meat is rich in essential nutrients, it provides proteins, vitamins and minerals, which all are crucial for human health (*Shah et al.,* 2014; *Geldenhuys et al.,* 2015). Among the various types of meat, poultry stands out for its advantageous nutritional composition that makes it highly valued for healthy dietary practices (*Jilo & Hasan,* 2022). It has a lower fat content in contrast to red meat, and is predomi-

***Corresponding author:** *mohammed.gagaoua@inrae.fr*

Received: October 24th 2023. Corrected November 3rd 2023. Accepted November 2nd 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

nantly composed of unsaturated fatty acids *(Saleh et al., 2020; Hailemariam et al.,* 2022). Overall, chicken meat and derived products are affordable, exempt of religious constraints, and have valuable technological characteristics, making them widely consumed sources of animal proteins (*Liu et al.,* 2012; *Vranić et al.,* 2014).

Despite these numerous advantages, industry is challenged with the fragile character of chicken meat that can alter in 4 to 8 days, owing to the white muscle structure, the overall health state of the animal and slaughter conditions *(Abdel-Salam et al., 2017; Alessandroni et al.,* 2021). The rate of spoilage is furthermore exacerbated by the post-slaughter handling at the retail phase due to cold chain breaks during transport and inappropriate storage temperatures (*Rani et al.,* 2017).

To reduce the economic losses induced by this deterioration and to satisfy the growing demand of the consumers, preservatives like sodium and potassium nitrites, butylated hydroxytoluene (BHT), sulphites and other chemical products are used to stabilise the biochemical and enzymatic processes, inhibit bacterial growth, prevent lipid oxidation reactions and to enhance the colour, flavour and tenderness properties (*Mani-López et al.,* 2016; *Gutiérrez-Del-río et al.,* 2021; *Atwaa et al.,* 2022). Although these chemical (synthetic) compounds are effective in extending the shelf-life of chicken meat with technological benefits and cost conveniences, they are highly questionable and controversial concerning their potential impact on human health (*Thakur et al.,* 2019; *Yu et al.,* 2021). For example, some of them have been deemed allergenic, like sulphites, carcinogenic like butylated hydroxyanisole (BHA) and BHT, or as precursors to carcinogenic components like nitrates and nitrites that react with certain amino acids during high-heat cooking to form nitrosamines *(Drabik-Markiewicz et al.,* 2010; *Muthukumar et al.,* 2020; *Xie et al.,* 2023). Thus, these compounds are no longer desirable due to the growing concerns by consumers over their intake of chemical ingredients in food. In fact, consumers are becoming more proactive about their health and they have place emphasis on products with transparent labelling, reduced or absent synthetic ingredients and minimally processed products, while having more expectations that products are locally sourced and/or of natural origin (*Fox et al.,* 2018*; Mesías et al.,* 2021).

Considering the above concerns, incorporating natural preservatives from plants in chicken meat preservation would then offer a multitude of benefits. For the industry, it provides an eco-friendly alternative to synthetic additives, aligning with the growing demand for more sustainable food production. Using plant-derived preservatives can also reduce production costs and improve supply chain efficiency, ultimately boosting profitability. Moreover, it enhances product quality, reducing food waste, while still ensuring safe and healthy products (*Seidavi et al.,* 2021). For consumers, the impact is profound, as they enjoy chicken products that are free from potentially harmful synthetic additives, resulting in improved food safety and overall well-being. This approach supports a healthier, more sustainable food industry, satisfying both producers and consumers (*Vinci et al.,* 2022; *Pinto et al.,* 2023). These aspects constitute the objectives of this review, which aims to provide an overview of the main plants and their compounds that have been identified to have antioxidant, antimicrobial and enzyme inhibitory properties, used to improve the quality and extend the shelf-life of chicken meat and its derived products. We also discuss the different processes of their incorporation, the mechanisms of action, and the challenges encountered when using natural extracts on muscle food products.

2. An overview of the main plants used for chicken meat preservation

Medicinal and aromatic plants have long been part of the cultural heritage of different ethnicities. They find their place in ancestral medicine, cosmetics and culinary recipes *(Miara et al.,* 2019a; *Miara et al.,* 2019b). In the context of traditional (ethnic) methods of meat preservation, different herbs are used to mask unpleasant or improve the odour and taste, along with increasing the shelf-life of the products (*Gagaoua & Boudechicha,* 2018; *Ez zoubi et al.,* 2022). Broiler meat from battery-farmed chicken presents a mild flavour and subtle taste, sometimes described as bland and insipid by consumers, who prefer local, traditional pasture-raised chicken (*Gnakari et al.,* 2007). However, it has the advantage of easily adapting to different seasonings and absorbing their aroma. This versatility facilitates the incorporation of plants, plant extracts and essential oils as preservatives, thereby enhancing the taste of chicken meat products and prolonging their shelf-life without negative influences on the inherent organoleptic characteristics (*Tian et al.,* 2014 ; *Qi et al.,* 2022).

Table 1. Summary table of key studies and findings regarding plant extract use in chicken meat preservation.

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Basil *(Ocimum basilicum)*	2.5 and 5 mg/ml (solution)	Raw and autoclaved meat	72h – 4°C and 18°C – EO – Sterile petri dishes	• Significant effect on normal flora • Reduction of artificially inoculated *Salmonella enteritidis* • Physicochemical parameters (pH, colour, texture, TBARS, cooking loss) beneficially affected for most of them	(*Stojanović-Radić et al.,* 2018)
Cinnamon *(Cinnamomum verum / cassia)*	0.25, 1 and 2% (w/v) EO	Chicken breast fillets	15 days – 4°C – Nanoemulsion with chitosan-pectin solution	• Strong *in vitro* antimicrobial activity against *L. monocytogenes* and *P. deceptionensis* • EO nanoemulsion improved the pH, oxidative stability, and colour properties of chicken breasts	(*Wang et al.,* 2021)
Cinnamon *(Cinnamomum verum / cassia)*	0.5 % of oil macerate (1g/100ml oil)	Ready-to-eat chicken patties	16 days – 4°C – Gelatine-chitosan nano-emulsion coating infused with EO + sterile polyethylene bags	• Better coating characteristics • Stronger antimicrobial activity • Lowest TVC, pH, TVBN and TBARS • Dramatically reduced moisture loss • Shelf-life extension by more than 4 days	(*Qiu et al.,* 2022)
Coriander *(Coriandrum sativum)*	1%	Chicken patties	9 days – 4°C – Aqueous extract	• Reduction of peroxide, Total carbonyls, metmyoglobin formation • Microbial growth (TPC) inhibited and low TBARS rates • No colour or odour changes after cooking	(*Ahmad et al.,* 2023)
Citrus *(Citrus spp.)*	0.1 and 0.2 ml /100g meat	Fresh ground chicken	14 days – 4°C – LDPE and LDPE/EVOH/LDPE films – Citrox® extract	• Extension of the microbiological shelf-life by 1–2 days (extract alone) and 3–4 days when combined with an O_2 absorber • No significant changes in colour, but positively significant in odour and taste • Physicochemical parameters slightly affected by the different treatments	(*Mexis et al.,* 2012)
Clove *(Syzygium aromaticum)*	0.5 and 1%	Raw chicken meat	15 days – 4°C – LDPE bags – Ethanolic extract	• Highly effective against microbial growth: TVC, LAB, *Enterobacteriaceae* and *Pseudomonas* spp. count • Prevention of lipid oxidation (TBARS) • Good extraction yield, overall acceptability and antioxidant potential: DPPH, FICA • Meat colour preservation	(*Zhang et al.,* 2016); (*Radha Krishnan et al.,* 2014)
Rosemary *(Rosmarinus officinalis))*					

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Rosemary *(Rosmarinus officinalis)*	EO/EtOH 30/70 at different concentrations from 0.1% to 4% w/w	Fresch sliced chicken breast meat	7 days – 4°C – directly sprayed on meat – PET packaging	• Antibacterial action of volatile components of *R. officinalis* extracted by hydrodistillation • BA production inhibition after just 2 days of storage • The antibacterial and anti-BA action was due to the formulation of a new active packaging system with essential oil of *R. officinalis*	(*Sirocchi et al.,* 2013)
Rosemary *(Rosmarinus officinalis)*	EO/tween 80 1% and 2% (w/v) solutions	Fresh minced chicken meat	21 days – 4°C – chitosan/ sodium caseinate – PLA film	• EO films showed antioxidant and inhibition of lipid peroxidation effects: DPPH and TBARS • EO film coated meat reported lower concentrations of heptanal, butanoic acid and ethanol	(*Fiore et al.,* 2021)
Curry *(Murraya kœnigii)*	1%	Restructured chicken slices	20 days – 7±1°C – Leaf powders – LDPE bags	• No significant difference in the cooking yield and proximate composition • Significantly lower microbial counts • No detection of yeast or mould • No significant changes in the sensory parameters, with a good overall acceptability	(*Najeeb et al.,* 2015)
Drumstick *(Moringa oleifera)*					
Mint *(Mentha spp.)*					
Fennel seeds *(Fœniculum vulgare)*	0.2% v/w	Chicken thighs	16 days – 4±0.5°C – EO – Vacuum packaging	• TVC reduction for *Enterobacteriaceae*, *Pseudomonas* spp, LAB • Prolongation of the shelf-life of chicken thighs	(*Kačániová et al.,* 2019)
Savory *(Satureja hortensis)*					
Garlic *(Allium sativum)*	Fresh garlic: 20, 30, 50 g/kg) Ground powder: 6, 9, 15 g/kg) Garlic EO: 0.06, 0.09, 0.15 g/kg)	Raw chicken sausage (thigh meat)	21 days – 3°C – Fresh garlic / garlic powder / garlic EO – Vacuum packaging in polyethylene bags	• Delay of lipid oxidation (TBA) • No changes in the compositional content • Reduction of the microbial count • Sensory results showed a good overall acceptability even though fresh garlic sausages had stronger flavour	(*Sallam et al.,* 2004)
Ginger *(Zingiber officinale)*	3 and 6 %	Chicken breast fillets	12 days – 4°C – EO (nano) emulsion edible coating	• Significant decrease of TPC • Non-significant TBARs effect • Better colour preservation • Lower cooking loss and good overall acceptability	(*Noori et al.,* 2018)
Green tea *(Camellia sinensis)*	0.5 %	Minced chicken breast	200 minutes – Hydroethanolic extract – Vacuum packaging – Freezing then mincing	• Pro-oxidative effect • Less antioxidant than mate	(*Jongberg et al.,* 2019)
Mate *(Ilex paraguariensis)*	0.01%, 0.05, 0.1 and 0.5 %			• No reaction with protein thiols in chicken meat • Direct dose-dependent response: protection of the protein thiols	

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Hawthorn *(Crataegus pinnatifida)*	0.5 and 1%	Cooked chicken breast meat	150, 200 and 250°C then overnight storage at 4°C	• Mitigation of HAA formation, especially at high cooking temperatures • No negative changes in structure, appearance, colour and odour	(*Tengilimoglu-Metin et al.,* 2017)
Laurel bay *(Laurus nobilis)*	1%	Fresh raw chicken breast slices	16 days – 4±1°C – Ethanolic extract – Sterile plastic bags	• Significant decrease in chemical parameters (pH, TBVN, TBA) • Marked decrease in bacterial counts (aerobic plate, total *coliform*, and total *Staphylococci* count) • Extension of the chicken meat shelf-life	(*Youssef et al.,* 2021)
Olive leaf *(Olea europaea)*	0.25, 0.5 and 1%	Raw poultry meat	15 days – 4±1°C – Plastic bags – Ethanolic extract	• Reduction of microbial growth (TABC, TPC, TEC, TSC and Total Mould and Yeast Count) • Preservation of chemical (pH, TVBN, TBARS) and sensory attributes • Good antioxidant effect and overall acceptability	(*Saleh et al.,* 2020)
Oregano *(Origanum vulgare)*	Glycerol, EO, N,O-carboxymethyl chitosan and EO/ N,O-carboxymethyl chitosan water solutions	Chicken breast fillets	14 days – 4°C	• EO and N,O-carboxymethyl chitosan used individually, showed a significant antibacterial and preservative effect • EO/ N,O-carboxymethyl chitosan combination resulted to a 6 day shelf-life extension of chicken fillets	(*Khanjari et al.,* 2013)
Oregano *(Origanum vulgare)*	5g EO /100g nanoemulsion	Chicken pâté	45 days – Nanoemulsion encapsulation – Pasteurisation in hot water bath and ambient temperature storage	• Good antimicrobial growth: low values of MIC and MBC on *E. coli* and *S. aureus* • No significant change in physicochemical properties of meat (moisture, protein, ash, fat, pH)	(*Moraes-Lovison et al.,* 2017)
Pepper seeds *(Piper annuum)*	1 % powder and 7% oil	Chicken sausages	14 days – 100°C for 30mn then 4°C ± 1°C – Cellulose casing and PVDC bags – Powder and EO	• Retarded lipid oxidation (lower TBARS values) • Sensory attributes and nutritional value favourably affected • No textural properties change, except for hardness decrease	(*Kim,* 2020)
Pomegranate *(Punica granatum)*	Pomegranate juice phenolics 8ml /100g meat Powder extract phenolics 1ml / 100g meat	Cooked chicken patties	15 days – 4°C – Rind powder and aqueous extract – Aerobic packaging in LDPE pouches	• Better protection against oxidative rancidity (TBARs) than BHT used as positive control • Total phenolic compounds increased in the final product • No negative effect on the sensory attributes	(*Naveena et al.,* 2008)

Plant name	Concentrations	Chicken meat product	Experimental storage parameters	Research output	References
Sage *(Salvia officinalis)*	0.2% w/w	Cooked chicken thigh and breast	96h – 4°C – Polyester film – Marinade and heating	• Lower TBARS values → Protection from oxidation processes • Increasing in moisture content • Great consumer acceptability	(*Sampaio et al.,* 2012)
Thyme *(Thymus vulgaris)*	0.05 wt/vol of EO blend	Fresh raw marinated chicken meat (Breast and wings)	12 days – +4°C Marinade with EO blend	• High lipid oxidation prevention potential (TBARS) • No pH, colour, shear force, moisture, cooking yield, purge loss or marinade uptake changes	(*Rimini et al.,* 2014)
		Frozen raw marinated chicken meat (Breast and wings)	90 days – -18°C – Marinade with EO blend		
Turmeric *(Curcuma longa)*	0.5 and 1%	Cooked chicken breast meatballs	4h at 4°C then 18mn cooking at 150, 200 and 250°C – Turmeric powder	• Dose-dependent inhibition of the heterocyclic aromatic amines (HAA) formation • Reduction of the cooking loss and the lipid oxidation • Preservation of colour properties	(*Kilic et al.,* 2021)

BA: Biogenic Amine – BHT : Butylated Hydroxytoluene – DPPH: 2,2-Diphenyl 1-picrylhydrazyle – EO: Essential Oil – EVOH: Ethylene Vinyl Alcohol – FICA: Ferrous Ion Chelating Activity – HAA: Heterocyclic Aromatic Amines – LAB: Lactic Acid Bacteria – LDPE: Low Density Polyethylene – MBC: Minimum Bactericidal Concentration – MIC: Minimum Inhibitory Concentration – PET: Polyethylene Terephthalate – PLA: Polylactic Acid – PVDC: Poly Vinylidene Chloride – TBA: Thiobarbituric Acid – TBARS: Thiobarbituric Acid Reactive Substances – TEC: Total Enterobacteriaceae Count – TPC: Total Psychrophilic Count – TSC: Total Staphylococcal Count – TVBN: Total Volatile Basic Nitrogen – TVC: Total Viable Count.

Table 1 offers a comprehensive overview of the plant extracts tested and added in different forms to improve and preserve the quality of chicken meat products and details their impacts on the products. The studies reported significant antimicrobial and antioxidant potential of the plants used. Furthermore, most of the studies evidenced positive impacts on the physicochemical, sensorial and nutritional properties of chicken meat products. It is noteworthy that the recovery of the extracts depends on the targeted bioactive compounds and the type or part of the plant. Furthermore, the aerial plant parts, encompassing fruits, leaves, flowers, and bark, serve as primary sources (*Kicel et al.,* 2019; *Polka & Podsędek,* 2019). In some bulbs and rhizomes like turmeric and ginger, the emphasis lies in their underground parts (*Elmowalid et al.,* 2019; *Kilic et al.,* 2021). Seeds and roots can be also used (*Melloul et al.,* 2022; *Sharma et al.,* 2023). A relatively new way to extract plant phytochemicals, significant due to reduced costs and less waste generation, is the valorisation of industry by-products rather than non-by-product plant materials. By-products include pomaces from the processing of tomato (seeds and peels), grape (seeds, skins and stems) and olive (skin, pulp, kernels and oil residue), which showed interesting biological activities and promising preservation abilities for meat products (*Gutiérrez-Del-río et al.,* 2021). Overall, it has been observed that the inclusion of plant extracts in the formulation and preparation of chicken meat products do not compromise the sensory properties or overall acceptability as assessed by sensory panellists (*Mohd Subakir et al.,* 2022; *Zhu et al.,* 2022). The following sections delve into these details and discuss some examples of the different plant extracts that have been incorporated as natural chicken meat preservatives.

3. Plant extracts and incorporation strategies

Several techniques for incorporating plant-based components into chicken meat and its derived products have been evaluated, which taken all together aimed to extend product shelf-life while improving or preserving product quality. These approaches encompass the utilisation of raw plant material and various forms of extracts as natural food additives in meat preparations during processing, as well as in the form of dietary supplements in animal feed during breeding.

3.1. Direct incorporation

Direct incorporation is a simple application, low cost, and does not require specific equipment or reagents. The plant material can be spread fresh or powdered onto chicken meat products. For instance, *Sallam et al.* (2004) added fresh or dried garlic cloves to raw chicken sausages, *Kilic et al.* (2021) incorporated powdered turmeric into chicken meatballs, *Najeeb et al.* (2015) tested powders of drumstick leaves, curry, and mint on restructured chicken slices, and *Kim* (2020) formulated chicken sausages enriched with pepper seed powder.

To strengthen the efficacy of phytochemicals, marination encompasses immersing chicken meat in a solution infused with aromatic plants, spices and other ingredients (*İncili et al.,* 2020). This approach solubilises the plant compounds, thereby increasing their availability to preserve meat, enhances the organoleptic properties, likely tenderness and juiciness, and reduces the cooking loss (*Sampaio et al.,* 2012; *Rimini et al.,* 2014; *Lytou et al.,* 2018; *Wu et al.,* 2019). Aqueous extracts can be further used. For example, the application of aqueous extracts of coriander and pomegranate rind powder has been reported by *Ahmad et al.* (2023) and *Naveena et al.* (2008). Aqueous extraction consists of soaking different parts of the plant in hot or cold water for a specified time, filtrating to discard the solid retentate and eventually reduce the liquid through evaporation and/or lyophilisation. Water has the ability to dissolve a wide range of compounds, and different biocomponents can be recovered depending on the adopted heating method: decoction, infusion or maceration (*Rahim et al.,* 2022).

3.2. Alcoholic and hydroethanolic extracts

Ethanol is less harmful than most other organic solvents and is the most recommended for food applications. The combination of water and alcohol allows the extraction of a larger group of compounds compared to using the solvents individually (*Alzeer & Abou Hadeed,* 2016; *Tobiszewski & Namieśnik,* 2017). Rosemary and clove hydroethanolic extracts, along with olive leaf ethanolic extract have been used as additives and revealed better preservative properties (increased shelf-life) of raw poultry meat stored at 4°C for 15 days (*Zhang et al.,* 2016; *Saleh et al.,* 2020). Laurel bay leaf ethanolic extract allowed 16 days of preservation for the same product and under the same conditions (*Youssef et al.,* 2021). It is noteworthy that the extraction yield and composition of the plant extracts depend on the chosen method and the variations in the time-temperature regime used. Conventional extraction methods such as maceration, digestion, percolation and Soxhlet, are effective in extracting most secondary metabolites of plants and are simple to replicate. However, these extraction methods are only adapted to small-scale batch production and involve several time and solvent-consuming steps (*Bitwell et al.,* 2023). Thus, developing environmentally friendly innovative methods that are adapted to large-scale production and that are economically viable are keystones in modern phytochemistry research. Newer methods have emerged, like accelerated solvent extraction, microwave assisted extraction, ultrasound assisted extraction (sonication) (*Nayak et al.,* 2015), supercritical fluid extraction (*Caredda et al.,* 2002), enzyme assisted extraction (*Rafińska et al.,* 2022), pressurised hot water extraction and deep eutectic solvents (*Loarce et al.,* 2021; *Liao et al.,* 2022).

3.3. Essential oils

Essential oils are obtained by hydro-distillation and are added directly as ingredients in chicken meat preparations; for this purpose, essential oils of fennel seeds, pepper seeds, garlic, basil, and rosemary are used (*Sallam et al.,* 2004; *Stojanović-Radić et al.,* 2018; *Kačániová et al.,* 2019; *Kim,* 2020). The oils can also be encapsulated to preserve their odours and flavours, protect them from degradation and likely improve their stability. In fact, encapsulation seemed to increase the bioavailability of essential oils by preserving them from degradation, especially by gastric acids (*Zhang et al.,* 2022; *Zhang & Piao,* 2023). Innovative techniques, such as nanoemulsions of essential oils and synergistic incorporation into packaging and edible coatings, is another way of improving their preservative properties (*Sirocchi et al.,* 2013; *Moraes-Lovison et al.,* 2017; *Noori et al.,* 2018; *Gagaoua et al.,* 2021; *Qiu et al.,* 2022).

3.4. Indirect incorporation

Innovative techniques such as nano-emulsions of essential oils and synergistic incorporation of plant extracts into packaging and edible coatings represent green approaches to improve chicken meat quality preservation while reducing or eliminating the strong odours and flavours of some aromatic plants (*Sirocchi et al.,* 2013; *Moraes-Lovison et al.,* 2017; *Noori et al.,* 2018; *Gagaoua et al.,* 2021; *Qiu et al.,* 2022). In this context, several approaches have been explored. For example, a coating made of a synergistic blend of propolis extract and chitosan, enriched with *Zataria multiflora* essential oil revealed substantial antimicrobial and antioxidant effect, while enhancing chemical characteristics and sensory acceptability of chicken breast meat (*Mehdizadeh & Mojaddar Langroodi,* 2019). Phenolic extracts of petioles from betel leaf have been also used to develop a sustainable, biodegradable, functional antioxidant film, successfully maintaining raw chicken meat quality for up to 12 days at refrigeration temperature (*Nandi & Guha,* 2024). In another study, lower values of pH, thiobarbituric acid reactive substances (TBARS) and total microbe counts after five days of storage were observed in chicken samples packed in carrageenan-based films fortified with medicinal plant extracts (*Seol et al.,* 2013). *Jacob Rani & Venkatachalam* (2023) conducted a study on poultry meat packaging with a chitosan-based active coating, synergised with nanoparticles synthesised from cellulose, hemicellulose and lignin from leaves of the abundant invasive plant, cattail (*Typha latifolia)*. The coating exhibited good antioxidant and antimicrobial activities due to the phenolic properties of the plant extracts, and so subsequently extended the shelf-life of the product. These few studies exemplified the potential for incorporating plant extracts with the aim of reducing wastage and improving the freshness and sensory qualities of chicken products.

3.5. In vivo feed supplementation

An alternative strategy regarding the use of plants to enhance the quality of chicken meat and increase its nutritional value is the inclusion of specific medicinal and aromatic plants in the animal diet as feed supplements (*Giannenas et al.,* 2020; *Jin et al.,* 2020; *Mohebodini et al.,* 2021). Phenolic compounds can be adopted to combat infectious agents as alternatives to antibiotics that can lead to resistance phenomena in animals with possible transmission to humans (*Mahfuz et al.,* 2021). The growth performance of battery and ground-raised broilers, evaluated by the measurement of the body weight gain and the consumption index, was significantly ameliorated after broilers were fed with green oak acorns (*Berkane et al.,* 2021). Dietary addition of oregano and germander for instance, decreased lipid oxidation, monitored by TBARS assay and total carbonyl values, leading to a storage duration of seven days (*Al-Hijazeen et al.,* 2022). Feed supplementation with thyme oil decreased the saturated fatty acid content of poultry meat and increased the unsaturated fatty acids, with unchanged TBARS values for 42 days at refrigeration temperature (*Canan Bölükbaşı & Erhan,* 2006).

4. Effects and mechanisms of action of plant extracts in chicken meat and processed products

4.1. Antimicrobial potential

Plant extracts have been proven to be valuable in reducing microbial growth in chicken meat. For instance, pomegranate juice marinades were able to delay the microbial growth of *Pseudomonas* spp., *Enterobacteriaceae*, *Brochothrix thermosphacta* and lactic acid bacteria (LAB) for 6 to 9 days at 4°C and 10°C on chicken breast fillets (*Lytou et al.,* 2018). The synergistic action of oregano essential oil and chitosan coating diminished *Pseudomonas deceptionensis* CM2 and bacteria total viable count (TVC) in chicken breast fillets stored in refrigerated conditions for 12 days (*Zheng et al.,* 2023). Citrox®, a commercial citrus extract also showed a positive effect on the reduction of the TVC, *Pseudomonas*, *Enterobacteriaceae*, LAB, and *Clostridium* spp., and prolonged the shelf-life of fresh ground chicken refrigerated at 4°C (*Mexis et al.,* 2012).

The mechanisms of action of plant extracts and essential oils against bacteria are intricate and multifaceted. They vary depending on the diverse plant constituents, type of microorganisms, and strains. These mechanisms are not completely elucidated yet, but the commonly known ones that can be enumerated as follows:

- *Cell membrane disruption:* Cell wall thickening is a significant pathway to antibiotic resistance in bacteria. Polyphenols, flavonoids and other bioactive compounds counteract it by compromising the membrane fluidity, rendering it permeable, and cell death occurs by leakage of the cytoplasmic content (*Weng et al.,* 2023). Flavonoids for instance, can interfere with lipid bilayers by inducing bacterial membrane disruption, which inhibits processes such as biofilm formation, cell envelope synthesis, and nucleic acid synthesis (*Górniak et al.,* 2019).
- *Efflux pumps inhibitors (EPIs):* Efflux pumps are membrane proteins maintaining cell homeostasis through active efflux. In bacteria, they are involved in (multi)drug resistance

mechanisms (*Kumawat et al.,* 2023). Numerous plant species have demonstrated their potential to inhibit these pumps and disturb the inner metabolism of Gram-positive and Gram-negative strains (*Seukep et al.,* 2020; *Brown et al.,* 2021; *Mehta et al.,* 2022).

- *Quorum sensing interference:* Quorum sensing is a paracrine cellular signalling system by which bacteria interact with each other and with their environment (*Thompson et al.,* 2023). Perturbing this process alters the genetic expression of virulence determinants and reduces the formation of biofilms (*Ivanov et al.,* 2022; *Kumawat et al.,* 2023).

These control modes not only reduce bacterial count and inhibit multiplication, but also reinstate antibiotic efficacy (*Ivanov et al.,* 2022). Other mechanisms such as oxygen quenching, the inhibition of enzyme activity, damage to DNA, ribosomes or mitochondria, protein denaturation, and induction of oxidative stress by reactive oxygen species (ROS) are other pathways that have been described in the literature (*Rout et al.,* 2022).

4.2. Antioxidant potential

Oxidation is the second most important degradation form after microbial spoilage of chicken meat, and of meat products in general (*Domínguez et al.,* 2019). In fact, oxidation leads to changes in several meat quality traits, like colour, taste and flavour. In fact, development of lipid rancidity leads to undesirable taste and flavour. The colour change is more noticeable on chicken thigh meat cuts, due to the physiological specifications of poultry, as pH and myoglobin content are higher in this cut and different from in the breast (*Wideman et al.,* 2016). Oxidative deterioration also alters the nutritional value by the loss of proteins and vitamins, along with the generation of toxic compounds (*Domínguez et al.,* 2019; *Dursun & Güler,* 2023). In this context, several plant extracts, which exhibited a strong antioxidant activity, were tested on chicken meat with the aim to increase its shelf-life and improve its nutritional quality. Rosemary, oregano, pomegranate, olive leaf and clove showed effectiveness in drastically reducing TBARS values, interpreted as a superior protection against oxidative rancidity of chicken meat lipids, even better than some synthetic preservatives like BHT (*Al-Hijazeen,* 2022; *Naveena et al.,* 2008; *Saleh et al.,* 2020; *Zhang et al.,* 2016).

Aromatic plants are rich in polyphenols and flavonoids that prevent oxidative damage in meat by forming multiple coordinate bonds with pro-oxidative compounds (*Gutiérrez-Del-río et al.,* 2021; *Pateiro et al.,* 2021). These bioactive compounds act as hydrogen atom donators, metallic ions chelators, ferrous reducing agents or radical scavengers by decomposing ROS species like hydrogen peroxide $H_2O_2^{\bullet}$ and superoxide anion $O_2^{-\bullet}$. These various mechanisms of action impede the oxidation reactions, neutralise free radicals and reduce lipid oxidation by lowering the production of peroxide molecules (*Köksal et al.,* 2017; *Yan et al.,* 2020).

4.3. Enzyme regulatory potential

When the animal is slaughtered oxygen and glucose delivery to cells are no longer active, therefore leading to dysregulated muscle homeostasis (*Ouali et al.,* 2013). The complex processes of post-mortem transformation of muscle into meat are initiated, and sophisticated biochemical reactions in the carcass are triggered (*Terlouw et al.,* 2021; *Lamri et al.,* 2023). Such pathways lead to the production of ROS. In this matter, polyphenols would act on the regulation of certain pathways and enzymes, such as NADH oxidase, by inhibiting ROS formation, thereby breaking the oxidation chain reaction (*Yan et al.,* 2020). They can also upregulate endogenous antioxidant enzymes like superoxide dismutase, catalase and glutathione peroxidase.

4.4. Preservation of physicochemical and sensory properties of meat

The correlation between the underlying mechanisms of action of plant extracts and the preservation of the physicochemical properties of chicken meat has been established from the foregoing discussed research results:

- The regulation of enzymes in the tenderisation process and scavenging ROS formation seemed to have a direct impact on the meat texture. For instance, meat from chicken fed with oregano essential oil has lower Warner-Bratzler (WB) shear force values (*Mahfuz et al.,* 2021). Improvements in the water holding capacity of the meat increases the cooking yield and decreases the purge loss, leading to a better meat tenderness and juiciness (*Zheng et al.,* 2023).

- Inhibiting lipid oxidation prevents the development of a rancid taste in meat. Furthermore, essential oils and aromatic compounds in the extracts allow the development of new aromas and flavours in chicken meat products, resulting generally in good overall acceptability by consumers (*Munekata et al.,* 2015; *Hadidi et al.,* 2022).
- Colour is influenced, among other factors, by exposure to oxygen, storage temperatures, and anatomical location of the meat cuts that affects the pH balance and the concentration of myoglobin (*Wideman et al.,* 2016). Packed chicken meat in edible coatings enriched with essential oils or sprayed on the surface with phenolic extracts promoted the oxygenation of myoglobin to form oxymyoglobin, which gives the bright, vivid, light pink hue to chicken meat, and inhibits myoglobin's oxidation to metmyoglobin, thus preserving the visual appeal of the meat (Figure 1) (*Gagaoua et al*., 2021; *Zhou et al*., 2021; *Wu et al*., 2022).

4.5. Nutritional value enhancement

Even though the primary objective for which plant extracts and essential oils are used in food as natural preservatives is for their antioxidant and antimicrobial effects, they still contribute indirectly to the preservation and enhancement of the nutritional content of the food. The antioxidant effects of polyphenols and terpenoids, along with iron sequestration by flavonoids preserve for instance, polyunsaturated fatty acids (PUFA), like omega-3 fatty acids (*Tang et al.,* 2002; *Gutiérrez-Del-río et al.,* 2021). Consuming food products enriched with aromatic plants increases the daily intake of polyphenols, known for their beneficial effects on health (*Fraga et al.,* 2010; *Vauzour et al.,* 2010; *Tresserra-Rimbau et al.,* 2018). Figure 1 depicts a few of the preservation effects of plant extracts on chicken meat.

5. Plant compounds involved in chicken meat quality preservation and/or improvement

Secondary metabolites, which originate mainly from defence reactions against environmental threats, exhibit unique and specific activities through distinct mechanisms, contributing to their importance in a variety of applications (*Gutiérrez-Del-río et al.,* 2021). The secondary metabolites that derive from primary metabolites during plant development have been the subject of much attention in the literature due to their structural diversity and properties, highlighting their importance in medicinal and culinary applications (*Twaij & Hasan*, 2022). Owing to the wide range of compounds that exist in the vegetal realm, all their differences, and in the absence of a universal classification, each author

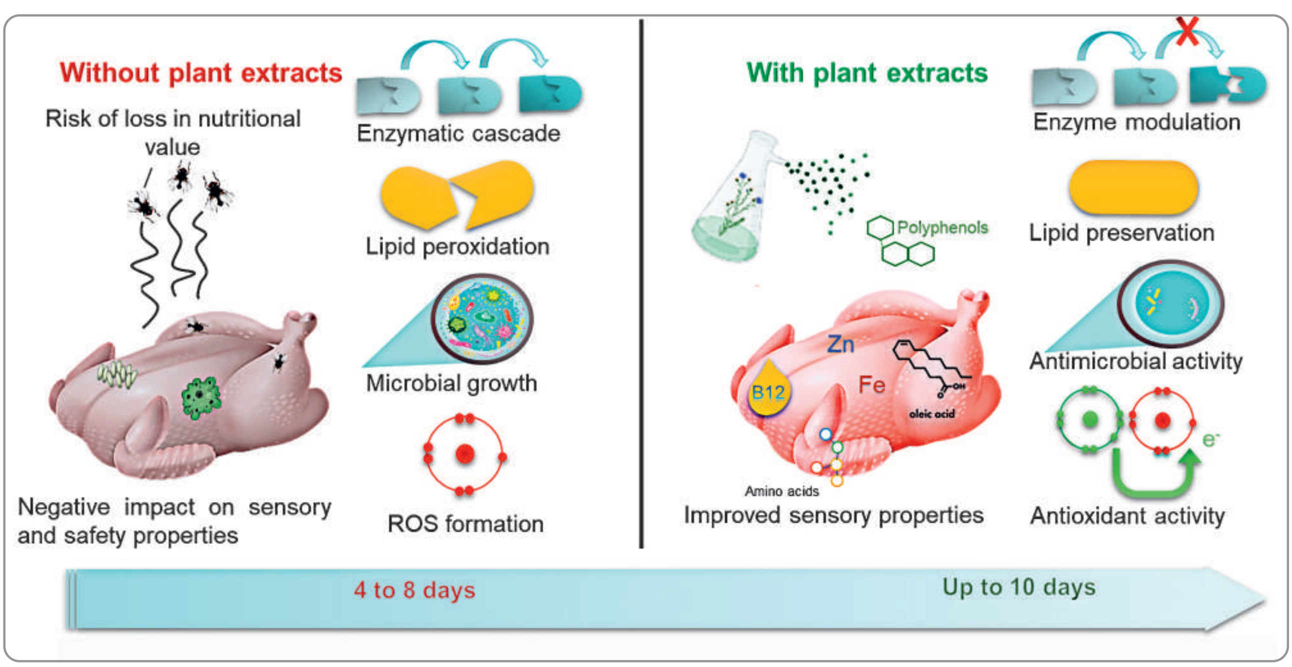

Figure 1. Visual illustration highlighting the positive impacts of chicken meat preservation that can be achieved with plant extracts.

sorts them according to their own study aims. For instance, *Arvind* (2016) used a classification based on the chemical composition: alkaloids, glycosides, polyphenols (flavonoids, phenolics and tannins), saponins, terpenes (carotenoids and steroids) and anthraquinones. *Ahmed et al.* (2017) referred to the British Nutrition Foundation that divides them into four categories: terpenoids, phenolics, nitrogen containing compounds and sulphur containing compounds, while *Kabera et al.* (2014) used a more generic classification system of three major groups: terpenoids, alkaloids and phenolics. Some of these various plant metabolites are particularly appreciated in the preservation of muscle foods according to *Biswas et al.* (2023) and are described in-depth in the following sections.

5.1. Polyphenols

Polyphenols are abundant in fruits, vegetables and herbs. They act as powerful antioxidants and antimicrobials when incorporated into meat products (*Wu & Zhou,* 2021; *Biswas et al.,* 2023). The ability of phenolic compounds to act as antioxidants relies on the quantity and location of hydroxylic groups within their structure, as these factors determine their effectiveness in neutralising reactive radicals. Consequently, polymers with an elevated concentration of hydroxylic groups exhibit a greater antioxidant capacity (*Oliveira et al.,* 2018). For example, pepper fruits (*Capsicum* spp.), one of the most widely used and appreciated spices in the world for their spiciness and unique flavours, are rich in phenolic compounds such as capsaicinoids, luteolin and quercetin (*Batiha et al.,* 2020a). An earlier study has shown that capsiate, dihydrocapsiate and their analogues possess very high antioxidant activity (*Rosa et al.,* 2002). Clove (*Syzygium aromaticum*) is another traditional spice used for food preservation, particularly in meat processing where it can replace chemical preservatives due to its antioxidant and antibacterial properties (*Cortés-Rojas et al.,* 2014; *Batiha et al.,* 2020b). Clove has been documented as a significant source of phenolic compounds, as it contains hydroxybenzoic, ferulic, caffeic, ellagic and salicylic acids (*Cortés-Rojas et al.,* 2014). Garlic (*Allium sativum* L.) is a well-known bulb in traditional medicine and culinary preparations, including traditional meat products (*Gagaoua & Boudechicha,* 2018). It is rich in phenols and various sulphur phytoconstituents such as alliin, allicin, ajoenes, vinyldithiins. It has been successfully evaluated for its various biological activities, including antibacterial, antiviral, antifungal, antiprotozoal and antioxidant (*Batiha et al.,* 2020b).

5.2. Flavonoids

Flavonoids are another class of plant compounds known for their antioxidant and antibacterial activities (*Dias et al.,* 2021). In fact, more than 6000 different flavonoids have been identified in plants so far (*Hichri et al.,* 2011). They are abundant in green plants, and are present mainly as glycosides in leaves, flowers, stems and roots (*Chen et al.,* 2023). Flavonoids' antioxidant capacities are modulated by the location of the catechol B-ring on the pyran C-ring, along with the quantity and arrangement of hydroxylic groups present on the catechol group within the B-ring (*Dias et al.,* 2021). Cloves for instance, contain quercetin and kaempferol (*Thomas et al.,* 2022). Moreover, multiple studies indicate that garlic, rich in flavonoids, phenols and various sulphur compounds, exhibits strong radical-scavenging activity (*Jang et al.,* 2017), and the antibacterial activity of these phytochemicals is linked to different pathways (*Górniak et al.,* 2019).

5.3. Terpenes

Terpenes are the main compounds of essential oils and are biologically generated by the mevalonate pathway (*Dhifi et al.,* 2016). From the molecular level viewpoint, they are constituted from 2-methylbuta-1,3-diene carbon structures, also known as isoprene units. These units are capable of being reordered into cyclic structures, thus explaining the important structural diversity of this group (*Hyldgaard et al.,* 2012; *Masyita et al.,* 2022). Terpenes are easily identified and classified by the number of isoprene units in their carbon skeleton (*Twaij & Hasan,* 2022). Terpenes play an important role in food safety without affecting food quality (*Falleh et al.,* 2020). Terpenes such as thymol, carvacrol and eugenol are found in essential oil of thyme, oregano, rosemary, and clove. They have been proven to possess antimicrobial properties (*Mendonca et al.,* 2018; *Bellés et al.,* 2019). Clove flower buds contain up to 18% essential oil composed of eugenol, eugenol acetate and β-cariofilene (*Jirovetz et al.,* 2006). An earlier study demonstrated the antimicrobial efficacy of essential oils from several spices: cinnamon, thyme, rosemary, garlic, sage, oregano, basil, marjoram, savory and clove (*Mendonca et* *al.,* 2018). Other studies further tested successfully the antibacterial efficacy of thyme and rosemary essential oils at very low concentrations against a mix of three strains of *Listeria monocytogenes* (*Giarratana et al.,* 2016). Moreover, others have shown that thyme, bay leaf, oregano and clove essential oils exhibit varying degrees of inhibition against *Escherichia coli* (*Thielmann et al.,* 2019).

6. Practical considerations for implementing plant extracts as meat preservatives

Natural bioactive compounds have clearly proven their effectiveness in reducing microbial growth, preventing oxidation, and enhancing the organoleptic properties of meat, including poultry. Nevertheless, some factors hinder their successful utilisation and pose challenges to their widespread industrial application for reducing chicken meat deterioration and for prolonging the shelf-life. In the following, we discuss some of the practical considerations that are worthy of consideration in order to avoid drawbacks associated with their use.

6.1. Determination of the composition and concentration of plant extracts

The composition and concentration of the bioactive compounds of plant extracts are not consistent across all sources and batches, and vary even for the same plant species according to growing conditions, harvest time and season, extraction settings, storage conditions and packaging methods (*Oluyemisi Folashade et al.,* 2012; *Tajik et al.,* 2014; *Pferschy-Wenzig & Bauer*, 2015). These result in unpredictable synergistic and antagonistic interactions between the extract compounds themselves, or between the extract compounds and the chicken meat matrix. These interactions can affect the stability of the extracts and their antioxidant and antimicrobial activity (*Lu et al.,* 2017; *Woroń & Siwek,* 2018; *Nguyen & Karboune,* 2023). Therefore, the standardisation and determination of the effective concentration are even more challenging: underdosage reduces the potency of the extract while too high concentrations may lead to unpleasant sensory changes and formulation issues, introducing unfamiliar textures or flavours, thus affecting the consumer acceptability of the final product. In the meat matrix, the presence of fatty acids, proteins and other components can favour these changes when reacting with the compounds of the plant extracts. Finding the right balance between preservation efficacy and sensory acceptability is crucial and a key challenge (*Lu et al.,* 2017; *Skochko et al.,* 2018; *Barbieri et al.,* 2019; *Sajad et al.,* 2020). Moreover, during the preparation of these additives, other interfering molecules or compounds can be extracted from the plant, making a purification step necessary. Purification techniques have made significant advancements in recent years and appear to address these issues effectively on an experimental level. However, the feasibility for industrial-scale implementation remains limited due to the associated high costs and the substantial equipment it necessitates (*Weil & Veraitch,* 2014; *Folim,* 2015).

6.2. Regulatory and safety aspects

Due to the complex composition of plant extracts, their use as food preservatives is conditioned by strict national and/or international standards and is under regulatory compliance. This is even more important when it comes to the determination of the concentration to be used in meat products, due to the nature of meat constituents and how they react with phytochemicals (*Alirezalu et al.,* 2020; *Biswas et al.,* 2023). As depicted in Figure 2, plant extracts are susceptible to diverse environmental contaminants, including pesticides, waterborne chemicals, synthetic drugs and heavy metals (*Han et al.,* 2016; *Kostic et al.,* 2019). Moreover, the native bacterial microbiota of plants can pose risks to human health, like mycotoxins from fungi or thermoresistant toxins from sporulating bacteria (*Omotayo et al.,* 2019; *Alirezalu et al.,* 2020). Genetic cross contamination within plant species is an inevitable occurrence, whether it involves organic or heirloom plants intermingling, or crossing paths with genetically modified crops. Such interactions can yield unexpected outcomes or the introduction of undisclosed compounds, such as allergens, toxins and even opioids, thereby complicating the contamination landscape (*Geller et al.,* 2015; *Cau et al.,* 2021). This intricate web of cross-contamination highlights the need for meticulous monitoring and regulation within the agricultural industry to ensure the safety and integrity of food supply (*Steier,* 2016).

Even though legal frameworks and directives can vary between countries, the safety and efficacy of the natural preservatives must be demonstrated in order to obtain regulatory acceptance. For instance, in the United States, the Food and Drug Administration (FDA) maintains a list of generally recognised as

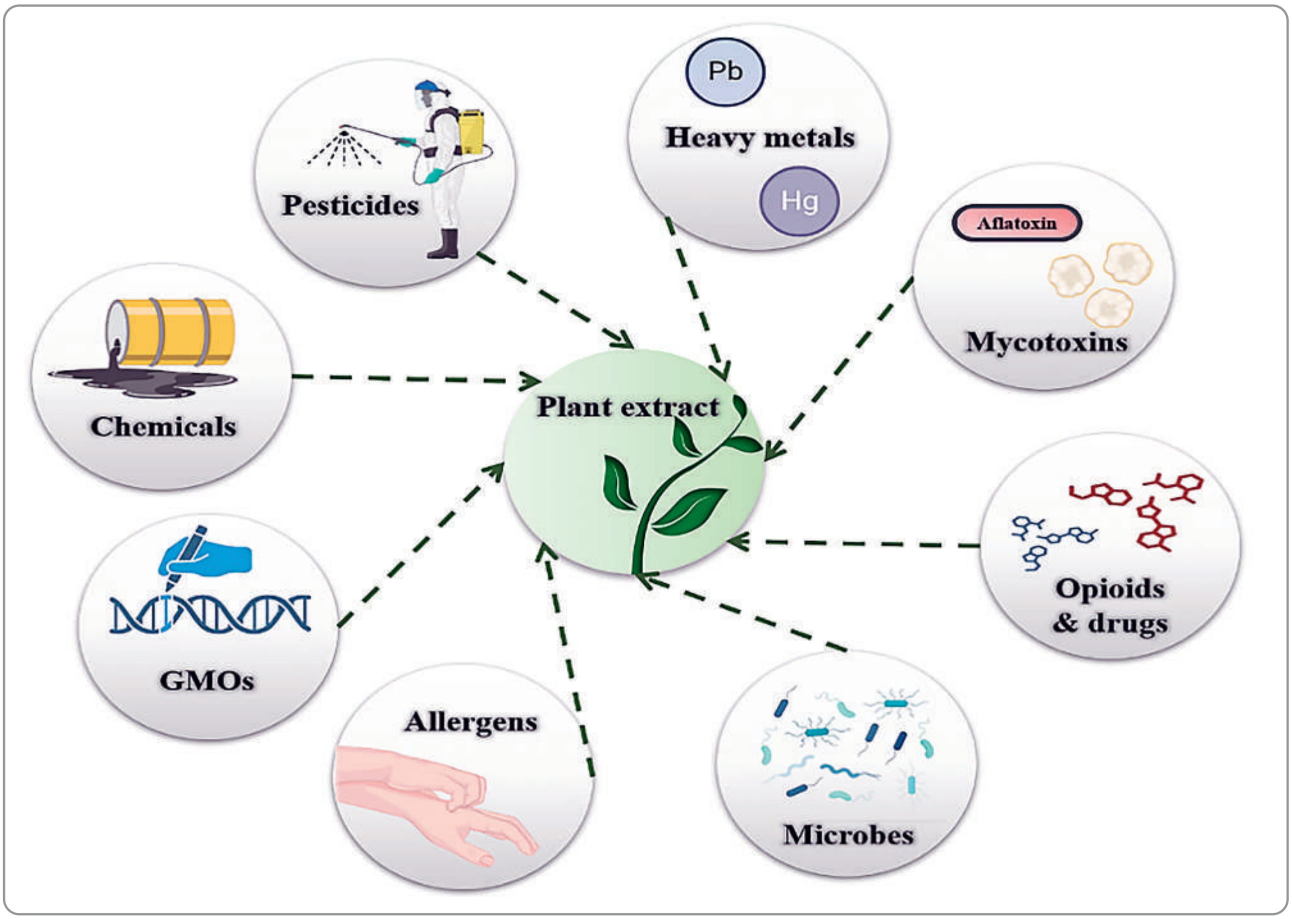

Figure 2. Safety hazards that can be associated with plant extract usage.

safe (GRAS) essential oils that can be used in meat products (*Khaneghah et al.,* 2017). In the European Union, the Regulation 1129/2011 prescribes permissible compounds and their limited doses in various food products, considering the composition of the product, and whether or not it will undergo thermal treatment *(Alirezalu et al.,* 2020). Regulation EU 1169/2011 also sets out the legal obligation to declare known allergens, like celery, sesame or soy (*Cau et al.,* 2021).

6.3. Bioavailability and intestinal absorption

When added to chicken meat, extracts from medicinal and aromatic plants have roles in the preservation of the product before consumption and the improvement of the product's sensory attributes (*Muhialdin et al.,* 2020; *Hassan et al.,* 2022). Polyphenols, the main secondary metabolites of plants, have seen greater consumption popularity in recent decades, causing a significant increase in the demand for polyphenol-enriched products. Selling arguments advocating the beneficial effects on the human body after ingestion, and even describing the products enriched with polyphenols as "superfood" contributed greatly to the development of this new dietary trend (*Fernández-Ríos et al.,* 2022). While plant components have shown their antioxidant, antimicrobial and enzyme regulatory efficacy as well as their contribution to reduce several diseases, scientists describe it as a marketing gimmick and are more sceptical about the real impact of polyphenols on the human body when ingested in food. This scepticism comes from the fact that the bioavailability and efficacy of consuming polyphenols in food are hardly predictable, and are influenced by a wide range of variables (*Tresserra-Rimbau et al.,* 2018). We believe that much work in this area is needed in the future.

6.4. Cost considerations

The cost of plant extract production and commercialisation is higher than for synthetic preservatives. The latter are cheaper due to their longer shelf-life, stability and mass-production adaptability. Therefore, scaling up the production of plant extracts to meet the demands of the food industry can present logistical challenges (*Surekha & Reddy,* 2014; *Vara et al.,* 2019). As a matter of fact, sourcing ingredients for natural preservative production is conditioned by the seasonality of plants and their geographical availability, causing supply chain complexations. Furthermore, import/export taxes, certification and labelling costs inflate the bill (*Balasubramaniam et al.,* 2022). The production plans have to be studied in depth and adapted to the current regulations and recommendations (*Lee & Paik,* 2016). For instance, the EU REACH Regulation (*EU*, 2006) on registration, evaluation, authorisation and restriction of chemicals strongly encourages the adoption of eco-friendly "green" solvents as alternatives to conventional organic ones. The selection of one solvent over another is a strategic decision, since it affects the extraction method, compound selectivity, production yield, costs and safety (*Pateiro et al.,* 2021). While multiple environmentally friendly extraction techniques have emerged at experimental level in scientific literature, the acquisition of avant-garde technologies has a cost. Moreover, the type of extract can present another drawback. A typical case in point would be the use of essential oils in food preservation. Otherwise indisputably effective as antioxidants and antimicrobials, essential oils are hydrophobic, rendering their solubilisation very technical; they are highly concentrated in volatile compounds, resulting in strong off-odours and aromas; and have a considerably low extractability and extraction yield (*Al-Refaie et al.,* 2023). Given these conditions, the production cost of using essential oils in chicken meat production is thus elevated (*Bouarab Chibane et al.,* 2019).

7. Conclusion

From this review, we can conclude that investigations of the utilisation of plant extracts to preserve chicken meat and its processed meat products have yielded a promising avenue for prolonging the shelf-life duration. This review highlighted the plant extracts that have rich composition in diverse groups of bioactive compounds, which confer strong microbial growth mitigation and enzyme inhibition, and prevent lipid and protein oxidation. They also can enhance the organoleptic and sensory properties of chicken meat products. However, the use of plant-based preservatives at an industrial scale faces some challenges, including standardisation, regulatory approval, sensory acceptability, and cost-effectiveness. Moreover, in the scientific literature, we have noticed a gap regarding chicken meat quality preservation in comparison to other meat species (mainly red meat products), and most existing studies only pulverise the surface, focusing on the antioxidant and antimicrobial effects using manual, conventional methods, without delving deeper into a better understanding of the underlying mechanisms or identifying the specific compounds involved in the preservation process. To overcome these challenges, it is necessary to initiate further interdisciplinary research efforts that combine principles from food science, biochemistry and biotechnology. For instance, omic approaches unravel complex molecular factors influencing chicken meat quality and could offer a holistic view to understand and predict quality changes during storage (*Wang et al.,* 2023). Furthermore, high-throughput screening through appropriate design of experiments can efficiently identify the potential extract/compound candidates, while microbiome analysis can clarify interactions of the compounds with chicken meat-associated microorganisms. Additionally, nanotechnology is another promising discipline that contributes to the optimisation of encapsulation and emulsion, with prominent uses in meat research (*Lamri et al.,* 2021). Nano-techniques protect the extracts from degradation during storage and guarantee suitable meat quality preservation without introducing the strong aromas of certain plant extracts into the meat products. In addition, nanotechnology can enable controlled release of the extracts, which in turn, increases the bioavailability and intestinal absorption of high value compounds like polyphenols and flavonoids from chicken meat-enriched products. Cutting-edge green processes for recovering natural compounds from plants are also highly regarded in the scientific community. For example, approaches such as supercritical fluid extraction, ultrasound extraction or microwave assisted extraction, coupled with the use of eco-friendly solvents like deep eutectic and ionic solvents demonstrate environmental responsibility and offer promising alternatives to the traditional extraction methods that use organic solvents, known to be toxic and polluting. Overall, the adoption of plant-based natural preservatives not only aligns with the clean label and health-conscious preferences of consumers, but also contributes to the sustainability of the meat industry by reducing its environmental impacts.

Očuvanje kvaliteta mesa živine biljnim ekstraktima: pregledni rad

Ines Feknous, Djamal Ait Saada, Cerine Yasmine Boulahlib, Laura Alessandroni, Sendous Wadjila Souidi, Ouiza Ait Chabane i Mohammed Gagaoua

INFORMACIJE O RADU

Ključne reči:
Bezbednost pilećeg mesa
Biljni ekstrakti
Rok upotrebe
Prirodni konzervansi
Bioaktivna jedinjenja
Konzervisanje mesa

APSTRAKT

Potrošači cene meso živine zbog njegove nutritivne vrednosti, niskog sadržaja masti, raznovrsnosti upotrebe u raznim kuhinjama i pristupačnih cena. Međutim, njegova podložnost kvarenju kao posledice više faktora pre klanja i prerade predstavlja izazov za industriju mesa, posebno u zemljama u razvoju. Da bi se poboljšala bezbednost živinskih proizvoda, koriste se sintetički konzervansi kao što su nitriti, butilovani hidroksitoluen i sulfiti. Trenutno, ovi aditivi/konzervansi, međutim, izazvaju zabrinutost zbog njihovog uticaja na zdravlje ljudi, što je dovelo do pomeranja kod potrošača na prirodne alternative, kao što su lekovite i aromatične biljke. Stoga se ovaj rad bavi potencijalom biljnih ekstrakata kao prirodnih konzervansa za poboljšanje kvaliteta i roka trajanja pilećeg mesa i prerađevina. Ovaj rad pruža pregled različitih biljnih ekstrakata i eteričnih ulja koja su pokazala antimikrobna, antioksidativna i inhibitorna svojstva enzima, bez ugrožavanja senzornih atributa proizvoda. Razmatraju se različite metode inkorporacije, uključujući direktnu inkorporaciju ili mariniranje u vodene i/ili alkoholne ekstrakte, i upotrebu eteričnih ulja, uključujući in vivo suplementaciju stočnom hranom. Sve u svemu, svaka metoda različito utiče na kvalitet finalnog proizvoda. Dalje smo sumirali sadašnja saznanja o mehanizmima delovanja testiranih biljnih ekstrakata, iako nisu u potpunosti razjašnjeni. Uprkos prednostima ovih jedinjenja, potrebno je rešiti neke izazove, uključujući standardizaciju sastava ekstrakata, usklađivanje osetljivosti bioaktivnih jedinjenja sa uslovima obrade, obezbeđivanje isplativosti i dobijanje regulatornih odobrenja za njihovu upotrebu. Povećanje proizvodnje u cilju zadovoljavanja potreba industrije takođe predstavlja neke tehničke izazove. Sve u svemu, primena prirodnih biljnih konzervansa ne samo da poboljšava kvalitet pilećeg mesa, već bi takođe mogla da podrži mesnu industriju u smislu uskladjivanja sa očekivanjima potrošača u razvoju za održive prehrambene proizvode.

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

References

Abdel-Salam, Z., Abdel-Salam, S. A. M. & Harith, M. A. (2017). Application of Laser Spectrochemical Analytical Techniques to Follow Up Spoilage of White Meat in Chicken. *Food Analytical Methods*, 10 (7), 2365–2372, https://doi.org/10.1007/S12161-017-0806-5

Ahmad, A., Mahmood, N., Hussain, M., Aiman, U., Al-Mijalli, S. H., Raza, M. A. & Al Jbawi, E. (2023). Improvement in oxidative stability and quality characteristics of functional chicken meat product supplemented with aqueous coriander extract. *International Journal of Food Properties*, 26 (1), 855–865, https://doi.org/10.1080/10942912.2023.2189086

Ahmed, E., Arshad, M., Zakriyya Khan, M., Shoaib Amjad, M., Mehreen Sadaf, H., Riaz, I., Sidra Sabir, P., Ahmad, N., Sabaoon, P., Correspondence Ejaz Ahmed, P. & Sabir, S. (2017). Secondary metabolites and their multidimensional prospective in plant life. *~ 205 ~ Journal of Pharmacognosy and Phytochemistry*, 6 (2), 205–214.

Alessandroni, L., Caprioli, G., Faiella, F., Fiorini, D., Galli, R., Huang, X., Marinelli, G., Nzekoue, A. F., Ricciutelli, M., Scortichini, S., Silvi, S., Tao, J., Tramontano, A., Turati, D. & Sagratini, G. (2021). A shelf-life study for the evaluation of a new biopackaging to preserve the quality of organic chicken meat. *Food Chemistry*, 371, 131134, https://doi.org/10.1016/j.foodchem.2021.131134

Al-Hijazeen, M. (2022). The combination effect of adding rosemary extract and oregano essential oil on ground chicken meat quality. *Food Science and Technology (Brazil)*, 42, https://doi.org/10.1590/fst.57120

Al-Hijazeen, M. A., AL-Rawashdeh, M. S. & Al-Rabadi, G. J. (2022). Cooked broiler meat quality affected by different Mediterranean medicinal plants in the diet. *Animal Bioscience*, 35 (2), 290–298, https://doi.org/10.5713/ab.21.0264

Alirezalu, K., Pateiro, M., Yaghoubi, M., Alirezalu, A., Peighambardoust, S. H. & Lorenzo, J. M. (2020). Phytochemical constituents, advanced extraction technologies and techno-functional properties of selected Mediterranean plants for use in meat products. A comprehensive review. In *Trends in*

Food Science and Technology (Vol. 100, pp. 292–306). Elsevier Ltd, https://doi.org/10.1016/j.tifs.2020.04.010

Al-Refaie, D., Mehyar, G. & Shahein, M. (2023). Functional Role of Essential Oils as Antimicrobial and Antioxidant Agents in Food Industry: A Review. *Jordan Journal of Agricultural Sciences*, 19, 70–88, https://doi.org/10.35516/jjas.v19i1.1237

Alzeer, J. & Abou Hadeed, K. (2016). Ethanol and its Halal status in food industries. *Trends in Food Science & Technology*, 58, 14–20, https://doi.org/https://doi.org/10.1016/j.tifs.2016.10.018

Arvind, K. S. (2016). Medicinal plants: Future source of new drugs. *International Journal of Herbal Medicine*, 4 (4), 59–64, https://doi.org/10.13140/RG.2.1.1395.6085

Atwaa, E., Shahein, M., Radwan, H., Mohammed, N., Aloraini, M., Albezrah, N., Alharbi, M., Adam, H., Daoud, M. & Elmahallawy, E. (2022). Antimicrobial Activity of Some Plant Extracts and Their Applications in Homemade Tomato Paste and Pasteurized Cow Milk as Natural Preservatives. *Fermentation*, 8, 428, https://doi.org/10.3390/fermentation8090428

Balasubramaniam, V. G., Ramakrishnan, S. R. & Antony, U. (2022). Chapter 13 — Opportunities and challenges of plant extracts in food industry. In S. A. Mir, A. Manickavasagan & M. A. Shah (Eds.), *Plant Extracts: Applications in the Food Industry* (pp. 295–315). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-822475-5.00002-8

Barbieri, G., Bergamaschi, M., Saccani, G., Caruso, G., Santangelo, A., Tulumello, R., Vibhute, B. & Barbieri, G. (2019). Processed meat and polyphenols: Opportunities, advantages, and difficulties. *Journal of AOAC International*, 102 (5), 1401–1406, https://doi.org/10.5740/jaoacint.19-0134

Batiha, G. E. S., Alqahtani, A., Ojo, O. A., Shaheen, H. M., Wasef, L., Elzeiny, M., Ismail, M., Shalaby, M., Murata, T., Zaragoza-Bastida, A., Rivero-Perez, N., Beshbishy, A. M., Kasozi, K. I., Jeandet, P. & Hetta, H. F. (2020a). Biological properties, bioactive constituents, and pharmacokinetics of some capsicum spp. and capsaicinoids. In *International Journal of Molecular Sciences* (Vol. 21, Issue 15, pp. 1–35). MDPI AG, https://doi.org/10.3390/ijms21155179

Batiha, G. E. S., Alkazmi, L. M., Wasef, L. G., Beshbishy, A. M., Nadwa, E. H. & Rashwan, E. K. (2020b). Syzygium aromaticum l. (myrtaceae): Traditional uses, bioactive chemical constituents, pharmacological and toxicological activities. In *Biomolecules* (Vol. 10, Issue 2). MDPI AG, https://doi.org/10.3390/biom10020202

Bellés, M., Alonso, V., Roncalés, P. & Beltrán, J. A. (2019). Sulfite-free lamb burger meat: antimicrobial and antioxidant properties of green tea and carvacrol. *Journal of the Science of Food and Agriculture*, 99 (1), 464–472, https://doi.org/10.1002/jsfa.9208

Berkane, F., Bouderoua, k., Ait Saada, D., & Selselet-Attou, G. (2021). Effects of Green Oaks Acorns (*Quercus ilex*) based Diets Added of Calcium Bentonite on Health of Broilers Reared in the Cages and Ground Modes. *Research Journal of Agronomy*, 15 (2), 7–11, https://doi.org/10.18805/IJAR.BF-1487

Biswas, O., Kandasamy, P., Nanda, P. K., Biswas, S., Lorenzo, J. M., Das, A., Alessandroni, L., Lamri, M., Das, A. K. & Gagaoua, M. (2023). Phytochemicals as natural additives for quality preservation and improvement of muscle foods: a focus on fish and fish products. *Food Materials Research*, 3 (1), 0–0, https://doi.org/10.48130/fmr-2023-0005

Bitwell, C., Indra, S. Sen, Luke, C. & Kakoma, M. K. (2023). A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants. *Scientific African*, 19, e01585, https://doi.org/https://doi.org/10.1016/j.sciaf.2023.e01585

Bouarab Chibane, L., Degraeve, P., Ferhout, H., Bouajila, J. & Oulahal, N. (2019). Plant antimicrobial polyphenols as potential natural food preservatives. *Journal of the Science of Food and Agriculture*, 99 (4), pp. 1457–1474, https://doi.org/10.1002/jsfa.9357

Brown, A. R., Ettefagh, K. A., Todd, D. A., Cole, P. S., Egan, J. M., Foil, D. H., Lacey, E. P. & Cech, N. B. (2021). Bacterial efflux inhibitors are widely distributed in land plants. *Journal of Ethnopharmacology*, 267, 113533, https://doi.org/https://doi.org/10.1016/j.jep.2020.113533

Canan Bölükbaşı, Ş. & Erhan, M. (2006). Effect of dietary thyme oil and vitamin E on growth, lipid oxidation, meat fatty acid composition and serum lipoproteins of broilers, http://www.sasas.co.za/sajas.asp

Caredda, A., Marongiu, B., Porcedda, S. & Soro, C. (2002). Supercritical carbon dioxide extraction and characterization of Laurus nobilis essential oil. *Journal of Agricultural and Food Chemistry*, https://doi.org/10.1021/jf0108563

Cau, S., Tilocca, M. G., Spanu, C., Soro, B., Tedde, T., Salza, S., Melillo, R., Piras, G., Virgilio, S., Vodret, B. & Mudadu, A. G. (2021). Detection of celery (Apium graveolens) allergen in foods of animal and plant origin by droplet digital PCR assay. *Food Control*, 130, 108407, https://doi.org/https://doi.org/10.1016/j.foodcont.2021.108407

Chen, S., Wang, X., Cheng, Y., Gao, H. & Chen, X. (2023). A Review of Classification, Biosynthesis, Biological Activities and Potential Applications of Flavonoids. In *Molecules* (Vol. 28, Issue 13). Multidisciplinary Digital Publishing Institute (MDPI), https://doi.org/10.3390/molecules28134982

Cortés-Rojas, D. F., de Souza, C. R. F. & Oliveira, W. P. (2014). Clove (Syzygium aromaticum): a precious spice. *Asian Pacific Journal of Tropical Biomedicine*, 4 (2), 90–96, https://doi.org/https://doi.org/10.1016/S2221-1691(14)60215-X

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N. & Mnif, W. (2016). Essential Oils' Chemical Characterization and Investigation of Some Biological Activities: A Critical Review. *Medicines*, 3 (4), 25, https://doi.org/10.3390/medicines3040025

Dias, M. C., Pinto, D. C. G. A. & Silva, A. M. S. (2021). Plant flavonoids: Chemical characteristics and biological activity. *Molecules*, 26 (17), https://doi.org/10.3390/molecules26175377

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 (0), MDPI, https://doi.org/10.3390/antiox8100429

Drabik-Markiewicz, G., Dejaegher, B., De Mey, E., Impens, S., Kowalska, T., Paelinck, H. & Vander Heyden, Y. (2010). Evaluation of the influence of proline, hydroxyproline or pyrrolidine in the presence of sodium nitrite on N-nitrosamine formation when heating cured meat. *Analytica Chimica Acta*, 657 (2), 123–130, https://doi.org/10.1016/j.aca.2009.10.028

Dursun, A. & Güler, Z. (2023). Colour and pigment in raw ground meat incorporated crushed garlic during the refrigerated storage: Their relationship to lipolytic and volatilomic changes. *Food Chemistry*, 419, https://doi.org/10.1016/j.foodchem.2023.136042

Elmowalid, G. A., Abd El-Hamid, M. I., Abd El-Wahab, A. M., Atta, M., Abd El-Naser, G. & Attia, A. M. (2019). Garlic and ginger extracts modulated broiler chicks innate immune responses and enhanced multidrug resistant Escherichia coli O78 clearance. *Comparative Immunology, Microbiology and Infectious Diseases*, 66, https://doi.org/10.1016/j.cimid.2019.101334

Falleh, H., Ben Jemaa, M., Saada, M. & Ksouri, R. (2020). Essential oils: A promising eco-friendly food preservative. *Food Chemistry*, 330, 127268, https://doi.org/https://doi.org/10.1016/j.foodchem.2020.127268

Fernández-Ríos, A., Laso, J., Hoehn, D., Amo-Setién, F. J., Abajas-Bustillo, R., Ortego, C., Fullana-i-Palmer, P., Bala, A., Batlle-Bayer, L., Balcells, M., Puig, R., Aldaco, R. & Margallo, M. (2022). A critical review of superfoods from a holistic nutritional and environmental approach. *Journal of Cleaner Production*, 379, https://doi.org/10.1016/j.jclepro.2022.134491

Ferreira V. C., Morcuende D., Hérnandez-López S. H., Madruga M. S., Silva F. A. & Estévez M. (2017). Antioxidant Extracts from Acorns (Quercus ilex L.) Effectively Protect Ready-to-Eat (RTE) Chicken Patties Irrespective of Packaging Atmosphere. *Journal of Food Science* 82, 622–31, DOI: 10.1111/1750-3841.13640.

Fiore, A., Park, S., Volpe, S., Torrieri, E., & Masi, P. (2021). Active packaging based on PLA and chitosan-caseinate enriched rosemary essential oil coating for fresh minced chicken breast application. *Food Packaging and Shelf Life*, 29, https://doi.org/10.1016/j.fpsl.2021.100708

Folim, G. H. (2015). *Purification columns and methods* (Patent No. US 2015/0258469 A1). Patent Application Publication, https://eureka.patsnap.com/pdfnew/?patentId=1fc03d46-86b4-498f-b5e9-e3a1c16b6f72

Fox, M., Mitchell, M., Dean, M., Elliott, C. & Campbell, K. (2018). The seafood supply chain from a fraudulent perspective. In *Food Security* (Vol. 10, Issue 4, pp. 939–963). Springer Netherlands, https://doi.org/10.1007/s12571-018-0826-z

Fraga, C. G., Galleano, M., Verstraeten, S. V. & Oteiza, P. I. (2010). Basic biochemical mechanisms behind the health benefits of polyphenols. In *Molecular Aspects of Medicine* (Vol. 31, Issue 6, pp. 435–445), https://doi.org/10.1016/j.mam.2010.09.006

Gagaoua, M., Bhattacharya, T., Lamri, M., Oz, F., Dib, A., Öz, E., Uysal Unalan, I. & Tomasevic, I. (2021). Green Coating Polymers in Meat Preservation. *Coatings*, 11, 1379, https://doi.org/10.3390/coatings11111379

Gagaoua, M. & Boudechicha, H. R. (2018). Ethnic meat products of the North African and Mediterranean countries: An overview. In *Journal of Ethnic Foods* (Vol. 5, Issue 2, pp. 83–98). Elsevier B.V, https://doi.org/10.1016/j.jef.2018.02.004

Geldenhuys, G., Hoffman, L. C. & Muller, N. (2015). The fatty acid, amino acid, and mineral composition of Egyptian goose meat as affected by season, gender, and portion. *Poultry Science*, 94 (5), 1075–1087, https://doi.org/10.3382/ps/pev083

Geller, A. I., Shehab, N., Weidle, N. J., Lovegrove, M. C., Wolpert, B. J., Timbo, B. B., Mozersky, R. P. & Budnitz, D. S. (2015). Emergency Department Visits for Adverse Events Related to Dietary Supplements. *New England Journal of Medicine*, 373 (16), 1531–1540, https://doi.org/10.1056/nejmsa1504267

Giannenas, I., Sidiropoulou, E., Bonos, E., Christaki, E. & Florou-Paneri, P. (2020). Chapter 1 — The history of herbs, medicinal and aromatic plants, and their extracts: Past, current situation and future perspectives. In P. Florou-Paneri, E. Christaki & I. Giannenas (Eds.), *Feed Additives* (pp. 1–18). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-814700-9.00001-7

Giarratana, F., Muscolino, D., Ragonese, C., Beninati, C., Sciarrone, D., Ziino, G., Mondello, L., Giuffrida, A. & Panebianco, A. (2016). Antimicrobial activity of combined thyme and rosemary essential oils against *Listeria monocytogenes* in Italian mortadella packaged in modified atmosphere: Thyme & Rosemary EOs vs L. monocytogenes. *Journal of Essential Oil Research*, 28 (6), 467–474, https://doi.org/10.1080/10412905.2016.1165744

Gnakari, D., Grah, B. & Adouko, A. (2007). Croissance corporelle et qualité organoleptique de la viande du poulet de chair et du poulet africain et leurs croisements en Côte d'Ivoire. In *Livestock Research for Rural Development* (Vol. 19, Issue 5).

Górniak, I., Bartoszewski, R. & Króliczewski, J. (2019). Comprehensive review of antimicrobial activities of plant flavonoids. In *Phytochemistry Reviews* (Vol. 18, Issue 1, pp. 241–272). Springer Netherlands, https://doi.org/10.1007/s11101-018-9591-z

Gutiérrez-Del-río, I., López-Ibáñez, S., Magadán-Corpas, P., Fernández-Calleja, L., Pérez-Valero, Á., Tuñón-Granda, M., Miguélez, E. M., Villar, C. J. & Lombó, F. (2021). Terpenoids and polyphenols as natural antioxidant agents in food preservation. *Antioxidants*, 10 (8), MDPI, https://doi.org/10.3390/antiox10081264

Hadidi, M., Orellana-Palacios, J. C., Aghababaei, F., Gonzalez-Serrano, D. J., Moreno, A. & Lorenzo, J. M. (2022). Plant by-product antioxidants: Control of protein-lipid oxidation in meat and meat products. *LWT*, 169, Academic Press, https://doi.org/10.1016/j.lwt.2022.114003

Hailemariam, A., Esatu, W., Abegaz, S., Urge, M., Assefa, G. & Dessie, T. (2022). Nutritional composition and sensory characteristics of breast meat from different chickens. *Applied Food Research*, 2 (2), https://doi.org/10.1016/j.afres.2022.100233

Han, L., Sapozhnikova, Y. & Matarrita, J. (2016). Evaluation of a new carbon/zirconia-based sorbent for the cleanup of food extracts in multiclass analysis of pesticides and environmental contaminants. *Journal of Separation Science*, 39, https://doi.org/10.1002/jssc.201600920

Hassan, A. H. A., Korany, A. M., Zeinhom, M. M. A., Mohamed, D. Sh. & Abdel-Atty, N. S. (2022). Effect of chitosan-gelatin coating fortified with papaya leaves and thyme extract on quality and shelf life of chicken breast fillet and Kareish cheese during chilled storage. *International Journal of Food Microbiology*, 371, 109667, https://doi.org/https://doi.org/10.1016/j.ijfoodmicro.2022.109667

Hichri, I., Barrieu, F., Bogs, J., Kappel, C., Delrot, S. & Lauvergeat, V. (2011). Recent advances in the transcriptional regulation of the flavonoid biosynthetic pathway. In *Journal of Experimental Botany* (Vol. 62, Issue 8, pp. 2465–2483), https://doi.org/10.1093/jxb/erq442

Hyldgaard, M., Mygind, T. & Meyer, R. L. (2012). Essential oils in food preservation: Mode of action, synergies, and interactions with food matrix components. *Frontiers in Microbiology*, 3 (JAN), https://doi.org/10.3389/fmicb.2012.00012

İncili, G. K., Akgöl, M., Aydemir, M. E., Alan, S., Mutlu, M., İlhak, O. İ. & Öksüztepe, G. (2020). Fate of Listeria monocytogenes and Salmonella Typhimurium in homemade marinade and on marinated chicken drumsticks, wings and breast meat. *LWT*, 134, https://doi.org/10.1016/j.lwt.2020.110231

Ivanov, M., Kostić, M., Stojković, D. & Soković, M. (2022). Rosmarinic acid–Modes of antimicrobial and antibiofilm activities of common plant polyphenol. *South African Journal of Botany*, 146, 521–527, https://doi.org/10.1016/j.sajb.2021.11.050

Jacob Rani B.S. & Venkatachalam S. (2023). Unleashing the potential of bio-nanoparticles from invasive cattail as reinforcement in packaging film to extend the shelf life of poultry meat. Packaging Technology and Science n/a DOI: https://doi.org/10.1002/pts.2773

Jilo, S. A. & Hasan, L. A. (2022). The Importance of Poultry Meat in Medicine: A Review. *Journal of World's Poultry Research*, 12 (4), 258–262, https://doi.org/10.36380/jwpr.2022.28

Jin, L.-Z., Dersjant-Li, Y. & Giannenas, I. (2020). Chapter 10 — Application of aromatic plants and their extracts in diets of broiler chickens. In P. Florou-Paneri, E. Christaki & I. Giannenas (Eds.), *Feed Additives* (pp. 159–185). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-814700-9.00010-8

Jirovetz, L., Buchbauer, G., Stoilova, I., Stoyanova, A., Krastanov, A. & Schmidt, E. (2006). Chemical Composition and Antioxidant Properties of Clove Leaf Essential Oil. *Journal of Agricultural and Food Chemistry*, 54 (17), 6303–6307, https://doi.org/10.1021/jf060608c

Jongberg, S., Racanicci, A. M. C., & Skibsted, L. H. (2019). Mate extract is superior to green tea extract in the protection against chicken meat protein thiol oxidation. Food Chemistry, 300, https://doi.org/10.1016/j.foodchem.2019.125134

Kabera, J. N., Semana, E., Mussa, A. R. & He, X. (2014). Plant Secondary Metabolites: Biosynthesis, Classification, Function and Pharmacological Properties. In *Journal of Pharmacy and Pharmacology* (Vol. 2).

Kačániová, M., Mellen, M., Vukovic, N. L., Kluz, M., Puchalski, C., Haščík, P. & Kunová, S. (2019). Combined effect of vacuum packaging, fennel and savory essential oil treatment on the quality of chicken thighs. *Microorganisms*, 7 (5), https://doi.org/10.3390/microorganisms7050134

Khaneghah, A. M., Hashemi, S. M. B. & Sant'Ana, A. de S. (2017). Essential Oils in Food Processing. In *Essential Oils in Food Processing* (pp. i–xviii). Wiley, https://doi.org/10.1002/9781119149392.fmatter

Khanjari, A., Karabagias, I. K., & Kontominas, M. G. (2013). Combined effect of N,O-carboxymethyl chitosan and oregano essential oil to extend shelf life and control Listeria monocytogenes in raw chicken meat fillets. *LWT — Food Science and Technology*, 53 (1), 94–99, https://doi.org/https://doi.org/10.1016/j.lwt.2013.02.012

Kicel, A., Owczarek, A., Gralak, P., Ciszewski, P. & Olszewska, M. A. (2019). Polyphenolic profile, antioxidant activity, and pro-inflammatory enzymes inhibition of leaves, flowers, bark and fruits of Cotoneaster integerrimus: A comparative study. *Phytochemistry Letters*, 30, 349–355, https://doi.org/https://doi.org/10.1016/j.phytol.2019.02.027

Kilic, S., Oz, E. & Oz, F. (2021). Effect of turmeric on the reduction of heterocyclic aromatic amines and quality of chicken meatballs. *Food Control*, 128, https://doi.org/10.1016/j.foodcont.2021.108189

Kim, Y. K. (2020). Quality improvement of the chicken sausage with pepper seed (Capsicum annuum l.). *Current Research in Nutrition and Food Science*, 8 (3), 829–836, https://doi.org/10.12944/CRNFSJ.8.3.14

Köksal, E., Bursal, E., Gülçin, İ., Korkmaz, M., Çağlayan, C., Gören, A. C. & Alwasel, S. H. (2017). Antioxidant activity and polyphenol content of Turkish thyme (Thymus vulgaris) monitored by liquid chromatography and tandem mass spectrometry. *International Journal of Food Properties*, 20 (3), 514–525, https://doi.org/10.1080/10942912.2016.1168438

Kostic, D., Arsic, B., Ranđelović, S., Pavlović, A., Tošić, S. & Stojanović, G. (2019). Correlation Analysis of Heavy Metals Contents of Malva sylvestris L. plant and Its Extracts from Polluted and Non-polluted Locations in Niš, Republic of Serbia. *Water, Air, & Soil Pollution*, 230, https://doi.org/10.1007/s11270-019-4153-6

Kumawat, M., Nabi, B., Daswani, M., Viquar, I., Pal, N., Sharma, P., Tiwari, S., Sarma, D. K., Shubham, S. & Kumar, M. (2023). Role of bacterial efflux pump proteins in antibiotic resistance across microbial species. In *Microbial Pathogenesis* (Vol. 181). Academic Press, https://doi.org/10.1016/j.micpath.2023.106182

Lamri, M., Bhattacharya, T., Boukid, F., Chentir, I., Dib, A. L., Das, D., Djenane, D. & Gagaoua, M. (2021). Nanotechnology as a processing and packaging tool to improve meat quality and safety. In *Foods* (Vol. 10, Issue 11). MDPI, https://doi.org/10.3390/foods10112633

Lamri, M., della Malva, A., Djenane, D., Albenzio, M. & Gagaoua, M. (2023). First insights into the dynamic protein changes in goat Semitendinosus muscle during the post-mortem period using high-throughput proteomics. *Meat Science*, 202, https://doi.org/10.1016/j.meatsci.2023.109207

Lee, N. K. & Paik, H. D. (2016). Status, antimicrobial mechanism, and regulation of natural preservatives in livestock food systems. In *Korean Journal for Food Science of Animal Resources* (Vol. 36, Issue 4, pp. 547–557). Korean Society for Food Science of Animal Resources, https://doi.org/10.5851/kosfa.2016.36.4.547

Liao, M., Zhao, Y., Yang, X., Yang, L., Liu, E.-H., Lu, B., Wang, J., Liu, X., Chang, Y. & Duan, L. (2022). A greener and sustainable route for medicinal plant analysis: Recycle utilization of hydrophobic deep eutectic solvent. *Microchemical Journal*, 178, 107372, https://doi.org/https://doi.org/10.1016/j.microc.2022.107372

Liu, X. De, Jayasena, D. D., Jung, Y., Jung, S., Kang, B. S., Heo, K. N., Lee, J. H. & Jo, C. (2012). Differential proteome analysis of breast and thigh muscles between Korean native chickens and commercial broilers. *Asian-Australasian Journal of Animal Sciences*, 25 (6), 895–902, https://doi.org/10.5713/ajas.2011.11374

Loarce, L., Oliver-Simancas, R., Marchante, L., Díaz-Maroto, M. C. & Alañón, M. E. (2021). Modifiers based on natural deep eutectic mixtures to enhance anthocyanins isolation from grape pomace by pressurized hot water extraction. *LWT*, 149, 111889, https://doi.org/https://doi.org/10.1016/j.lwt.2021.111889

Lu, H., Lu, Z., Li, X., Li, G., Qiao, Y., Borris, R. P. & Zhang, Y. (2017). Interactions of 172 plant extracts with human organic anion transporter 1 (SLC22A6) and 3 (SLC22A8): A study on herb-drug interactions. *PeerJ*, 2017 (5), https://doi.org/10.7717/peerj.3333

Lytou, A. E., Nychas, G. J. E. & Panagou, E. Z. (2018). Effect of pomegranate based marinades on the microbiological, chemical and sensory quality of chicken meat: A metabolomics approach. *International Journal of Food Microbiology*, 267, 42–53, https://doi.org/10.1016/j.ijfoodmicro.2017.12.023

Mahfuz, S., Shang, Q. & Piao, X. (2021). Phenolic compounds as natural feed additives in poultry and swine diets: a review. In *Journal of Animal Science and Biotechnology* (Vol. 12, Issue 1). BioMed Central Ltd, https://doi.org/10.1186/s40104-021-00565-3

Mani-López, E., Palou, E. & López-Malo, A. (2016). Preservatives: Classifications and Analysis. *Encyclopedia of Food and Health*, https://doi.org/10.1016/B978-0-12-384947-2.00567-5

Masyita, A., Mustika Sari, R., Dwi Astuti, A., Yasir, B., Rahma Rumata, N., Emran, T. Bin, Nainu, F. & Simal-Gandara, J. (2022). Terpenes and terpenoids as main bioactive compounds of essential oils, their roles in human health and potential application as natural food preservatives. *Food Chemistry: X*, 13, https://doi.org/10.1016/j.fochx.2022.100217

Mehdizadeh T. & Mojaddar Langroodi A. (2019). Chitosan coatings incorporated with propolis extract and Zataria multiflora Boiss oil for active packaging of chicken breast meat. *International Journal of Biological Macromolecules* 141, 401–409, DOI: https://doi.org/10.1016/j.ijbiomac.2019.08.267.

Mehta, J., Rolta, R. & Dev, K. (2022). Role of medicinal plants from North Western Himalayas as an efflux pump inhibitor against MDR AcrAB-TolC Salmonella enterica serovar typhimurium: In vitro and In silico studies. *Journal of Ethnopharmacology*, 282, 114589, https://doi.org/https://doi.org/10.1016/j.jep.2021.114589

Melloul, S., Zehioua, R. & Meniai, A.-H. (2022). Supercritical CO2 extraction of bioactive compounds from local Peganum Harmala plant seeds and optimization of the extraction yield and the antioxidant activities. *Sustainable Chemistry and Pharmacy*, 28, 100729, https://doi.org/https://doi.org/10.1016/j.scp.2022.100729

Mendonca, A., Jackson-Davis, A., Moutiq, R. & Thomas-Popo, E. (2018). Use of Natural Antimicrobials of Plant Origin to Improve the Microbiological Safety of Foods. In *Food and Feed Safety Systems and Analysis* (pp. 249–272). Elsevier, https://doi.org/10.1016/B978-0-12-811835-1.00014-2

Mesías, F. J., Martín, A. & Hernández, A. (2021). Consumers' growing appetite for natural foods: Perceptions towards the use of natural preservatives in fresh fruit. *Food Research International*, 150, https://doi.org/10.1016/j.foodres.2021.110749

Mexis, S. F., Chouliara, E. & Kontominas, M. G. (2012). Shelf life extension of ground chicken meat using an oxygen absorber and a citrus extract. *LWT*, 49 (1), 21–27, https://doi.org/10.1016/j.lwt.2012.04.012

Miara, M. D., Bendif, H., Rebbas, K., Rabah, B., Hammou, M. A. & Maggi, F. (2019). Medicinal plants and their traditional uses in the highland region of Bordj Bou Arreridj (Northeast Algeria). *Journal of Herbal Medicine*, 16, 100262, https://doi.org/https://doi.org/10.1016/j.hermed.2019.100262

Miara, M. D., Teixidor-Toneu, I., Sahnoun, T., Bendif, H. & Ait Hammou, M. (2019). Herbal remedies and traditional knowledge of the Tuareg community in the region of Illizi (Algerian Sahara). *Journal of Arid Environments*, 167, 65–73, https://doi.org/10.1016/J.JARIDENV.2019.04.020

Mohd Subakir, F. N., Zaharudin, N., Mohamed Azman, N. A., & Samat, N. (2022). Thiobarbituric Reactive Substance (TBARS) and sensory evaluation of breast chicken meat from broiler fed with Kappaphycus alvarezii and Sargassum polycystum seaweeds formulated feed. *Food Research*, 6, 107–115, https://doi.org/10.26656/FR.2017.6(S2).022

Mohebodini, H., Jazi, V., Ashayerizadeh, A., Toghyani, M. & Tellez-Isaias, G. (2021). Productive parameters, cecal microflora, nutrient digestibility, antioxidant status, and thigh muscle fatty acid profile in broiler chickens fed with Eucalyptus globulus essential oil. *Poultry Science*, 100 (3), 100922, https://doi.org/https://doi.org/10.1016/j.psj.2020.12.020

Moraes-Lovison, M., Marostegan, L. F. P., Peres, M. S., Menezes, I. F., Ghiraldi, M., Rodrigues, R. A. F., Fernandes, A. M. & Pinho, S. C. (2017). Nanoemulsions encapsulating oregano essential oil: Production, stability, antibacterial activity and incorporation in chicken pâté. *LWT*, 77, 233–240, https://doi.org/10.1016/j.lwt.2016.11.061

Muhialdin, B. J., Kadum, H., Fathallah, S. & Meor Hussin, A. S. (2020). Metabolomics profiling and antibacterial activity of fermented ginger paste extends the shelf life of chicken meat. *LWT*, 132, 109897, https://doi.org/https://doi.org/10.1016/j.lwt.2020.109897

Munekata, P. E. S., Calomeni, A. V, Rodrigues, C. E. C., Fávaro-Trindade, C. S., de Alencar, S. M. & Trindade, M. A. (2015). Peanut skin extract reduces lipid oxidation in cooked chicken patties. *Poultry Science*, https://doi.org/10.3382/ps/pev005

Muthukumar, J., Selvasekaran, P., Lokanadham, M. & Chidambaram, R. (2020). Food and food products associated with food allergy and food intolerance — An overview. In *Food Research International* (Vol. 138). Elsevier Ltd, https://doi.org/10.1016/j.foodres.2020.109780

Najeeb, A. P., Mandal, P. K. & Pal, U. K. (2015). Efficacy of leaves (drumstick, mint and curry leaves) powder as natural preservatives in restructured chicken block. *Journal of Food Science and Technology*, 52 (5), 3129–3133, https://doi.org/10.1007/s13197-014-1316-8

Nandi S. & Guha P. (2024). Development, characterization and application of starch-based film containing polyphenols of piper betle L. waste in chicken meat storage. *Food Chemistry*, 431, 137103, DOI: https://doi.org/10.1016/j.foodchem.2023.137103.

Naveena, B. M., Sen, A. R., Vaithiyanathan, S., Babji, Y. & Kondaiah, N. (2008). Comparative efficacy of pomegranate juice, pomegranate rind powder extract and BHT as antioxidants in cooked chicken patties. *Meat Science*, 80 (4), 1304–1308, https://doi.org/10.1016/j.meatsci.2008.06.005

Nayak, B., Dahmoune, F., Moussi, K., Remini, H., Dairi, S., Aoun, O. & Khodir, M. (2015). Comparison of microwave, ultrasound and accelerated-assisted solvent extraction for recovery of polyphenols from Citrus sinensis peels. *Food Chemistry*, 187, 507–516, https://doi.org/https://doi.org/10.1016/j.foodchem.2015.04.081

Nguyen, M. M. & Karboune, S. (2023). Combinatorial Interactions of Essential Oils Enriched with Individual Polyphenols, Polyphenol Mixes, and Plant Extracts: Multi-Antioxidant Systems. *Antioxidants*, 12 (2), https://doi.org/10.3390/antiox12020486

Noori, S., Zeynali, F. & Almasi, H. (2018). Antimicrobial and antioxidant efficiency of nanoemulsion-based edible coating containing ginger (Zingiber officinale) essential oil and its effect on safety and quality attributes of chicken breast fillets. *Food Control*, 84, 312–320, https://doi.org/10.1016/j.foodcont.2017.08.015

Oliveira, V., Ferreira, F., Cople, M., Labre, T., Augusta, I., Gamallo, O. & Saldanha, T. (2018). Use of Natural Antioxidants in the Inhibition of Cholesterol Oxidation: A Review: Inhibition of cholesterol oxidation…. *Comprehensive Reviews in Food Science and Food Safety*, 17, https://doi.org/10.1111/1541-4337.12386

Oluyemisi Folashade, K., Eghrevba, H. O. & Ahmadu, P. O. (2012). Standardization of herbal medicines — A review. *International Journal of Biodiversity and Conservation*, 4 (3), https://doi.org/10.5897/ijbc11.163

Omotayo, O. P., Omotayo, A. O., Mwanza, M. & Babalola, O. O. (2019). Prevalence of mycotoxins and their consequences on human health. In *Toxicological Research* (Vol. 35, Issue 1, pp. 1–7). Korean Society of Toxicology, https://doi.org/10.5487/TR.2019.35.1.001

Ouali, A., Gagaoua, M., Boudida, Y., Becila, S., Boudjellal, A., Herrera-Mendez, C. H. & Sentandreu, M. A. (2013). Biomarkers of meat tenderness: Present knowledge and perspectives in regards to our current understanding of the mechanisms involved. *Meat Science*, 95 (4), 854–870, https://doi.org/https://doi.org/10.1016/j.meatsci.2013.05.010

Pateiro, M., Gómez-Salazar, J. A., Jaime-Patlán, M., Sosa-Morales, M. E. & Lorenzo, J. M. (2021). Plant extracts obtained with green solvents as natural antioxidants in fresh meat products. In *Antioxidants* (Vol. 10, Issue 2, pp. 1–21). MDPI, https://doi.org/10.3390/antiox10020181

Pferschy-Wenzig, E.-M. & Bauer, R. (2015). The relevance of pharmacognosy in pharmacological research on herbal medicinal products. *Epilepsy & Behavior*, 52, 344–362, https://doi.org/https://doi.org/10.1016/j.yebeh.2015.05.037

Pinto, L., Tapia-Rodríguez, M. R., Baruzzi, F., & Ayala-Zavala, J. F. (2023). Plant Antimicrobials for Food Quality and Safety: Recent Views and Future Challenges. In Foods (Vol. 12, Issue 12). MDPI, https://doi.org/10.3390/foods12122315

Polka, D. & Podsędek, A. (2019). Biotechnology and Food Science Phenolics composition and antioxidant capacity of guelder rose fruit, flower and bark extracts. In *Biotechnol Food Sci* (Vol. 83, Issue 1), http://www.bfs.p.lodz.pl

Qi, J., Du, C., Yao, X., Yang, C., Zhang, Q. & Liu, D. (2022). Enrichment of taste and aroma compounds in braised soup during repeated stewing of chicken meat. *LWT*, 168, 113926, https://doi.org/https://doi.org/10.1016/j.lwt.2022.113926

Qiu, L., Zhang, M., Chitrakar, B., Adhikari, B. & Yang, C. (2022). Effects of nanoemulsion-based chicken bone gelatin-chitosan coatings with cinnamon essential oil and rosemary extract on the storage quality of ready-to-eat chicken patties. *Food Packaging and Shelf Life*, 34, https://doi.org/10.1016/j.fpsl.2022.100933

Radha Krishnan, K., Babuskin, S., Azhagu Saravana Babu, P., Sasikala, M., Sabina, K., Archana, G., Sivarajan, M., & Sukumar, M. (2014). Antimicrobial and antioxidant effects of spice extracts on the shelf life extension of raw chicken meat. *International Journal of Food Microbiology*, 171, 32–40.

Rafińska, K., Wrona, O., Krakowska-Sieprawska, A., Walczak-Skierska, J., Kiełbasa, A., Rafiński, Z., Pomastowski, P., Kolankowski, M. & Buszewski, B. (2022). Enzyme-assisted extraction of plant material — New functional aspects of the process on an example of Medicago sativa L. *Industrial Crops and Products*, 187, 115424, https://doi.org/https://doi.org/10.1016/j.indcrop.2022.115424

Rahim, M. Z., Prinsi, B., Espen, L., Benabdelkader, T., Nabiev, M. & Houali, K. (2022). Comparative analysis of the chemical constituents and in vitro antioxidant activities of different aqueous extracts of the Cistanche phelypaea (L.) Cout. from Algeria. *South African Journal of Botany*, 148, 259–267, https://doi.org/10.1016/j.sajb.2022.04.041

Rani, Z. T., Hugo, A., Hugo, C. J., Vimiso, P. & Muchenje, V. (2017). Effect of post-slaughter handling during distribution on microbiological quality and safety of meat in the formal and informal sectors of South Africa: A review. *South African Journal of Animal Science*, 47 (3), 255–267, https://doi.org/10.4314/sajas.v47i3.2

Rimini, S., Petracci, M., & Smith, D. P. (2014). The use of thyme and orange essential oils blend to improve quality traits of marinated chicken meat. *Poultry Science*, 93 (8), 2096–2102, https://doi.org/10.3382/ps.2013-03601

Rosa, A., Deiana, M., Casu, V., Paccagnini, S., Appendino, G., Ballero, M. & Dessí, M. A. (2002). Antioxidant Activity of Capsinoids. *Journal of Agricultural and Food Chemistry*, 50 (25), 7396–7401, https://doi.org/10.1021/jf020431w

Rout, S., Tambe, S., Deshmukh, R. K., Mali, S., Cruz, J., Srivastav, P. P., Amin, P. D., Gaikwad, K. K., Andrade, E. H. de A. & Oliveira, M. S. de. (2022). Recent trends in the application of essential oils: The next generation of food preservation and food packaging. In *Trends in Food Science and Technology* (Vol. 129, pp. 421–439). Elsevier Ltd, https://doi.org/10.1016/j.tifs.2022.10.012

Sajad, S., Ahmad, I. S., Snober Irshad, I., Qureshi, I. A., Aaliya Fayaz, I., Farukh Mehraj, I., Heena Jalal, I., Corresponding Author, I., Ahmad, S., Irshad, S., Qureshi, A., Fayaz, A., Mehraj, F. & Jalal, H. (2020). Influence of the aqueous extract of dandelion (Taraxacum officinale) powder on the quality of chicken meat loaves. ~ *1579 ~ Journal of Entomology and Zoology Studies*, 8 (4), 1579–1582, http://www.entomoljournal.com

Saleh, E., Morshdy, A. E., El-Manakhly, E., Al-Rashed, S., Hetta, H. F., Jeandet, P., Yahia, R., El-Saber Batiha, G. & Ali, E. (2020). Effects of olive leaf extracts as natural preservative on retailed poultry meat quality. *Foods*, 9 (8), https://doi.org/10.3390/foods9081017

Sallam, K. I., Ishioroshi, M. & Samejima, K. (2004). Antioxidant and antimicrobial effects of garlic in chicken sausage. *LWT*, 37 (8), 849–855, https://doi.org/10.1016/j.lwt.2004.04.001

Sampaio, G. R., Saldanha, T., Soares, R. A. M., & Torres, E. A. F. S. (2012). Effect of natural antioxidant combinations on lipid oxidation in cooked chicken meat during refrigerated storage. *Food Chemistry*, 135 (3), 1383–1390, https://doi.org/10.1016/j.foodchem.2012.05.103

Seidavi, A., Tavakoli, M., Slozhenkina, M., Gorlov, I., Hashem, N. M., Asroosh, F., Taha, A. E., Abd El-Hack, M. E., & Swelum, A. A. (2021). The use of some plant-derived products as effective alternatives to antibiotic growth promoters in organic poultry production: a review. In *Environmental Science and Pollution Research* (Vol. 28, Issue 35, pp. 47856–47868). Springer Science and Business Media Deutschland GmbH, https://doi.org/10.1007/s11356-021-15460-7

Seol K.-H., Joo B.-J., Kim H., Chang O.-K.I., Ham J., Oh M.-H., Park B.-Y. & Lee M. (2013). Effect of Medicinal Plant Extract Incorporated Carrageenan Based Films on Shelf-Life of Chicken Breast Meat. *Korean Journal for Food Science of Animal Resources*, 33, DOI: 10.5851/kosfa.2013.33.1.53.

Seukep, A. J., Kuete, V., Nahar, L., Sarker, S. D. & Guo, M. (2020). Plant-derived secondary metabolites as the main source of efflux pump inhibitors and methods for identification. *Journal of Pharmaceutical Analysis*, 10 (4), 277–290, https://doi.org/https://doi.org/10.1016/j.jpha.2019.11.002

Shah, M. A., Bosco, S. J. D. & Mir, S. A. (2014). Plant extracts as natural antioxidants in meat and meat products. In *Meat Science* (Vol. 98, Issue 1, pp. 21–33). Elsevier BV, https://doi.org/10.1016/j.meatsci.2014.03.020

Sharma, H., Narshimhaji, Ch. V. & Singh, R. (2023). Relative estimation of beta-sitosterol in alcoholic extracts of roots and small branches of oroxylum indicum (L.) Kurz by HPTLC for plant part substitution, medicinal uses and conservation. *Journal of Applied Research on Medicinal and Aromatic Plants*, 35, 100496, https://doi.org/https://doi.org/10.1016/j.jarmap.2023.100496

Sirocchi, V., Caprioli, G., Cecchini, C., Coman, M., Cresci, A., Maggi, F., Papa, F., Ricciutelli, M., Vittori, S. & Sagratini, G. (2013). Biogenic Amines as freshness index of meat wrapped in an innovative active packaging system formulated with essential oils of Rosmarinus officinalis L. *International Journal of Food Science and Nutrition*, 64, https://doi.org/10.3109/09637486.2013.809706

Skochko, O. I., Shevchenko, I. I., Polichuk, G. E. & Paska, M. Z. (2018). The estimation of effects of food crioprotectors on quality indicators of semi-fragrances. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies*, 20 (90), 27–31, https://doi.org/10.32718/nvlvet9006

Steier, G. (2016). Textbox: Cross-Contamination, Genetic Drift, and the Question of GMO Co-existence with Non-GM Crops. In *International Food Law and Policy* (pp. 177–178), https://doi.org/10.1007/978-3-319-07542-6_7

Stojanović-Radić, Z., Pejčić, M., Joković, N., Jokanović, M., Ivić, M., Šojić, B., Škaljac, S., Stojanović, P. & Mihajilov-Krstev, T. (2018). Inhibition of Salmonella Enteritidis growth and storage stability in chicken meat treated with basil and rosemary essential o ils alone or in combination. *Food Control*, 90, 332–343, https://doi.org/10.1016/j.foodcont.2018.03.013

Surekha, M. & Reddy, S. M. (2014). Preservatives | Classification and Properties. In C. A. Batt & M. Lou Tortorello (Eds.), *Encyclopedia of Food Microbiology (Second Edition)* (pp. 69–75). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-384730-0.00257-3

Tajik, H., Farhangfar, A., Moradi, M. & Razavi Rohani, S. M. (2014). Effectiveness of Clove Essential Oil and Grape Seed Extract Combination on Microbial and Lipid Oxidation Characteristics of Raw Buffalo Patty During Storage at Abuse Refrigeration Temperature. *Journal of Food Processing and Preservation*, 38, https://doi.org/10.1111/j.1745-4549.2012.00736.x

Tang, S. Z., Kerry, J. P., Sheehan, D. & Buckley, D. J. (2002). *Antioxidative mechanisms of tea catechins in chicken meat systems*. www.elsevier.com/locate/foodchem

Tengilimoglu-Metin, M. M., Hamzalioglu, A., Gokmen, V., & Kizil, M. (2017). Inhibitory effect of hawthorn extract on heterocyclic aromatic amine formation in beef and chicken breast meat. *Food Research International*, 99, 586–595, https://doi.org/10.1016/j.foodres.2017.06.044

Terlouw, C. E. M., Picard, B., Deiss, V., Berri, C., Hocquette, J. F., Lebret, B., Lefèvre, F., Hamill, R. & Gagaoua, M. (2021). Understanding the determination of meat quality using biochemical characteristics of the muscle: Stress at slaughter and other missing keys. *Foods* 10 (1). MDPI AG, https://doi.org/10.3390/foods10010084

Thakur, N., Mendiratta, S., Chauhan, G., Soni, A. & Agrawal, R. (2019). Antioxidant and Antimicrobial Effect of Oregano Essential Oil on Shelf-Life of Chicken Patties. *International Journal of Current Microbiology and Applied Sciences*, 8, 3076–3087, https://doi.org/10.20546/ijcmas.2019.802.360

Thielmann, J., Muranyi, P. & Kazman, P. (2019). Screening essential oils for their antimicrobial activities against the foodborne pathogenic bacteria Escherichia coli and Staphylococcus aureus. *Heliyon*, 5 (6), https://doi.org/10.1016/j.heliyon.2019.e01860

Thomas, J., Patel, A., Das Sivadasan, S., Sreevallabhan, S., Illathu Madhavamenon, K. & Mohanan, R. (2022). Clove bud (Syzygium aromaticum L.) polyphenol helps to mitigate metabolic syndrome by establishing intracellular redox homeostasis and glucose metabolism: A randomized, double-blinded, active-controlled comparative study. *Journal of Functional Foods*, 98, https://doi.org/10.1016/j.jff.2022.105273

Thompson, T., Busetti, A. & Gilmore, B. (2023). Quorum Sensing in Halorubrum saccharovorum Facilitates Cross-Domain Signaling between Archaea and Bacteria. *Microorganisms*, 11, 1271, https://doi.org/10.3390/microorganisms11051271

Tian, H., Li, F., Qin, L., Yu, H. & Ma, X. (2014). Discrimination of Chicken Seasonings and Beef Seasonings Using Electronic Nose and Sensory Evaluation. *Journal of Food Science*, 79, https://doi.org/10.1111/1750-3841.12675

Tobiszewski, M. & Namieśnik, J. (2017). Greener organic solvents in analytical chemistry. *Current Opinion in Green and Sustainable Chemistry*, 5, 1–4, https://doi.org/https://doi.org/10.1016/j.cogsc.2017.03.002

Tresserra-Rimbau, A., Lamuela-Raventos, R. M. & Moreno, J. J. (2018). Polyphenols, food and pharma. Current knowledge and directions for future research. In *Biochemical Pharmacology* (Vol. 156, pp. 186–195). Elsevier Inc, https://doi.org/10.1016/j.bcp.2018.07.050

Twaij, B. M. & Hasan, M. N. (2022). Bioactive Secondary Metabolites from Plant Sources: Types, Synthesis, and Their Therapeutic Uses. *International Journal of Plant Biology*, 13 (1), 4–14, https://doi.org/10.3390/ijpb13010003

Vara, S., Karnena, M. K. & Dwarapureddi, B. K. (2019). 6 — Natural Preservatives for Nonalcoholic Beverages. In A. M. Grumezescu & A. M. Holban (Eds.), *Preservatives* *and Preservation Approaches in Beverages* (pp. 179–201). Academic Press, https://doi.org/https://doi.org/10.1016/B978-0-12-816685-7.00006-9

Vauzour, D., Rodriguez-Mateos, A., Corona, G., Oruna-Concha, M. J. & Spencer, J. P. E. (2010). Polyphenols and human health: Prevention of disease and mechanisms of action. *Nutrients* 2 (11), pp. 1106–1131, MDPI AG, https://doi.org/10.3390/nu2111106

Vinci, G., Maddaloni, L., Prencipe, S. A., & Bernardo, A. (2022). Integrated Study for the Shelf-life Evaluation in Food: Use of Spices, Herbs, and Bio-packaging. In Emerging Challenges in Agriculture and Food Science Vol. 7 (pp. 40–50). Book Publisher International (a part of SCIENCEDOMAIN International), https://doi.org/10.9734/bpi/ecafs/v7/3676A

Vranić, D., Milićević, D., Korićanac, V., Trbović, D., Babić, J., Petrović, Z. & Parunović, N. (2014). Cholesterol and total lipid content in raw and heat processed commercially produced meat from two farms. *Meat Technology*, 55 (2), 130–141, https://www.journalmeattechnology.com/index.php/meat_technology/article/view/195/144

Wang, J., Ren, B., Bak, K. H., Soladoye, O. P., Gagaoua, M., Ruiz-Carrascal, J., Huang, Y., Zhao, Z., Zhao, Y., Fu, Y. & Wu, W. (2023). Preservative effects of composite biopreservatives on goat meat during chilled storage: Insights into meat quality, high-throughput sequencing and molecular docking. *LWT*, 184, 115033, https://doi.org/https://doi.org/10.1016/j.lwt.2023.115033

Wang, W., Zhao, D., Xiang, Q., Li, K., Wang, B., & Bai, Y. (2021). Effect of cinnamon essential oil nanoemulsions on microbiological safety and quality properties of chicken breast fillets during refrigerated storage. *LWT*, 152, https://doi.org/10.1016/j.lwt.2021.112376

Weil, B. & Veraitch, F. (2014). *Bioprocessing Challenges Associated with the Purification of Cellular Therapies* (pp. 129–156), https://doi.org/10.1007/978-94-007-7196-3_6

Weng, Z., Zeng, F., Wang, M., Guo, S., Tang, Z., Itagaki, K., Lin, Y., Shen, X., Cao, Y., Duan, J. & Wang, F. (2023). Antimicrobial activities of lavandulylated flavonoids in Sophora flavences against methicillin-resistant Staphylococcus aureus via membrane disruption. *Journal of Advanced Research*, https://doi.org/https://doi.org/10.1016/j.jare.2023.04.017

Wideman, N., O'Bryan, C. A. & Crandall, P. G. (2016). Factors affecting poultry meat colour and consumer preferences — A review. *World's Poultry Science Journal*, 72 (2), 353–366, https://doi.org/DOI: 10.1017/S0043933916000015

Woroń, J. & Siwek, M. (2018). Unwanted effects of psychotropic drug interactions with medicinal products and diet supplements containing plant extracts. *Psychiatria Polska*, 52 (6), 983–996, https://doi.org/10.12740/PP/OnlineFirst/80998

Wu, H., Bak, K. H., Goran, G. V. & Tatiyaborworntham, N. (2022). Inhibitory mechanisms of polyphenols on heme protein-mediated lipid oxidation in muscle food: New insights and advances. In *Critical Reviews in Food Science and Nutrition*. Taylor and Francis Ltd, https://doi.org/10.1080/10408398.2022.2146654

Wu, Q. & Zhou, J. (2021). Chapter Two — The application of polyphenols in food preservation. In D. Granato (Ed.), *Advances in Food and Nutrition Research* (Vol. 98, pp. 35–99). Academic Press, https://doi.org/https://doi.org/10.1016/bs.afnr.2021.02.005

Xie, Y., Geng, Y., Yao, J., Ji, J., Chen, F., Xiao, J., Hu, X. & Ma, L. (2023). N-nitrosamines in processed meats: Exposure, formation and mitigation strategies. *Journal of Agriculture and Food Research*, 13, https://doi.org/10.1016/j.jafr.2023.100645

Yan, Z., Zhong, Y., Duan, Y., Chen, Q. & Li, F. (2020). Antioxidant mechanism of tea polyphenols and its impact on health benefits. In *Animal Nutrition* (Vol. 6, Issue 2, pp. 115–123). KeAi Communications Co, https://doi.org/10.1016/j.aninu.2020.01.001

Youssef, E. A., Saad, S. M., Hassan, M. A. & Ibrahim, H. M. (2021). Assessment of the effects of selected plant extracts on quality indices and shelf life of raw chilled chicken meat. *Benha Veterinary Medical Journal* (Vol. 40).

Yu, H. H., Chin, Y. W. & Paik, H. D. (2021). Application of natural preservatives for meat and meat products against food-borne pathogens and spoilage bacteria: A review. In *Foods* (Vol. 10, Issue 10). MDPI, https://doi.org/10.3390/foods10102418

Zhang, D., Ivane, N. M. A., Haruna, S. A., Zekrumah, M., Elysé, F. K. R., Tahir, H. E., Wang, G., Wang, C. & Zou, X. (2022). Recent trends in the micro-encapsulation of plant-derived compounds and their specific application in meat as antioxidants and antimicrobials. In *Meat Science* (Vol. 191). Elsevier Ltd, https://doi.org/10.1016/j.meatsci.2022.108842

Zhang, H., Wu, J. & Guo, X. (2016). Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality. *Food Science and Human Wellness*, 5 (1), 39–48, https://doi.org/10.1016/j.fshw.2015.11.003

Zhang, L. & Piao, X. (2023). Use of aromatic plant-derived essential oils in meat and derived products: Phytochemical compositions, functional properties, and encapsulation. In *Food Bioscience* (Vol. 53). Elsevier Ltd, https://doi.org/10.1016/j.fbio.2023.102520

Zheng, K., Li, B., Liu, Y., Wu, D., Bai, Y. & Xiang, Q. (2023). Effect of chitosan coating incorporated with oregano essential oil on microbial inactivation and quality properties of refrigerated chicken breasts. *LWT*, 176, https://doi.org/10.1016/j.lwt.2023.114547

Zhou, X., Zong, X., Zhang, M., Ge, Q., Qi, J., Liang, J., Xu, X. & Xiong, G. (2021). Effect of konjac glucomannan/carrageenan-based edible emulsion coatings with camellia oil on quality and shelf-life of chicken meat. *International Journal of Biological Macromolecules*, 183, 331–339, https://doi.org/10.1016/j.ijbiomac.2021.04.165

Zhu, Y., Li, X., Da, C., Liang, P., Jin, S., & Tang, C. (2022). Effects of Cyclocarya paliurus (Batal.) Extracts on Oxidative Stability and Sensory Quality in Meat Products (Frankfurters). *Foods*, 11 (22), https://doi.org/10.3390/foods11223721

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

UDK: 641.1:577.112
613.2:502.131.1
ID: 133269769
https://doi.org/10.18485/meattech.2023.64.3.3

Review paper

Protein sources in human and animal diet

Marija Starčević[1], Nataša Glamočlija[1], Jelena Janjić[1], Branislav Baltić[2], Snežana Bulajić[1], Radmila Marković[1] and Milan Ž. Baltić[1]*

[1] *The Faculty of Veterinary Medicine, University of Belgrade, Bulevar oslobođenja 18, 11000 Belgrade, Serbia*
[2] *Institute of Meat Hygiene and Technology, Kaćanskog 13, 11000 Belgrade, Serbia*

A R T I C L E I N F O

Keywords:
Proteins
Insects
Proteins of unicellular organisms
Algae

A B S T R A C T

Current estimates predict that due to population growth by 2050, the world will need about 70% more food than is currently being produced. With the growth of the population whose diet also requires protein intake, livestock production will continue to grow, and proteins of animal origin will remain an important part of the population's diet. The production of proteins of animal origin will increase in the future mainly due to the increased production of pork and poultry meat. Therefore, the demand for protein in feed will increase, as pigs and poultry have a greater need for protein in feed compared to ruminants. Therefore, the needs and challenges for nowadays are to find those sources of protein that will satisfy the nutritional needs of the largest part of the population and animals, and for which production will be cheaper and more accessible than for the sources of protein that are currently used in human and animal nutrition. To date, several new sources of protein for human and animal nutrition are already in use, and their importance will be even greater in the future. Insects, proteins from single-celled organisms and algae are increasingly used as alternative protein supplements. In addition, microbial technology and biological fermentation can improve the digestibility and, thus, the utility value of protein supplements.

1. Introduction

By 2050, the world population is expected to reach 10 billion. Current estimates predict that the world will, therefore, need about 70% more food than is currently being produced (*Liu et al.,* 2022). The structure of the world's population is changing as the consumption power of a large number of people increases, primarily in Asia. Namely, the world has already reached a turning point where more than half of the population is now considered middle class or richer and where the majority lives in cities. Regardless of the increase in the number of people belonging to the middle class, stratification among the population will exist also in the future, so a large part of the world's population will not have enough food, especially that of high value, which is food of animal origin. The latest data indicate that almost 690 million people in the world are malnourished, and predictions are that by 2030, that number will reach 840 million. The areas most affected by hunger are Africa, Asia and partly Latin America (*WHO,* 2020). That is why the needs and challenges in today's time are to find those types of food that will meet the nutritional needs of the majority of the population, and for which production will be cheaper and more accessible than for production of food of animal origin.

Another problem we face is the lack of variety of foods used in people's diets. The population uses a small number of foods in their diet, so 75% of the world's food production is obtained from only 12 types of plants and 5 types of animals (*FAO,* 1999). Almost 60% of the total calories obtained from plants come from just three types of plants, rice, corn and wheat. A lack of variety in human diet can

***Corresponding author:** Marija Starčević, marijadok@gmail.com

Received: April 27th 2023. Accepted May17th 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

have a negative impact on health. Although middle- and upper-class people may consume enough calories, energy-dense diets lead to obesity (*Rouhani et al.,* 2016). In addition, a monotonous diet cannot provide enough vitamins and minerals, resulting in health problems (*Aiking and de Boer,* 2020). There is an array of untapped food species that can provide diverse nutrients while also providing unique tastes and textures for discerning consumers (*Colgrave et al.,* 2021). One of the ways to offer the population diversity in diet, and on the other hand to meet the nutritional needs of a large part of the poor population, is to use in the diet more proteins obtained from plants and other sources (*Aiking and de Boer,* 2020).

2. Sources of protein in human and animal nutrition

Proteins are important macronutrients in human and animal nutrition, because they play a key role in growth and physiological processes in the body (*Boye et al.,* 2012). All amino acids are important in the synthesis and functioning of muscles and organs, as well as enzymes, hormones and the immune system (*Wu,* 2009). Amino acids are classified as essential and non-essential, based on whether the body can synthesize a particular amino acid. Non-essential amino acids can be synthesized *de novo* by the human body, while essential amino acids cannot be synthesized, so the only source of essential amino acids is protein in food. Therefore, it is important to ensure their adequate dietary intake (*FAO,* 2013). The amount of protein that the population over the age of 18 should consume every day (recommended daily food intake) has been determined and amounts to 0.83 g of protein per kg of body weight. Protein intake for children, pregnant women, lactating women and the elderly population is higher than recommended for adults (*EFSA,* 2012).

Dietary proteins differ in chemical, biological, functional and nutritional characteristics depending on their source and molecular structure (*Day et al.,* 2022). It is generally known that animal proteins have a higher nutritional value than plant proteins due to their amino acid composition, digestibility and ability to transport other important nutrients, such as calcium and iron. In addition, their technological properties, such as gelling, emulsifying and foaming, give food an attractive texture and sensory properties, so they are considered more valuable than plant-based proteins (*Kim et al.,* 2020). Although proteins of plant origin are being increasingly represented in the human diet due to their sustainability, as well as health and ethical reasons, their nutritional value is lower compared to proteins of animal origin. Namely, proteins of plant origin have an unbalanced amino acid composition and reduced or slower digestibility due to their molecular structure (*Day et al.,* 2022). Additionally, there are a number of arguments why an exclusively plant-based diet can lead to nutrient deficiencies, as some essential nutrients are absent or present in small amounts in plant-based foods, such as vitamin B12 or iodine. Other essential micronutrients may be present in sufficient quantities in plant foods, such as calcium (Ca) or zinc (Zn), but the low availability of these minerals in many plants due to the presence of phytates or oxalates may lead to their deficiencies in humans (*Adhikari et al.,* 2022).

3. Proteins of animal origin

The use of food of animal origin in human nutrition has a long history. There are assumptions that meat was used during human evolution 5–7 million years ago. The use of meat went through four periods during evolution: 1) random hunting and eating the remains of dead animals, 2) real hunting that began about 2 million years ago, 3) then the domestication and breeding of animals, as well as the cultivation of agricultural crops that occurred before 10,000 years ago, 4) and, nowadays, the use of food of animal origin with an unfavourable composition of fatty acids that are harmful to human health (*Larsen*, 2003). About 2.5 million years ago, human ancestors used stone tools to remove meat from animals. Although human ancestors used meat in their diet, it was not a significant part of their nutrition until organized hunting began about 2 million years ago (*Shipman,* 1986). At that time, groups of hunters joined together and caught large prey, which allowed a greater amount of food of animal origin to be eaten. It is very possible that hunting contributed to the improvement of the health of human ancestors, so about 2.0–1.7 million years ago there was a significant size increase (by 33% in men and by 37% in women) and an increase in body weight (by 44% in men and by 55% in women) (*McHenry and Coffing,* 2000). The development of agriculture approximately 10,000 years ago was a great improvement for humans, because life then changed from surviving day to day by hunting and gathering to organized and safer food production. However, with the development of agriculture, a change in human nutrition occurred, so the consumption of meat decreased, and the intake of cereals increased. Archaeological evidence confirms that during this period, there was a deterioration in human health, as the frequency of caries, anaemia due to iron deficiency, infections and the development of osteoporosis increased. With the development of agriculture, people began to gather around arable land, and this created ideal conditions for disease transmission (*Larsen,* 2003). Nowadays, the consumption of meat has increased, and with it the frequency of cardiovascular diseases. Although the diet of modern man is in many ways similar to the diet of people more than 10,000 years ago who were hunter gatherers, the deterioration of human health today can be explained by the lower intake of monounsaturated and polyunsaturated fatty acids, as well as lack of physical activity (*Cordain et al.,* 2002).

Meat, eggs and dairy products have exceptional nutritional value, as they contain high-value proteins, fats (n-3 fatty acids), carbohydrates and micronutrients, such as various minerals (calcium, iron and zinc) and vitamins. Food of animal origin produces 18% of the total calories and 25% of the total protein produced in the world. Malnutrition, which occurs due to insufficient intake of protein of animal origin, is a constant problem in poor countries. Adding animal protein to the diet of people who do not consume enough high-quality protein could prevent the development of sarcopenia, osteoporosis and anaemia (*Colgrave et al.,* 2021). With the growth of the population whose diet also requires protein intake, livestock production will continue to grow, and animal protein will remain an important part of the population's diet (*Tilman and Clark,* 2014). Predictions are that from 2005 to 2050, meat production will increase by 57%, and milk by 48%. Therefore, livestock production will increase by 21% from 2010 to 2025 (*Kim et al.,* 2019). Of the total produced food of animal origin, cattle make up 45%, poultry 31%, and pigs 20% (*Mottet et al.,* 2017). The production of protein of animal origin will grow in the future, mostly thanks to the increased production of pork and poultry meat. Therefore, the demand for protein in feed will increase, as pigs and poultry have a greater need for protein in feed compared to ruminants (*Kim et al.,* 2019). In addition, the use of fish in the human diet provides high-value proteins, but also various necessary micronutrients, including vitamins (A, B and D), minerals (calcium, iodine, zinc, iron and selenium) and polyunsaturated n-3 fatty acids, such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). With population growth and increased consumer awareness of the health benefits of using fish in the human diet, the average world fish consumption has increased to 20 kg per year per capita. This demand for fish now far exceeds the sustainable yield from the ocean, with aquaculture supplying more than half of total fish production. However, in order to increase the production of fish from aquaculture, several challenges need to be overcome, primarily insufficient quantity of feed for fish nutrition, environmental pollution, poor water quality, fish diseases, as well as a lack of regulations regarding this branch of agriculture (*Colgrave et al.,* 2021).

In pigs, the need for protein in the diet differs according to the age and physiological state of the animal (pregnancy, lactation), and is often determined according to the weight of the animal. Daily requirements for lysine in pigs increase with growth from 4.0 g/day to 18.3 g/day when animals reach 100 kg of body weight. So far, several essential amino acids are added to pig diets, such as lysine, threonine, methionine, tryptophan, valine, arginine and isoleucine. Adding these essential amino acids to pig diets can reduce the amount of legume and animal protein required in pig nutrition (*Kim et al.,* 2019). Proteins of animal origin, such as blood cells, blood meal, blood plasma, milk powder, fish meal, meat and bone meal, poultry by-products, dried eggs and whey protein concentrate are used as feed for piglets. These feeds of animal origin have high nutrient digestibility and contain functional proteins that improve the health of weaned piglets (*Weaver et al.,* 2014).

Protein and amino acid requirements in poultry nutrition depend on their productivity. Turkeys and broilers require high levels of protein and amino acids in their diets to meet their rapid growth needs (*National Research Council,* 1994). Breed, housing (cage or floor system, stocking density), egg yield, environmental temperature and diseases affect the protein needs of laying hens and ducks (*Kim et al.,* 2019). Dietary protein requirements of poultry are often met by providing 17–22% vegetable protein feed, 1–2% animal protein feed and 0.2–0.5% synthetic amino acids (*National Research Council,* 1994). Young, fast-growing, heavy-line turkeys require 28% crude protein in their diet, so turkey meal contains more than 50% protein nutrients (soybean meal and fish meal). For feeding geese and ducks, cottonseed meal and rapeseed meal can be used as substitutes for soybean meal, while fishmeal is rarely used (*Kim et al.,* 2019).

In the past, feed for carnivorous fish was largely produced from fishmeal and fish oil derived from fish caught in the open sea. Therefore, fishmeal, as an excellent source of protein and essential nutrients for fish, is a limited natural resource and its annual production is about 5 million tons. Fish oil is also a highly sought product due to its richness in n-3 fatty acids. Over the years, aquaculture has redistributed the use of these limited resources, so today instead of fishmeal and fish oil, some plants (soybean, corn, oilseed rape and wheat flour) and by-products of animal origin (poultry meal, blood flour, feather meal and meat and bone meal) are used (*Naylor et al*., 2000). However, one of the biggest challenges today is the current restrictions placed by many countries on the use of animal by-products as a source of protein in feed. Moreover, the availability and price of plant nutrients often vary, so proteins from algae and insects are increasingly used for fish nutrition (*Colgrave et al.,* 2021).

4. Proteins of vegetable origin

Plants in human nutrition are important, because they are a source of carbohydrates, fats, proteins, fibre, as well as short-chain n-3 fatty acids. Soybeans, beans and to a lesser extent peas are the main sources of protein of vegetable origin. In the near future, soybean is likely to become a main source of plant-based protein because of its desirable processing properties (e.g. texture, taste, and appearance) and nutritional quality. Compared to other types of plants, soybean is very similar to beef and dairy products in terms of amino acid composition and protein digestibility (*Colgrave et al.,* 2021). Today, new sources of plant-based protein that can be used in human nutrition are being researched, while ensuring that consumers get all the necessary essential amino acids through their diet, because many plants lack certain essential amino acids. Additional research should include improving the quality and quantity of protein in grains (e.g. buckwheat and quinoa) and legumes (e.g. chickpeas, fava beans and lentils) that are underutilized in our diet. There will also be a need to develop new plant varieties that could accommodate different climate regions and/or soils. In addition, technological innovation will lead to the development of new products rich in plant-based proteins, such as bakery products, pasta, breakfast cereals and snacks, or substitutes for meat or dairy products (*Colgrave et al.,* 2021).

In animal nutrition, the main sources of plant protein are proteins obtained from oilseeds. Of the total oilseeds produced, soybean meal is in first place with 226 million tons (70%), followed by rapeseed meal with 39 million tons (12%) (*American Soybean Association*, 2017). Animals have a unique ability to incorporate inedible or low-value plants for humans into high-value proteins, increasing the amount of protein available for human consumption (*Mottet et al.,* 2017). Protein supplements are one of the most expensive and limiting food ingredients. Until now, soybean meal, as a by-product of soybean oil extraction, was the main source of high-quality protein for animal nutrition. Namely, 85% of the world's soybean production is annually processed into soybean cake and oil, of which approximately 97% is used as animal feed (*Kim et al*., 2019). However, due to the large number of hungry people in the world, the justification of feeding animals with soy protein, as well as the use of other oilseeds and cereals in the diet of animals that are also food for humans, is increasingly being considered. Therefore, there is an increasing need to find new nutrients and new sources of protein for animals and to replace the existing ones (*FAOSTAT*, 2016). The supply of nutrients in the future will be affected by many factors, including the availability of arable land and water, climate change, energy costs and the possibility of improved yields (*Kim et al.,* 2019). In addition, the need for protein in feed can be reduced by improving the efficiency of animal nutrition and the nutritional value of feed ingredients (*Mottet et al.,* 2017).

Although leguminous products are most often added to the meal for pigs as the main source of protein, by-products of the milling and brewing industry can also be used as protein feeds of vegetable origin (up to 30%). Anti-nutritional substances found in protein feeds, including trypsin inhibitors, allergens (such as glycinin and β-conglycinin) and flatulence-producing compounds (oligosaccharides such as raffinose), limit their use in diet for piglets. With certain processing procedures, e.g. fermentation or the use of enzymes, the anti-nutritive substances in these nutrients can be inactivated, so legumes can also be used in the diet for piglets (*Kim et al.,* 2019). Since antimicrobial growth promoters are not desirable in piglet diet, it should be formulated to be low in crude protein to reduce the incidence of diarrhoea (*Heo et al.,* 2009). In addition, decreasing the crude protein content by adding synthetic amino acids to diet for piglets can reduce faecal nitrogen excretion and ammonia emissions (*Kim et al.,* 2019).

Adding larger amounts of protein nutrients of plant origin to poultry meals is not possible due to the presence of indigestible ingredients and/or due to the presence of anti-nutritive or toxic substances (*Kim et al.,* 2019). Similar to pigs, adding synthetic amino acids to poultry feed can reduce the use of animal protein sources in these feeds, and reduce nitrogen pollution of the environment (*Bregendahl et al.,* 2008). In order to produce sufficient quantities of poultry feed in the future, it is important to predict the increase in poultry meat consumption in the coming decades. New protein feeds, such as insects, proteins from single-celled organisms and algae will be of great importance in the future as protein supplements in poultry nutrition (*Makkar*, 2017). In addition, microbial technology and biological fermentation can be used to improve the digestibility and, therefore, the use of protein supplements (*Verstraete and De Vrieze,* 2017).

Unlike pigs and poultry, ruminants meet their needs for amino acids through two different sources: proteins from feed that pass through the rumen undegraded and proteins synthesized by microorganisms in the rumen (microbial protein). These protein sources are then digested and absorbed in the lower parts of the digestive tract, where the absorbed amino acids are defined as metabolic protein. Microbial protein is an essential protein source for cattle and sheep and can provide approximately 70% of total metabolic protein requirements (*Sok et al.,* 2017). In addition, microbial protein is an excellent source of essential amino acids, and its optimal production requires the simultaneous use of protein nutrients with degradable proteins, as well as fermentable carbohydrate nutrients that provide the necessary energy for protein synthesis in the rumen (*Schwab and Broderick*, 2017). More than 60% of crude protein can be broken down in the rumen to provide ammonia for the growth of microorganisms. While a large amount of ammonia can be used by microorganisms in the rumen for protein synthesis, excess ammonia can be absorbed into the animal's bloodstream and excreted through urine and faeces (*Kim et al.,* 2019). However, ruminants have a lower utilization of nitrogen taken through feed, so in dairy cows 72%, beef cattle 78% and sheep 81% of the nitrogen taken in is excreted through faces and urine. For now, the most acceptable approach is to feed ruminants with lower protein rations to reduce nitrogen excretion. One study found that feeding dairy cows with diets containing 169 g/kg dry matter of crude protein instead of 183 g/kg of dry matter had no adverse effect on milk production, but nitrogen excretion in faeces and urine decreased by 11% (*Hynes et al.,* 2016).

Because an insufficient quantity of protein feed is being produced, researchers and the feed industry have taken various approaches to improve the supply of protein feed. Firstly, alternative protein sources, such as insect protein and algal protein, have been developed to replace conventional protein feeds for poultry, pigs and fish. Then, genetic selection has reduced the content of anti-nutritional substances (soy with lower oligosaccharide content and corn with lower phytate content) or improved the content of desirable nutrients (soy with higher methionine content, corn with higher lysine content and higher phytase activity). Furthermore, the processing and treatment of protein supplements, such as the removal of oligosaccharides or trypsin inhibitors from soy, has improved their usability. Finally, synthetic amino acids as well as enzymes are added to animal feed to improve protein digestibility and reduce the amount of added crude protein (*Kim et al.,* 2019).

5. Sources of protein from the sea: algae and seaweed

Algae can be divided into microalgae and macroalgae (seaweed). Algae have been part of the human diet for thousands of years and provide a variety of nutrients essential to human health, including vitamins, minerals, fibre and protein. Microalgae and seaweed consume carbon dioxide in their metabolism by absorbing it directly from the sea together with nitrogen and phosphorus. The importance of algae in human nutrition is reflected in the fact that their large-scale production will be possible in closed production systems or bioreactors that use recycled water and carbon dioxide produced by other industrial activities (*Caporgno and Mathys,* 2018).

The majority of algal protein production is expected to come from two freshwater algae species, the filamentous cyanobacterium *Arthrospira platensis* (spirulina) and the unicellular green alga *Chlorella*. These two algae are recognized as sources of high-value proteins, as they contain up to 70% protein in dry matter, as well as all essential amino acids (although smaller amounts of cysteine and lysine). In addition, algae are rich in minerals, such as calcium, iron and copper, and n-3 fatty acids, but they are also one of the few non-animal sources of vitamin B12 (*Caporgno and Mathys*, 2018). However, the possibilities of their use in human nutrition are limited by intense pigment and taste (*Colgrave et al.,* 2021). One of the disadvantages of algal proteins is that the proteins are often bound to carbohydrates in the cell wall, thus limiting the availability of the protein to digestive enzymes. Phenolic compounds, found in various types of algae, bind amino acids, forming insoluble compounds and reducing the digestibility of proteins. However, improved digestibility of algae proteins is possible after the application of enzymes, temperature or pressure in order to break the bonds between proteins and other compounds (*Kadam et al.,* 2013). Pigments (e.g. carotenes, chlorophylls and phycobiliproteins) and flavours of algae currently limit the amounts that can be added to many food products. As mentioned earlier, processing technologies can isolate proteins or remove unwanted colour or taste and thus allow for wider application of algal proteins (*Colgrave et al.,* 2021).

Although the nutritional value of microalgae was investigated in the fifties of the last century, recent research has established their potential as a third-generation raw material for the production of biofuels, whereby the produced biomass can be used as the main ingredient of animal feed (*Lum et al.,* 2013). Defatted microalgae contain approximately 20–45% crude protein with a desirable amino acid composition. In addition, defatted microalgae had a positive effect on protein synthesis in the liver and muscles. Defatted microalgae are not only an excellent source of protein, but are a source of n-3 polyunsaturated fatty acids (PUFA) and iron to enrich their content in meat and eggs. However, although the addition of microalgae to beef diet increased the PUFA content of beef, their addition negatively affected the taste and colour of the meat (*Kim et al.,* 2019).

6. Insects as a source of protein

Entomophagy, or the practice of using insects as food, has been part of human history for thousands of years, during which it has played an important role in some cultural and religious rituals around the world. During the past, the ancestors of *Homo sapiens* and early human communities used insects in their diet as a source of nutrients. Before humans invented tools for hunting and gathering food, insects played a significant role in human nutrition, which was confirmed by analysing the composition of coprolites – the fossilized remains of ancient human faeces (*Hardy et al.*, 2017). According to *Yi et al.* (2010), insects were part of the diet in China as early as 3200 years ago. The earliest written evidence of the use of insects in human food in Europe is described in the work of Aristotle (384–322 BC), *Historia Animalium*, in which he described how female crickets tasted best after mating due to the presence of ripe eggs. In the holy books of the Christian, Jewish and Islamic religions, there are sections related to entomophagy (*Govorushko,* 2019).

Insects have a high nutritional value, because they are rich in proteins that contain essential amino acids, and their digestibility is similar or slightly lower compared to egg or beef proteins (*van Huis,* 2013). Insects are a good source of proteins, minerals, vitamins and energy, they can cost less than animal protein, and their use can prevent many cases of malnutrition in the poor population. The advantages of raising insects for human and animal consumption are that they can provide or supplement the increasing demand for protein (*Alexander et al.,* 2017). Compared to other food sources, the advantage of growing insects are that they require less space and water, have a short life cycle and better feed conversion, are more nutritious for humans compared to many types of food, the products obtained from them can be used in diet for people and animals, they are easily transported, and as far as insect breeding is concerned, the return on invested funds is quick, the earnings are high and no extensive training is required (*Govorushko,* 2019).

Edible insects have a higher protein content than other sources of protein, such as beef, chicken, fish and soybeans (*Teffo et al.,* 2007). The nutritional value of insects can vary significantly depending on the type of insect, growth stage and feeding method. Thus, adult mealworms are an excellent source of iron, iodine, manganese, magnesium and zinc, while their larvae are rich in B group vitamins. Edible crickets are a rich source of macronutrients, proteins (about 70%), lipids (7–25%) and carbohydrates, as well as micronutrients (vitamins). Due to their nutritional value, insects are suitable as food for both humans and animals (*Imathiu*, 2020).

A large number of different species of insects (over 2000) are consumed by about 2 billion people every day in more than 100 countries. Despite the long history of their use in food in some parts of the world, insects have not found their place in the cuisine of Western civilization. In developed countries, consumers hardly accept insects as a source of protein, so by processing insects and extracting high-value protein in the form of powder, this reluctance can be overcome (*Colgrave et al.,* 2021). The acceptance of insects in human nutrition can be boosted for three reasons, namely the positive impacts on human health and environmental protection and for economic reasons. The advantage for human health is reflected in the fact that insects are a good substitute for proteins of animal origin, many types of insects have a high protein content and enough calcium, iron and zinc, and in addition, insects are already part of the diet of many peoples. The advantages for the environment are that insects release much smaller amounts of harmful greenhouse gases compared to other animals, raising insects requires far less land and water than raising livestock and insects are cold-blooded animals, so their efficiency of converting feed into protein is very high. The economic and social reasons that make the breeding of insects more desirable than the breeding of livestock are that their breeding does not require high technology and large investment, and the breeding of insects provides opportunities for both urban and rural populations (*Govorushko,* 2019).

For animal nutrition, insects that use food waste in their diet can provide a significant amount of protein for feeding fish and livestock. By the way, insects are natural feed for fish and poultry. Five main insect species have been investigated for the production of protein feeds and they are: the common housefly (*Musca domestica*), the black soldier fly (*Hermetia illucens*), the large yellow mealworm (*Tenebrio molitor*), grasshoppers (*Locusta migratoria*, *Schistocerca gregaria, Okia specesis*) and silkworm (*Bombyx mori*) (*Makkar et al.,* 2014). The use of insects as a source of protein for animal feed is considered promising and sustainable (*Allegretti et al.,* 2018).

While the benefits of entomophagy are many, one of the biggest obstacles to using insects in human and animal nutrition is food and feed safety. Eating insects carries the risk of chemical, physical and biological hazards or the occurrence of allergies. Cases of histamine poisoning have been described after eating fried insects that have a higher histidine content (*Govorushko*, 2019). Possible risks of disease occurrence after the use of insects in human and animal nutrition can be overcome by introducing hygienic practices in the entire chain of production of insects as food. Further research is needed to determine the possible presence of toxins or allergens in insects used in human and animal diets (*Colgrave et al.,* 2021). In addition, there are legal obstacles that will have to be overcome in the future in order to enable a wider application of insects in human and animal nutrition. Recently, EFSA approved the use of mealworms for human consumption, so this insect could be found in a snack, as an ingredient of certain feeds or served as a main dish (*Colgrave et al.,* 2021).

7. Single-cell protein

For more than four decades single-cell protein has been recognized as a possible protein source for livestock, especially for monogastric animals (*Taylor and Senior*, 1978). Single-cell proteins are isolated from the cells of microorganisms, as dried cells and/or as purified proteins. Single-cell proteins have a high protein content (60–82% of dry matter weight), desirable amino acid composition, low fat content, and a higher protein content than carbohydrates (*Srividya et al.,* 2013; *Bajpai,* 2017). In addition, single-cell proteins contain vitamins (e.g. thiamin, riboflavin, pyridoxine, nicotinic acid, pantothenic acid, folic acid, biotin, cyanocobalamin, ascorbic acid, β-carotene and α-tocopherol), essential amino acids, minerals, nucleic acids and lipids (*Suman et al*., 2015). So far, single-cell protein has been widely used in human food as a carrier of flavours and vitamins, in animal feeds (for pigs, poultry, cattle, fish), and in paper and lead industries (*Bratosin et al*., 2021). Although single-cell proteins can be produced by many microorganisms, including bacteria, yeasts and fungi, only a small number of organisms are used commercially. Yeasts are probably the most widely accepted and used source of single-cell protein. The most commonly used yeast species are *Candida, Hansenula, Pichia, Torulopsis* and *Saccharomyces*. In addition, microorganisms can use as a substrate for fermentation agricultural waste, such as rice straw, rice husks, manure and starch residue, converting them into high value protein (*Oshoma and Eguakun-Owie*, 2018). There are two main advantages of using waste for the production of single-cell protein, namely the conversion of cheap organic waste into a useful product and the reduction of environmental pollution. Cellulose, hemicellulose and lignin are natural wastes from wood and can be a substrate for microorganisms, but they must first be chemically (acidic hydrolysis) or enzymatically (cellulases) broken down into sugars that can be fermented by microorganisms. Agricultural waste can be an excellent substrate for the economic production of single-cell protein, resulting in a product rich in good quality protein and suitable for animal feed. After processing, single-cell protein can also be used by humans in food (*Yunus et al.,* 2015).

Currently, single-cell protein is commercially used as a feed supplement for feeding laying hens, fattening poultry, beef, pigs and fish, then as a food additive (carriers of vitamins and aromas and emulsifiers), to improve the nutritional value of food (ready-to-eat meals, soups), as cultures for fermentation (baker's, brewer's and wine yeast) and in industrial processes, as a foam stabilizer and in paper and leather processing. Single-cell protein is primarily used as a protein supplement in the diet of humans and animals and a substitute for high-value proteins of animal origin, due to its low production cost, easy production methods and high nutritional value (*Bratosin et al.,* 2021).

Various substrates can be used for the production of microorganisms, such as energy-rich raw materials (gas oil, natural gas, ethanol, methanol, *n*-alkanes and acetic acid), raw materials of plant origin (starch, sugar and cellulose), waste of different origins (sulphite waste, molasses, whey, milk and fruit waste) and carbon dioxide (*Bratosin et al.,* 2021). The choice of substrate depends on its price, availability, oxygen required for fermentation, the amount of heat produced and the possibility of cooling the fermenter, but also the costs related to post-treatment processing (*Suman et al*., 2015). Selected substrates are used for the growth of microorganisms in order to increase their mass. Fermentation is the main process responsible for single-cell protein production. The available biomass is harvested when the fermentation process is complete and the biomass is further processed by purification, cell disruption, washing and protein extraction to ensure high protein content (*John et al.,* 2011).

The nutritional and dietary values of single-cell protein depend on the microorganisms used. The amino acid composition of bacteria-derived proteins is similar to fish proteins, and yeast proteins are similar to soy proteins. Microorganisms used for single-cell protein production must not be pathogenic, must not synthesize toxins, must be fast-growing and produce a large amount of biomass, easy to handle and easily separated from the substrate (*Bratosin et al.,* 2021).

Although single-cell proteins have very desirable properties, there are limitations to their application because some microbes can produce toxic compounds, their cell wall is indigestible, and/or they have a high concentration of nucleic acids that cause certain health problems (*Kim et al.,* 2019). Single-cell protein contains up to 16% nucleic acids, which can be a problem if it is intended for human consumption, as the recommended content of nucleic acids in human nutrition is up to 2% (*Nangul and Bhatia*, 2013). Purines produced by the breakdown of nucleic acids during metabolic processes are responsible for increasing the level of uric acid in the blood, which can lead to the formation of gout and kidney stones (*Nasseri et al.,* 2011). The process of preparing a single-cell protein for human consumption also involves developing the desired aroma and taste of the product, which makes the process less profitable. In addition, single-cell protein can cause allergic reactions in some people with sensitive digestive systems. Waste materials used as a substrate for single-cell protein production can contain unknown substances that could cause other health problems (*Spalvins et al.,* 2018). In addition, single-cell proteins are deficient in sulphur-containing amino acids (methionine and cysteine), so supplementation of these amino acids is necessary. However, if attention is paid to these shortcomings and they are removed, single-cell proteins represent an excellent protein supplement for human and animal nutrition due to their nutritional value, and their use will be greater in the future.

8. Conclusion

Insufficient protein production for human and animal nutrition is already a problem. With the increase in the population in the future, the need for protein in human and animal nutrition will increase significantly. Current academic research is aimed at finding as many new sources of protein for human and animal nutrition as possible, such as algae, insects and single-cell proteins. However, finding new sources of protein will not satisfy the protein needs of humans and animals unless new ways of processing these proteins are applied to increase their digestibility and safety. In addition, new protein production technologies should enable the use of by-products from various industries in order to reduce the amount of waste and environmental pollution, and make the products cheap and affordable for everyone.

Izvori proteina u ishrani ljudi i životinja

Marija Starčević, Nataša Glamočlija, Jelena Janjić, Branislav Baltić , Snežana Bulajić, Radmila Marković i Milan Ž. Baltić

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

Ključne reči:
Proteini
Insekti
Proteini jednoćelijskih organizama
Alge

A P S T R A K T

Trenutne procene predviđaju da će zbog rasta stanovništva do 2050. godine svetu biti potrebno oko 70% više hrane nego što se trenutno proizvodi. Sa rastom stanovništva čija ishrana zahteva i unos proteina, stočarska proizvodnja će nastaviti da raste, a proteini životinjskog porekla će ostati važan deo ishrane stanovništva. Proizvodnja proteina životinjskog porekla će se u budućnosti povećati uglavnom zbog povećane proizvodnje svinjskog i živinskog mesa. Shodno tome, potražnja za proteinima u stočnoj hrani će se povećati, jer svinje i živina imaju veću potrebu za proteinima u hrani u odnosu na preživare. Stoga su potrebe i izazovi današnjice da se pronađu oni izvori proteina koji će zadovoljiti nutritivne potrebe najvećeg dela populacije i životinja, a čija će proizvodnja biti jeftinija i pristupačnija nego za izvore proteina koji su trenutno dostupni i koristi se u ishrani ljudi i životinja. Do danas se u upotrebi pojavilo nekoliko novih izvora proteina za ishranu ljudi i životinja, a njihov značaj će u budućnosti biti još veći. Insekti, proteini iz jednoćelijskih organizama i alge se sve više koriste kao alternativni proteinski dodaci. Pored toga, mikrobna tehnologija i biološka fermentacija mogu poboljšati svarljivost i, samim tim, upotrebnu vrednost proteinskih suplemenata.

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

Acknowledgements: The study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract number 451-03-47/2023-01/200143).

References

Adhikari, S., Schop, M., de Boer, I. J. M. & Huppertz, T. (2022). Protein quality in perspective: A review of protein quality metrics and their applications. *Nutrients*, 14, 947.

Aiking, H. & de Boer, J. (2020). The next protein transition. *Trends in Food Science & Technology,* 105, 515–522.

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D. & Rounsevell, M. D. (2017). Losses, inefficiencies and waste in the global food system. *Agricultural Systems*, 153, 190–200.

Allegretti, C., Talamini, E., Schmidt, V., Bogomi, P.C. & Ortega, E. (2018). Insect as feed: an energy assessment of insect meal as a sustainable protein source for the Brazilian poultry industry. *Journal of Cleaner Production,* 171, 403–412.

American Soybean Association (2017). Soy Stats 2017: A Reference Guide to Important Soybean Facts and Figures. St. Louis, MO: Am. Soybean Assoc. 36 pp.

Bajpai, P. (2017). Singe Cell Protein Production from Lignocellulosic Biomass. Singapore, Springer.

Boye, J., Wijesinha-Bettoni, R. & Burlingame, B. (2012). Protein quality evaluation twenty years after the introduction of the protein digestibility corrected amino acid score method. *British Journal of Nutrition*, 108, S183–S211.

Bratosin, B. C., Darjan, S. & Vodnar, D. C. (2021). Single cell protein: A potential substitute in human and animal nutrition. *Sustainability*, 13, 9284.

Bregendahl, K., Roberts, S. A., Kerr, B. & Hoehler D. (2008). Ideal ratios of isoleucine, methionine, methionine plus cystine, threonine, tryptophan, and valine relative to lysine for White Leghorn-type laying hens of twenty-eight to thirty-four weeks of age. *Poultry Science,* 87, 744–758.

Caporgno, M. P. & Mathys, A. (2018). Trends in microalgae incorporation into innovative food products with potential health benefits. *Frontiers in Nutrition*, 5, 58.

Colgrave, M. L., Dominik, S., Tobin, A.B., Stockmann, R., Simon, C., Howitt, C. A., Belobrajdic, D. P., Paull, C. & Vanhercke, T. (2021). Perspectives on future protein production. *Journal of Agricultural and Food Chemistry*, 69, 15076–15083.

Cordain, L., Eaton, S. B., Brand Miller, J., Mann, N. & Hill, K. (2002). The paradoxical nature of hunter-gatherer diets: meat-based, yet nonatherogenic. *European Journal of Clinical Nutrition*, 56, S1–S11.

Day, L., Cakebread, J.A. & Loveday, S.M. (2022). Food proteins from animals and plants: Differences in the nutritional and functional properties. *Trends in Food Science & Technology*, 119, 428–442.

EFSA, (2012). Panel on Dietetic Products; Nutrition and Allergies (NDA). Scientific Opinion on Dietary Reference Values for protein, 10, 2557.

FAO, (1999). Women: Users, Preservers and Managers of Agrobiodiversity; Rome, Italy.

FAO, (2013). Dietary Protein Quality Evaluation in Human Nutrition: Report of an FAO Expert Consultation; FAO: Auckland, New Zealand.

FAOSTAT, (2016). Food and Agriculture Data 2016. Rome: Food Agric. Organ.

Govorushko, S. (2019). Global status of insects as food and feed source: A review. *Trends in Food Science & Technology,* 91, 436–445.

Hardy, K., Radini, A., Buckley, S., Blasco, R., Copeland, L., Burjachs, F., Girbal, J., Yll, R., Carbonell, E. & Bermúdez de Castro, J. M. (2017). Diet and environment 1.2 million years ago revealed through analysis of dental calculus from Europe's oldest hominin at Sima del Elefante, Spain. *Naturwissenschaften,* 104 (1–2), 2.

Heo, J. M., Kim, J. C., Hansen, C. F., Mullan, B. P., Hampson, D. J. & Pluske, J. R. (2008). Effects of feeding low protein diets to piglets on plasma urea nitrogen, faecal ammonia nitrogen, the incidence of diarrhoea and performance after weaning. *Archives of Animal Nutrition,* 62, 343–358.

Hynes, D. N., Stergiadis, S., Gordon, A. & Yan, T. (2016). Effects of nitrogen levels in concentrate supplements on animal performance and nitrogen utilization of lactating dairy cows fed fresh-cut perennial grass. *Journal of Dairy Science,* 99, 8111–8120.

Imathiu, S. (2020). Benefits and food safety concerns associated with consumption of edible insects. *NFS Journal*, 18, 1–11.

John, R. P., Anisha, G. S., Nampoothiri, K. M. & Pandey, A. (2011). Micro and macroalgal biomass: A renewable source for bioethanol. *Bioresource Technology,* 102, 186–193.

Kadam, S. U., Tiwari, B. K. & O'Donnell, C. P. (2013). Application of novel extraction technologies for bioactives from marine algae. *Journal of Agricultural and Food Chemistry,* 61, 4667–4675.

Kim, W., Wang, Y. & Selomulya, C. (2020). Dairy and plant proteins as natural food emulsifiers. *Trends in Food Science & Technology*, 105, 261–272.

Larsen, C. S. (2003). Animal source foods and human health during evolution. *The Journal of Nutrition*, 133 (11), 3893S–3897S.

Liu, F., Li, M., Wang, Q., Yan, J., Han, S, Ma, C., Ma, P., Liu, X. & McClements D. J. (2022). Future foods: Alternative proteins, food architecture, sustainable packaging, and precision nutrition. *Critical Reviews in Food Science and Nutrition*, 25, 1–22.

Lum, K. K., Kim, J. G. & Lei, X. G. (2013). Dual potential of microalgae as a sustainable biofuel feedstock and animal feed. *Journal of Animal Science and Biotechnology,* 4, 53.

Makkar, H. P. S. (2017). Review: feed demand landscape and implications of food-not-feed strategy for food security and climate change. *Animal*, 12 (8), 1744–1754.

Makkar, H. P. S., Tran, G., Heuze, V. & Ankers P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, 97,1–33.

McHenry, H. M. & Coffing, K. (2000). *Australopithecus* to *Homo*: transformations in body and mind. *The Annual Review of Anthropology*, 29, 125–146.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C. & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14, 1–8.

Nangul, A. & Bhatia, R. (2013). Microorganisms: A marvellous source of single cell proteins. *Journal of Microbiology, Biotechnology and Food Sciences*, 3, 15–18.

Nasseri, A. T., Rasoul-Amini, S., Morowvat, M. H. & Younes, G. (2011). Single cell protein: Production and process. *American Journal of Food Technology*, 6 (2), 2, 103–116.

National Research Council (1994). Nutrient Requirements of Poultry. National Academy Press, Washington DC, 9th rev. ed.

Naylor, R., Goldburg, R., Primavera, J., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, 405, 1017–1024.

Oshoma, C. E. & Eguakun-Owie, S. O. (2018). Conversion of food waste to single cell protein using *Aspergillus niger*. *Journal of Applied Sciences and Environmental Management*, 22 (3), 350–355.

Rouhani, M. H., Haghighatdoost, F., Surkan, P. J. & Azadbakht, L. (2016). Associations between dietary energy density and obesity: A systematic review and meta-analysis of observational studies. *Nutrition*, 32, 1037–1047.

Schwab, C. G. & Broderick, G. A. (2017). A 100-year review: protein and amino acid nutrition in dairy cows. *Journal of Dairy Science,* 100, 10094–10112.

Shipman, P. (1986). Scavenging or hunting in early hominids: theoretical framework and tests. *American Anthropologist*, 88, 27–43.

Spalvins, K., Zihare, L. & Blumberga, D. (2018). Single cell protein production from waste biomass: Comparison of various industrial by-products. *Energy Procedia*, 147, 409–418.

Srividya, A. R., Vishnuvarthan, V. J., Murugappan, M. & Dahake, P. G. (2013). Single cell protein — a review. *International Journal of Pharmaceutical Research*, 2, 472–485.

Suman, G., Nupur, M., Anuradha, S. & Pradeep B. (2015). Single cell protein production: A review. *International Journal of Current Microbiology and Applied Sciences*, 4, 251–262.

Taylor I. J., Senior P. J. (1978). Single cell proteins: a new source of animal feeds. *Endeavour*, 2, 31–34.

Teffo, L. S., Toms, R. B. & Eloff, J. N. (2007). Preliminary data on the nutritional composition of the edible stink-bug, *Encosternum delegorguei Spinola*, consumed in Limpopo province, South Africa. *South African Journal of Science*, 103, 434–436.

Tilman, D. & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, 515, 518–522.

van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *The Annual Review of Entomology*, 58, 563–583.

Verstraete, W. & De Vrieze, J. (2017). Microbial technology with major potentials for the urgent environmental needs of the next decades. *Microbial Biotechnology*, 10, 988–994.

Weaver, A. C., Campbell, J. M., Crenshaw, J. D., Polo, J., Kim, S. W. (2014). Efficacy of dietary spray dried plasma protein to mitigate the negative effects on performance of pigs fed diets with corn naturally contaminated with multiple mycotoxins. *Journal of Animal Science,* 92, 3878–3886.

WHO (2020). The State of Food Security and Nutrition in the World 2020: Transforming Food Systems for Affordable Healthy Diets; Food and Agriculture Organization: Rome, Italy.

Wu, G. (2009). Amino acids: Metabolism, functions, and nutrition. *Amino Acids*, 37, 1–17.

Yi, C., He, Q., Wang, L. & Kuang, R. (2010). The utilization of insect-resources in Chinese rural area. *Journal of Agricultural Science*, 2, 146–154.

Yunus, F.-u.-N., Nadeem, M. & Rashid, F. (2015). Single-cell protein production through microbial conversion of lignocellulosic residue (wheat bran) for animal feed. *The Journal of the Institute of Brewing*, 121, 553–557.

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

UDK: 637.523.058
ID: 133281289
https://doi.org/10.18485/meattech.2023.64.3.4

Review paper

Different approaches in reformulation of dry fermented sausages

Stefan Simunović[1], Tamara Gerić[1], Tatjana Baltić[1], Ivana Branković Lazić[1], Milan Milijašević[1], Srđan Stefanović[1] and Sara Z. Simunović[1]*

[1] *Institute of Meat Hygiene and Technology, Kaćanskog 13, 11000 Belgrade, Serbia*

A R T I C L E I N F O

Keywords:
Fermented sausage
Low-fat
Nitrite-free
Fat reduction
Nitrite reduced

A B S T R A C T

Salting is considered to be one of the oldest food preservation techniques. In the past, salt that was used in meat product formulations always contained different types of impurities, among which were sodium nitrite and potassium nitrite. Today, nitrite salts are considered to be one of the most important additives in processed meat production. Due to their negative impact on human health, however, the industry has a challenge to find suitable ways to reduce nitrite content in meat products or to remove nitrites altogether from meat product formulations. Another challenge facing the meat industry is the formulation of low-fat products or products containing vegetable oils, which have more favourable n-3/n-6 fatty acid ratios than animal fats. Next, since excessive intake of sodium chloride was found to have negative effects on human health, the industry has to find a way to reduce the amount of this salt in meat products or to replace sodium chloride with different salts in order to meet consumer demands. In this paper, we review different approaches to reducing nitrites, fatty tissue and sodium chloride in dry fermented sausages.

1. Introduction

Fermented sausage production originated around the Mediterranean, where ancient Egyptians and Greeks stuffed salted meat and fat into casings of slaughtered animals (*Zanardi & Novelli*, 2021). The Romans inherited these production methods, but they also introduced the use of spices, which led to fermented sausages becoming a group of products with very differentiated flavours. The popularity of fermented sausages can be attributed to their high nutritional value and long shelf life, which were especially important in the past. Despite technological development in the 20th century, methods for producing fermented sausages have not changed much. Generally, they are produced from meat, fatty tissue, salt and spices. Meat and fatty tissue are cut into small cubes, to which salt and spices are added. The mixture is stuffed into casings and subjected to fermentation and drying, and sometimes smoking.

The amount of fatty tissue used in sausage production depends on the traditional formulation of each specific type of sausage. In addition, cutting methods for both meat and fatty tissue have an impact on the sausage's specific technological and sensory parameters, especially on drying kinetics and taste. Fatty tissue has an great influence on the flavour and texture of sausages. Fat also acts as a medium for the dissolution of liposoluble substances, like vitamins and aromatic compounds. From the human health point of view, fat is very important as it provides a high amount of energy, and it is also good source of essential fatty acids. However, the modern human diet often involves excessive consumption of fat. That is why, in the last few decades, many health initiatives from food companies have been directed towards the reduction of fat content in their products or replacement of fats high in saturated fatty acids with those rich in unsaturated fatty acids (*Rajic et al.*, 2022).

Corresponding author: Simunovic Stefan: *stefan.simunovic@inmes.rs*

Paper received November 16th 2023. Paper accepted December 13th 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

According to the World Health Organisation (WHO), consumption of saturated fatty acids, which occur in large amounts in animal fat, should not exceed 10% of daily total energy consumption (*WHO*, 2023). Excessive fat intake leads to a number of cardiovascular diseases, like elevated blood pressure, coronary heart disease, obesity and others (*WHO*, 2013).

Salting is considered to be one of the oldest food preservation techniques. The first written evidence of salted food trading dates back to the 12th century BCE, when salted fish was sold in the Eastern Mediterranean (*Binkerd & Kolari*, 1975). In the 9th century, salting, together with smoking of meat, was already considered to be an old practice (*Binkerd & Kolari*, 1975). Back then, the origin of salt consumed in a specific region was determined by its natural availability. Hence, in the Mediterranean area, salt usually originated from the sea, while in regions distant from the sea, salt was obtained from minerals that are naturally rich in sodium chloride. Technological procedures at that time were not advanced enough to ensure production of high purity sodium chloride. Hence, the salt that was used in the past contained different types of impurities, among which was potassium nitrite.

Nitrite salts are one of the most commonly used additives in processed meat production. These salts have positive effects on numerous quality characteristics of meat products. The most important effect of nitrites is development of the characteristic bright pink colour of cured meat. In addition, nitrites act as strong antioxidants by slowing down fatty acid oxidation, which is the main reason for the development of rancidity in processed meat. Some studies also point out the great importance of nitrites in the flavour development of meat products (*Simunovic et al.*, 2023) and in antimicrobial effects against specific types of bacteria (*Christiansen et al.*, 1973). Despite the advantages of using nitrite with respect to many quality parameters, the International Agency for Research on Cancer (IARC) classified nitrites in group 2A as probably cancerogenic substances. More precisely, it is believed that changes to which nitrites are subjected during production of meat products can lead to the formation of carcinogenic nitrosamines (*Simunovic et al.*, 2022a). In recent years, consumers have become more open to concept of "clean label" food, due to the increase in health concerns regarding processed food.

The aim of this manuscript was to summarize achievements regarding strategies for the reformulation of dry fermented sausages. These include: i) nitrite reduction or use of nitrite replacers; ii) fatty tissue reduction or replacement with vegetable oils and; iii) sodium chloride reduction or replacement, or application of saltiness-enhancing compounds.

2. Nitrites

In 1925, the United States Department of Agriculture permitted the use of sodium nitrite in the production of processed meats (*Binkerd & Kolari*, 1975). Levels of nitrites that can be added to meat products remained more or less the same to this day. Back then, sodium nitrite could be added up to 200 mg/kg of the product. Today, the European Regulation on food additives No 1333/2008 prescribes limits for the use of sodium or potassium nitrite that depend on the type of product, but generally range from 100 to 175 mg/kg of the product *(EC, 2008)*. These limits are the same in Serbia, as in 2018, the local regulation on food additives was harmonised with the European law *(Official Gazette of the Republic of Serbia, 2018)*.

As fermented sausages are usually low pH and low water activity (a_w) products, they are considered to be an undesirable environment for the growth of many pathogenic bacteria. It seems that the main problem in obtaining a long shelf life in traditional dry fermented sausages is lipid oxidation, i.e., oxidation of fatty acids that results in development of a rancid flavour. It is believed that this is the result of the formation of compounds such as aldehydes, ketones, alcohols, esters and others. When oxygen is present, it is only possible to slow down oxidation of fatty acids, but not to stop the process. This is where nitrites play a crucial role, by biding with haem that acts as a catalyst for lipid oxidation (*Karwowska et al.*, 2019).

Besides of their irreplaceable effect on the colour of cured meat products, some justification for the use of nitrites in processed meat production is found in their antimicrobial activity. However, some studies have questioned whether the use of nitrites in some types of meat products is justified regarding the control of botulinum toxin production. In the study of *Hospital et al.* (2016), spores of *Clostridium botulinum* were inoculated into the meat batter of *fuet*, a traditional Spanish fermented sausage, but *C. botulinum* was not capable of surviving the low pH and a_w found in this specific study's conditions. On the other hand, in the case of dry meat products, the use of nitrites has been banned in the production of traditional Parma ham for more than 30 years. During that period, there have been no cases of botulism connected with Parma ham, while at the same time, the characteristic red colour of the product is maintained thanks to the exchange of ions in the porphyrin ring of myoglobin (*Honikel*, 2008).

There have been numerous attempts to reduce the use of nitrites in meat products using a few different approaches. The first approach includes direct reduction of the nitrite level in product formulation, while still taking care that nitrite salts are added in amounts that are sufficient to ensure their positive effects on product quality. The second approach is by application of various compounds that act as nitrite alternatives. Since nitrites have multiple effects on a number of quality traits in meat products, separate compounds are usually used for colour enhancement, flavour development, stabilisation of lipids and antimicrobial activity. The third approach is the application of nitrate-rich ingredients. The main idea of this approach is that the activity of bacteria present in the meat batter of fermented sausages reduces nitrate to nitrite. Thus, there is indirect production of nitrite which can exert its influence on product quality.

2.1. Nitrite reduction

In a recent study, *Simunovic et al.* (2022a) produced traditionally fermented *kulen* sausage with 50% nitrite reduction and without nitrite. The goal of the study was to evaluate the influence of sodium nitrite on various quality parameters of the product. *Kulen* is traditionally produced using high levels of red paprika powder, which has an important influence on the sausage colour. The study revealed that colour parameters remained the same, regardless of the level of nitrite used in *kulen* formulation. With respect to oxidative stability, nitrite proved to be powerful antioxidant, as *kulen* produced without sodium nitrite had significantly higher thiobarbituric acid reactive substance (TBARS) levels, which were used as a measure of the development of secondary lipid oxidation products (*Simunovic et al.*, 2023). On the other hand, TBARS levels were similar when the sodium nitrite content in *kulen* formulation was reduced from 110 mg/kg to 55 mg/kg. Since fatty acids can be oxidised, it is very important to determine levels of free fatty acids. Levels of free fatty acids were the highest in sausages formulated without nitrites, but similar between sausages formulated with 110 mg/kg or 55 mg/kg of sodium nitrite, which is in accordance with the levels of TBARS. The study of *Simunovic et al.* (2022a) revealed that oral processing parameters differed, depending on the level of nitrite. More precisely, the consumption time for one bite(s) and the number of chewing strokes were significantly lower in sausages formulated without nitrites. These results are consistent with the results obtained by texture profile analysis, by which it was found that values of hardness, gumminess and chewiness of nitrite-free *kulen* were significantly lower than those of nitrite-formulated sausages. The cohesiveness of nitrite-free sausages was numerically lower than for nitrite-formulated *kulen*, but was not statistically significantly different. *Simunovic et al.* (2023) showed that sensory panel scores for aroma, taste, consistency and sensory acceptability of nitrite-free *kulen* were significantly lower than those of *kulen* formulated with sodium nitrite, regardless of concentration. In general, the results of these two studies showed there is no negative effect from reducing sodium nitrite in *kulen* from 110 mg/kg to 55 mg/kg, according to all analysed quality parameters. On the other hand, complete removal of nitrite from the formulation resulted in reduced oxidative stability, different texture and lower sensory acceptability of *kulen* compared with nitrite-formulated *kulen*.

2.2. Nitrate alternatives

In fermented sausages, the main idea of utilising vegetables that are rich in nitrates is their conversion to nitrites during sausage ripening. Since an important effect of nitrites is the formation of a characteristic pink, cured meat colour, most of the studies regarding nitrite substitutes focused in the first place on colour. *Ozaki et al.* (2021a) evaluated the possibility of using beetroot and radish powders as nitrite alternatives. The idea of using beetroot and radish lies in their high levels of nitrates, which according to authors are around 16,000 and 14,000 mg/kg in dry powder form. Beetroot and radish powders were separately added to fermented sausages at concentrations of 0.5% and 1%. The most promising results in terms of product colour were obtained using 0.5% radish powder. The study showed that during drying of sausage with added beetroot and radish powders, nitrite was formed after seven days. At the end of processing, sausages formulated without nitrites but added beetroot and radish powders, regardless of concentration, had significantly lower TBARS values, indicating less oxidative stability, than nitrite-formulated sausages. However, at the end of the storage period that lasted for 60 days, TBARS values of all batches were similar with the exception of the control no. 2 that was produced without nitrites, beetroot or radish powder. *Ozaki et al.* (2021a) evaluated nitrite replacement with a combination of radish powder and oregano essential oil in cooked fermented sausages. They produced two combinations, one that contained 0.5% radish powder and 100 mg/kg of oregano essential oil, and a second that was formulated with 1% radish powder and 100 mg/kg of oregano essential oil. Sensory analysis showed no difference between control sausages and those formulated with radish powder and oregano essential oil. In addition, sausages produced with the combination of 1% radish powder and 100 mg/kg of oregano essential oil showed similar TBARS values as the control that was formulated with 150 mg/kg of sodium nitrite. Similarly to their previous study (*Ozaki et al*., 2021a), nitrite was formed after eight days of drying, probably as a result of nitrate reduction to nitrite (*Ozaki et al.*, 2021b).

Sucu & Turp (2018) added beetroot powder into the traditional Turkish fermented sausage, *sucuk.* Four batches were made in total. The first was produced as a control and contained 150 mg/kg of sodium nitrite, the second was produced using the combination of 100 mg/kg of sodium nitrite and 0.12% beetroot powder, the third was formulated using 50 mg/kg of sodium nitrite and 0.24% beetroot powder, while the fourth contained only 0.35% beetroot powder. Residual nitrite content was similar during the entirety of the ripening, regardless of the initial nitrite levels in sausage formulation (*Sucu & Turp*, 2018). On the other hand, nitrite addition showed a significant effect on lactic acid bacteria, as the highest number of these bacteria was found in nitrite-free sausages, i.e., sausages formulated with the addition of 0.35% beetroot powder. In terms of colour, all batches of *sucuk* produced with beetroot powder had a significantly higher a^* value, while neither nitrite reduction nor beetroot application effected changes in L^* or b^* values. From the consumer point of view, beetroot use in the sausages did not compromise the overall acceptability of *sucuk,* since all analysed batches had similar scores for outside appearance, inside appearance, outside colour, inside colour, texture and overall acceptability (*Sucu & Turp*, 2018).

3. Fat

In the production of pork fermented sausages, firm fatty tissue, which is naturally located on M. *longissimus dorsi*, is used. Firm fatty tissue has higher levels of saturated fatty acids and consequently a higher melting point than other animal fats. Because of this, cutting and achieving the desired granulation of fat in the meat batter is easier. Granulation and the distribution of fatty tissue in the sausage affects drying kinetics of the product (*Lorenzo & Franco*, 2012).

In the study of *Simunovic et al.* (2022b), traditional Serbian tea sausage was produced with three different levels of pork fatty tissue. The first batch was used as a control and contained 25% pork firm fatty tissue. The second batch contained around 17.5% of this tissue, while the third batch was produced using 10% fat. At the beginning of production, sausage formulated with only 10% fat had a significantly higher moisture content than other sausage types, as was expected, since meat contains more moisture than does fatty tissue. However, at the end of drying, more precisely after 35 days of ripening, sausage formulated with 10% fatty tissue had the lowest moisture content among the sausage types. These results indicate the great importance of fat level on the drying kinetics of fermented sausages. The higher level of fat used in the tea sausage was found to slow down the ripening process, which helps in achieving the characteristic speed of drying. *Simunovic et al.* (2022b) indicated that fat level does not affect colour parameters of the sausages, as had been indicated by other authors. This disagreement is because in most of the studies in the past, the colour of fat on the sausage cross section was not independently measured (*Lorenzo & Franco*, 2012). In terms of texture, *Simunovic et al.* (2022b) showed that by decreasing the level of fat in the sausage formulation, the sausage became harder, as measured using a texture analyser. Similarly, values of chewiness and gumminess increased with the increasing level of meat in the formulation. The numbers of total viable bacteria and lactic acid bacteria were similar in all analysed batches of tea sausage. TBARS value, which was used as a measure of the level of lipid oxidation, was not affected by fat reduction. On the other hand, sensory parameters, which were evaluated by sensory panel, were significantly different among the sausage types. The reduced-fat tea sausage was assessed by the method of oral processing, which is relatively new in sensory analysis. The results showed significant differences among the batches in terms of values obtained for consumption time of one bite(s), chewing rate (chew/s), eating rate (g/s) and fat intake rate (fat/s). Sausages produced with 10% fatty tissue obtained significantly lower scores than the other sausage types for overall acceptability after both 28 and 35 days of ripening. On the other hand, sausages produced with 10% and with 17.5% fat had similar values for overall acceptability after 28 days of ripening. The results showed that if drying the 17.5% fat sausages continued until 35 days, overall acceptability scores significantly decreased.

Lorenzo & Franco (2012) evaluated fat's effect on various quality properties of dry foal sausage. In total, three batches were made, each containing different levels of firm fatty tissue. The first was formulated with 20%, the second with 10% and the third with 5% pork back fat. In terms of bacterial counts, lactic acid bacteria, *Micrococcaceae* and total viable count, fat reduction showed no significant effect. However, sausages formulated with the lowest level of fat had significantly higher pH than the other sausages. This is in accordance with the results of *Simunovic et al.* (2022b), who reported that with a decreasing content of fatty tissue in tea sausage formulation, the pH increased. *Lorenzo & Franco* (2012) conducted a sensory study in which thirteen sensory traits of reduced fat foal sausages were assessed. Sausages formulated with 5% pork fatty tissue had significantly lower scores for juiciness, fat distribution and fat/lean ratio than higher fat sausages. On the other hand, scores for hardness, taste intensity, black pepper odour and cohesiveness were higher for low-fat sausage. With regard to texture, the results of *Lorenzo & Franco* (2012) were in accordance with those later reported by *Simunovic et al.* (2022b), who found that reducing fat in fermented sausage results in increasing hardness.

The second approach in formulating low-fat products is to replace pork fat with various types of vegetable oils (*Bolumar et al*., 2015; *Stajić et al.*, 2018). Since oils are mostly liquid at the room temperature, it is crucial to stabilize them. One of the most common ways to do that is to form oleogels (*Zampouni et al.*, 2022). *Stajić et al.* (2018) added flaxseed oil into the formulation of fermented sausages. Sausages enriched with flaxseed oil contained a more favourable n-3/n-6 fatty acid ratio. However, sensory scores for colour, odour, aroma, taste, texture and overall acceptability were significantly lower in sausages enriched with flaxseed oil than those scores for control sausages. Importantly, encapsulation of oil resulted in significantly higher (more acceptable) sensory scores in comparison with scores obtained for sausages in which the liquid form of flaxseed oil was added (*Stajić et al.*, 2018). This finding supported *Bolumar et al.* (2015), as those authors reported that sausages enriched with olive oil were unable to keep oil within the meat batter.

4. Salt

Salt is an essential part of the human diet, as it is necessary for maintenance of normal functions of the human body. On the other hand, if consumed in excessive amounts, salt is dangerous to human health. High intake of salt can lead to various health conditions, such as high blood pressure, different types of cardiovascular diseases, cancer, obesity and osteoporosis (*WHO*, 2023). According to WHO (*WHO*, 2023), the recommended daily adult intake

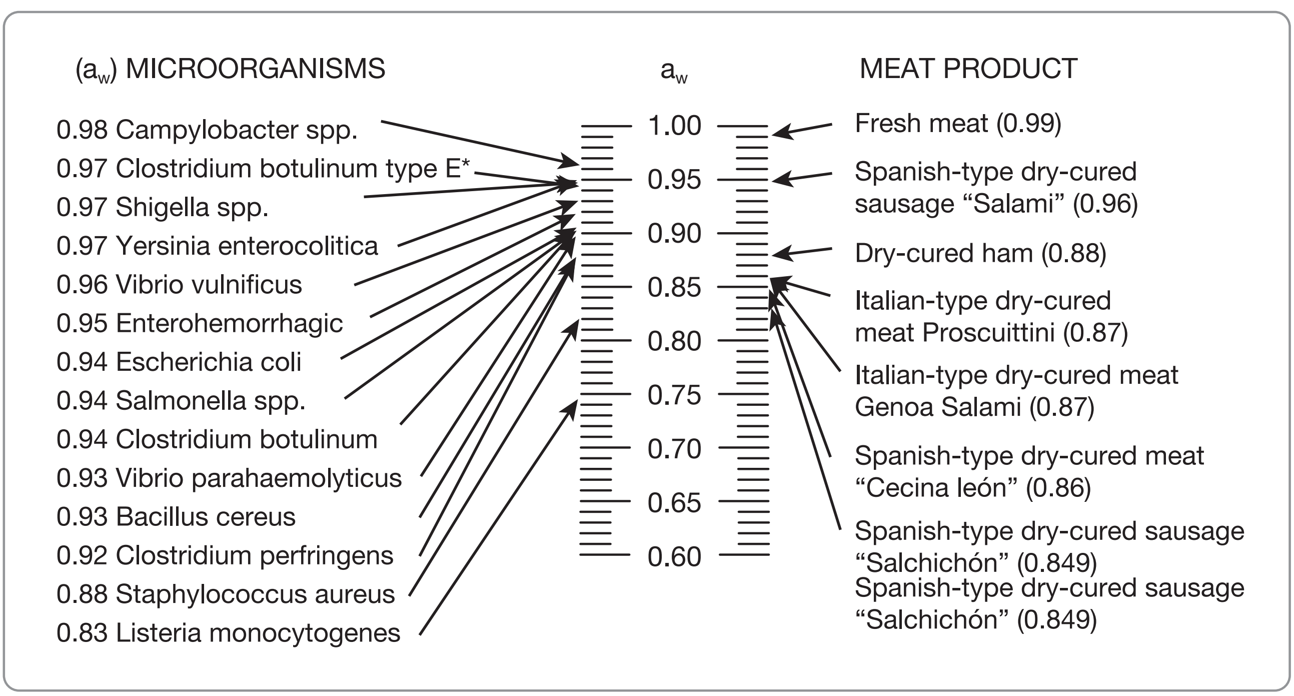

Figure 1. Minimum a_w values for growth of different bacteria and a_w values of popular meat products (*Grau et al.*, 2014).

of salt (measured as sodium equivalent) is less than less than 2 g of sodium/day; this corresponds to less than 5 g of sodium nitrite/day.

In recent decades, there have been numerous attempts to formulate foods with lower sodium levels. These include different approaches, among which two were the most common. The first is reducing sodium chloride in product formulations, while the second is replacing sodium chloride with other types of salt. In addition, a recent study has used saltiness-enhancing peptides in low-sodium meat products (*Chen et al*., 2023). In the production of dry fermented sausages, salt is of great importance for drying and maintaining low a_w. Figure 1 presents the lowest a_w values at which the specified bacteria can grow and typical a_w values of popular meat products.

Şimşek *et al.* (2023) partly replaced sodium chloride in *sucuk* with potassium chloride, magnesium chloride and calcium chloride, and they reported the most promising alternative was the combination of 50% sodium chloride, 30% potassium chloride and 20% magnesium chloride. Generally, potassium chloride causes a bitter taste to develop, which is why it is crucial to determine the extent to which this no-sodium salt can be added to a meat product formulation but not affect consumer acceptability.

Različiti pristupi u optimizaciji procesa proizvodnje fermentisanih kobasica

Stefan Simunović, Tamara Gerić, Tatjana Baltić, Ivana Branković Lazić, Milan Milijašević, Srđan Stefanović i Sara Z. Simunović

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

Ključne reči:
Fermentisane kobasice
Nitriti
Čvrsto masno tkivo
Smanjenje sadržaja masti

A P S T R A K T

Soljenje se smatra jednom od najstarijih tehnika konzervisanja. U prošlosti, so koja se koristila u proizvodnji proizvoda od mesa sadržala je različite vrste nečistoća, od kojih su neke bili natrijum i kalijum nitrit. Danas se nitritne soli smatraju jednim od najvažnijih aditiva u proizvodnji proizvoda od mesa. Zbog njihovog negativnog uticaja na zdravlje ljudi, industrija ima izazov da pronađe odgovarajući način da smanji sadržaj nitrita ili pak da potpuno prestane sa njihovom upotrebom Drugi izazov sa kojim se suočava industrija mesa je formulisanje proizvoda sa niskim sadržajem masti ili proizvoda sa dodatim biljnim uljima koja imaju povoljniji odnos n-3/n-6 masnih kiselina. Dalje, pošto je utvrđeno da prekomereni unos natrijum-hlorida negativno utiče na zdravlje ljudi, industrija se suočava sa potražnjom proizvoda sa smanjenim sadržajem natrijum-hlorida i proizvodima u kojima se koriste zamene za natrijum-hlorid. U ovom radu dajemo pregled različitih pristupa u smanjenju nitrita, masnog tkiva i natrijum-hlorida u proizvodnji suvih fermentisanih kobasica.

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

Funding: The study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract number 451-03-47/2023-01/200143) and Contract number — Grant No. 451-03-47/2023-01/200050 from 03.02.2023.

References

Binkerd, E. F., & Kolari, O. E. (1975). The history and use of nitrate and nitrite in the curing of meat. *Food and Cosmetics Toxicology,* 13 (6), 655–661.

Bolumar, T., Toepfl, S., & Heinz, V. (2015). Fat Reduction and Replacement in Dry-Cured Fermented Sausage by Using High Pressure Processing Meat as Fat Replacer and Olive Oil. *Polish Journal of Food and Nutrition Sciences,* 65 (3), 175–182.

Chen, R., Liu, X.-C., Xiang, J., Sun, W., & Tomasevic, I. (2023). Prospects and challenges for the application of salty and saltiness-enhancing peptides in low-sodium meat products. *Meat Science*, 204, 109261.

Christiansen, L. N., Johnston, R. W., Kautter, D. A., Howard, J. W., & Aunan, W. J. (1973). Effect of nitrite and nitrate on toxin production by *Clostridium botulinum* and on nitrosamine formation in perishable canned comminuted cured meat. *Applaied Microbiology,* 25 (3), 357–362.

European Commission (EC) (2008). Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives, http://data.europa.eu/eli/reg/2008/1333/oj

Grau, R., Andres, A., & Barat, J. M. (2014). Principles of Drying *Handbook of Fermented Meat and Poultry* (pp. 31–38).

Honikel, K. O. (2008). The use and control of nitrate and nitrite for the processing of meat products. *Meat Science,* 78 (1), 68–76.

Hospital, X. F., Hierro, E., Stringer, S., & Fernández, M. (2016). A study on the toxigenesis by *Clostridium botulinum* in nitrate and nitrite-reduced dry fermented sausages. *International Journal of Food Microbiology,* 218, 66–70.

Karwowska, M., Kononiuk, A., & Wójciak, K. M. (2019). Impact of Sodium Nitrite Reduction on Lipid Oxidation and Antioxidant Properties of Cooked Meat Products. *Antioxidants (Basel),* 9 (1).

Lorenzo, J. M., & Franco, D. (2012). Fat effect on physico-chemical, microbial and textural changes through the manufactured of dry-cured foal sausage lipolysis, proteolysis and sensory properties. *Meat Science,* 92 (4), 704–714.

Official Gazette of the Republic of Serbia (2018). Regulation on food additives, 53/2018.

Ozaki, M. M., Munekata, P. E. S., Jacinto-Valderrama, R. A., Efraim, P., Pateiro, M., Lorenzo, J. M., & Pollonio, M. A. R. (2021a). Beetroot and radish powders as natural nitrite source for fermented dry sausages. *Meat Science,* 171, 108275.

Ozaki, M. M., Santos, M. D., Ribeiro, W. O., Azambuja Ferreira, N. C., Picone, C. S. F., Domínguez, R., Lorenzo, J. M. & Pollonio, M. A. R. (2021b). Radish powder and oregano essential oil as nitrite substitutes in fermented cooked sausages. *Food Research International,* 140, 109855.

Rajic, S., Đorđević, V., Tomasevic, I., & Djekic, I. (2022). The role of food systems in achieving the sustainable development goals: Environmental perspective. *Business Strategy and the Environment,* 31 (3), 988–1001.

Şimşek, D., Yılmaz Oral, Z. F., Jaberi, R., Kaya, M., & Kaban, G. (2023). Partial Replacement of NaCl by KCl, $MgCl_2$ and $CaCl_2$ Chloride Salts in the Production of Sucuk: Effects on Volatile Compounds, Lipid Oxidation, Microbiological and Sensory Properties. *Foods,* 12 (19). Retrieved from doi:10.3390/foods12193525

Simunovic, S., Đorđević, V. Ž., Lakićević, B., Djekic, I., Lorenzo, J. M., Barba, F. J., & Tomasevic, I. (2022a). Digital Evaluation of Nitrite-Reduced "Kulen" Fermented Sausage Quality. *Journal of Food Quality,* 2022, 2480746.

Simunovic, S., Đorđević, V. Ž., Rašeta, M., Lukić, M., Lorenzo, J. M., Djekic, I., & Tomašević, I. (2022). Reformulation of Traditional Fermented Tea Sausage Utilizing Novel (Digital) Methods of Analysis. *Foods,* 11 (8), 1090.

Simunovic, S., Đorđević, V., Simunović, S. Z., Franco, D., Stajic, S., & Tomaševic, I. (2023). Sensory quality, oxidative stability, textural and fatty acid profile of nitrite-reduced kulen fermented sausage during ripening. *Meat Technology,* 64 (2), 212–217.

Stajić, S., Stanišić, N., Lević, S., Tomović, V., Lilić, S., Vranić, D., Jokanović, M., & Živković, D. (2018). Physico-Chemical Characteristics and Sensory Quality of Dry Fermented Sausages with Flaxseed Oil Preparations. *Polish Journal of Food and Nutrition Sciences,* 68 (4), 367–375.

Sucu, C., & Turp, G. Y. (2018). The investigation of the use of beetroot powder in Turkish fermented beef sausage (sucuk) as nitrite alternative. *Meat Science,* 140, 158–166.

World Health Organisation (WHO) (2023). Fat intake, https://www.who.int/data/gho/indicator-metadata-registry/imr-details/3418

World Health Organisation (WHO) (2023). Sodium reduction, https://www.who.int/news-room/fact-sheets/detail/salt-reduction

Zampouni, K., Soniadis, A., Dimakopoulou-Papazoglou, D., Moschakis, T., Biliaderis, C. G., & Katsanidis, E. (2022). Modified fermented sausages with olive oil oleogel and NaCl–KCl substitution for improved nutritional quality. *LWT,* 158, 113172.

Zanardi, E. & Novelli, E. (2021). Italian Salami. In P. E.S. Munekata, M. Pateiro, D. Franco & J. M. Lorenzo (Eds.), *Pork* (1st Edition ed., pp. 285-310). Boca Raton: CRC Press.

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

UDK: 604.4:637.5
664:502.131.1
ID: 133165833
https://doi.org/10.18485/meattech.2023.64.3.5

Review Paper

Sustainable landscape of cultured meat in developing countries: opportunities, challenges, and sustainable prospects

Wenxuan Guo[1] and Dawan Wiwattanadate[2]*

[1] Chulalongkorn University, Interdisciplinary Program Graduate School Environment Development and Sustainability, Bangkok, 10330, Thailand
[2] Chulalongkorn University, Faculty of Engineering, Bangkok, 10330, Thailand

ARTICLE INFO

Keywords:
Cultured meat
Developing countries
Meat alternatives
Sustainable meat

ABSTRACT

This study aimed to comprehensively examine the research on cultured meat in developing countries over the past decade, focusing on its opportunities and challenges for sustainable meat systems. The research method included a combination of literature review and text mining. The study found that research on cultured meat in developing countries has focused on consumer attitudes and acceptance, cultural factors, and policy and regulation. Consumer purchase intentions, attitudes, and knowledge levels significantly impact the promotion and adoption of cultured meat. At the same time, cultural factors, religious regulations, and sustainability challenges are also important factors affecting the development of cultured meat in developing countries. Furthermore, developing and implementing policy and regulatory frameworks are critical to fostering the development of sustainable meat systems. Through the combination of literature review and text analysis, this study provides an in-depth look at research on cultured meat in developing countries over the past decade. The findings suggest that consumer attitudes, cultural factors, and sustainability challenges are central topics in cultured meat research in developing countries. However, relatively little research has been done on social acceptance, economic feasibility, and technology adoption. These findings provide important insights for policymakers, researchers, and relevant stakeholders in formulating policies and strategies to advance sustainable food systems.

1. Introduction

Cultured or cellular meat has attracted extensive attention and research as an innovative food production technology (*Ye et al.,* 2022). Cultured meat is an emerging food technology that produces meat products in the laboratory through cell culture. It involves harvesting and multiplying muscle tissue from animal cells (*Treich*, 2021). This approach helps reduce reliance on traditional farming and slaughter, reduces environmental impact, and provides sustainable meat options to meet growing food demand. Cultured meat can also reduce animal harm and eliminate animal welfare issues associated with farming (*Gerhardt et al*., 2020).

With a growing global population and increasing demand for animal protein, conventional farming faces challenges, including resource consumption, environmental impact, and animal welfare issues. In this context, cultured meat as a sustainable way of food production is considered to have great potential to provide new solutions for global food safety and sustainable development challenges (*Guan et al.,* 2021).

Research on cultured meat has made remarkable progress over the past decade. Extensive research has been conducted on cell meat tech-

***Corresponding author:** Wenxuan Guo. guowenxuan199602@gmail.com

Received: July 17th 2023. Accepted November 6th 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

nology (*Kashim et al.,* 2022), consumer acceptance (*Mancini & Antonioli,* 2020), market potential (*Hopkins*, 2015), and environmental impact relative to meat products (*Hadi & Brightwell,* 2021). These studies provide valuable insights into the potential and challenges of growing meat.

Previous studies have found that consumer acceptance of cultured meat is one of the critical factors driving its marketing (*Guerrero et al.,* 2013). Studies have shown that consumers' acceptance of cultured meat varies across countries and regions, influenced by culture, religion, traditional eating habits, and food safety. For example, cultural and religious beliefs, particularly concerning vegetarianism and reverence for animals, influenced consumers' acceptance of cultured meat (*Chriki & Hocquette*, 2020). Similarly, research conducted in Muslim-majority countries, such as Malaysia, has highlighted the importance of halal certification and religious considerations in determining consumer acceptance of cultured meat products (*Hamdan et al.,* 2021).

Furthermore, traditional eating habits and culinary preferences significantly shape consumers' attitudes toward cultured meat. A study conducted in Brazil, a country known for its rich meat-eating tradition, found that consumers' familiarity with and preference for traditional meat-based dishes influenced their acceptance of cultured meat (*Heidemann et al.*, 2020). Similarly, research conducted in South Africa revealed that cultural norms and preferences for specific types of meat, such as game meat, influenced consumers' willingness to adopt cultured meat (*Domingo & Nadal,* 2017; *Tsvakirar et al.,* 2023).

Food safety is another important factor influencing consumer acceptance of cultured meat. Research conducted in various countries has shown that concerns about the safety and quality of cultured meat products impact consumers' willingness to consume them (*Kamalapuram et al.,* 2021). For instance, a study conducted in China found that consumers expressed concerns about the potential presence of harmful substances and the overall safety of cultured meat (*Zhang et al.,* 2020). Addressing these food safety concerns through transparent communication and regulatory measures is crucial for gaining consumer trust and acceptance.

However, despite the enormous interest in cultured meat in the scientific and industrial communities, research on cultured meat in some developing countries has been relatively sparse. In the research literature of the past decade, limited research on cultured meat comes from these countries. This limits our ability to recognize and assess engagement and research priorities in cultured meat research in developing countries.

Therefore, this study aims to fill this research gap by exploring the level of engagement and focus of research on cultured meat in developing countries. This study will review and comprehensively analyze the scientific research literature on cultured meat in the past ten years to obtain relevant information, i.e., the research status and trends in the area of cultured meat in developing countries.

Through the conduct of this study, the summarized research on projected cultured meat and consumer preferences provides a comprehensive perspective on a global scale, providing relevant stakeholders, policymakers, and anxious manufacturers with information about the sustainability, consumer acceptance, and market of projected growth for cultured meat. There is a need for this important information on the potential of cultured meat to drive its further development and the technologies required to achieve the goal of a sustainable food system.

2. Materials and Methods

This study aimed to gather relevant scientific literature on cultured meat-related research. A comprehensive search was conducted using the Web of Science and Scopus databases to achieve the objectives. These databases were chosen for their extensive coverage of scientific, technical, medical, and social sciences literature.

The selection of keywords for this study was based on previous research conducted in the field (Table 1). An extensive literature review was conducted to identify relevant topics and themes related to meat consumption, safety, processing, sustainability, and alternative meat production. The keywords used for the search included "meat safety", "meat consumption", "meat processing", "sustainable meat production", "cell-based meat", "plant-based meat", "meat alternatives", "meat nutrition", "meat history", and "environmental impact of meat production". (*Gómez-Luciano, Vriesekoop & Urbano,* 2019; *Mancini & Antonioli,* 2020; *Kashim et al.,* 2022). These keywords were selected to encompass a wide range of relevant topics.

The inclusion criteria for article selection were as follows: articles published within the past ten years (from 2013 to now), articles written in English, and peer-reviewed research articles, reviews, and meta-analyses. Articles that did not meet these criteria were excluded from the study.

Table 1. Literature collection strategy

	Document Collection Strategy
1	Choose Scopus and Web of Science databases.
2	Search for keywords, such as "meat alternatives", "plant-based protein" and related terms (see in the text above), to further narrow the search.
3	Read the title, abstract and keywords of each article to screen articles related to meat substitutes.
4	For the selected articles, check the impact factor and journal information for the publishing journals to determine whether the articles meet the inclusion criteria.
5	Record information such as title, author, journal name, and DOI of eligible articles, and create a literature collection list.
6	Further expand or narrow the search and add or adjust keywords as needed to get more comprehensive or specific meat substitute related articles.
7	Organize the collected articles into text.

The initial search results were evaluated based on their titles and abstracts during the screening process. Full-text articles were obtained for potentially relevant studies that met the inclusion criteria. Two independent reviewers conducted the study selection process, and any disagreements were resolved through discussion and consensus.

Data extraction involved analyzing the selected articles to gather relevant information on meat-related topics such as safety, consumption patterns, processing techniques, sustainable production methods, nutritional aspects, historical perspectives, and environmental impacts.

In summary, this study utilized a systematic approach to search and select relevant articles from central databases, ensuring a comprehensive literature review on meat-related research. The inclusion and exclusion criteria were applied to ensure

Table 2. Thematic analysis steps

	Description
1	Collect literature text.
2	Data preprocessing: Clean and preprocess text data, including removing stop words, punctuation marks, and numbers, performing stemming or lemmatization, etc.
3	Build a bag-of-words model or term frequency-inverse document frequency (TF-IDF) matrix: Transform text data into a bag-of-words model or TF-IDF matrix to represent the frequency or importance of each word in a document.
4	Run the topic modeling algorithm: Use the topic modeling algorithm, Latent Dirichlet Allocation.
5	Determine the number of topics: Determine the appropriate number of topics by model evaluation metrics (such as perplexity or consistency), domain knowledge, or actual needs.
6	Interpreting and identifying topics: Based on the topic modeling results, extract the keywords for each topic, and manually analyze and explain the meaning and relevance of the topics. Identify the topics.
7	Topic Validation and Tuning: Validate and tune topic models for accuracy and consistency based on domain expert feedback or further analysis.
8	Result Presentation: Present the results of topic analysis in the form of charts, tables or descriptions, showing the keywords, weights, and related documents of each topic, as well as the relationship and trend between topics.
9	Discussion and Interpretation: An in-depth discussion and interpretation of thematic analysis results, exploring the insights, trends, and connections found, as well as their significance and application to the field of study.

the selection of high-quality studies aligned with the research objectives. The gathered data was then further analyzed and synthesized to provide valuable insights into the selected topics.

To comprehensively understand the research topic, the researchers employed three complementary analytical techniques: thematic analysis, word cloud analysis, and topic network graph analysis. The choice between these techniques is based on their ability to provide multidimensional subject understanding and capture different aspects of the data complementary to each other.

The thematic analysis identified and categorized critical themes in the scientific research literature related to cultured meat. The study included a systematic review of the finally selected articles, a diverse body of published research conducted between 2013 and now. Articles were carefully reviewed using text mining software to form common themes, and sub-themes were identified and recorded in a topic coding matrix. These themes were extracted from the articles' contents and represent the main areas of concern and discussion within the research field.

Word cloud analysis visualizes the frequency and importance of specific keywords using software tools to highlight the most frequently occurring keywords in the selected articles (*Philip*, 2020). Word clouds determine the size and prominence of each word in the cloud based on its frequency of occur-

Table 3. Word cloud analysis steps

	Description
1	Collect literature text.
2	Data preprocessing.
3	Construct word frequency matrix: Calculate the occurrence frequency of each word.
4	Calculate word frequency/TF-IDF: Perform word frequency statistics or calculate TF-IDF value for each word, which is used for the size and weight of word cloud.
5	Build a word cloud: According to the word frequency or TF-IDF value, generate a word cloud image, wherein words that occur with higher frequency are displayed larger in the image.

Table 4. Thematic Network Analysis Steps

	Description
1	Collect literature.
2	Data preprocessing.
3	Build a bag-of-words model: Convert text data into a bag-of-words model, which represents the frequency of occurrence of each word in the document.
4	Run the Latent Dirichlet Allocation algorithm (LDA): Use the LDA algorithm to perform topic modeling on the bag-of-words model, and infer the hidden topic distribution in each document.
5	Extract topic keywords: According to the LDA model, extract the keywords of each topic.
6	Construct a topic network: According to the co-occurrence relationship of topic keywords, construct a topic network, where each topic represents a node, and the co-occurrence relationship represents an edge.
7	Analyzing the topic network: Analyze the topic network, such as calculating the degree of nodes, betweenness centrality and other indicators, and exploring the relationship between topics.
8	Visual topic network: Use visualization tools to visualize the topic network to help understand the structure and relationship between topics.
9	Interpret and evaluate results: Interpret the structure and relationships of topic networks and evaluate the validity and feasibility of topic network analysis.

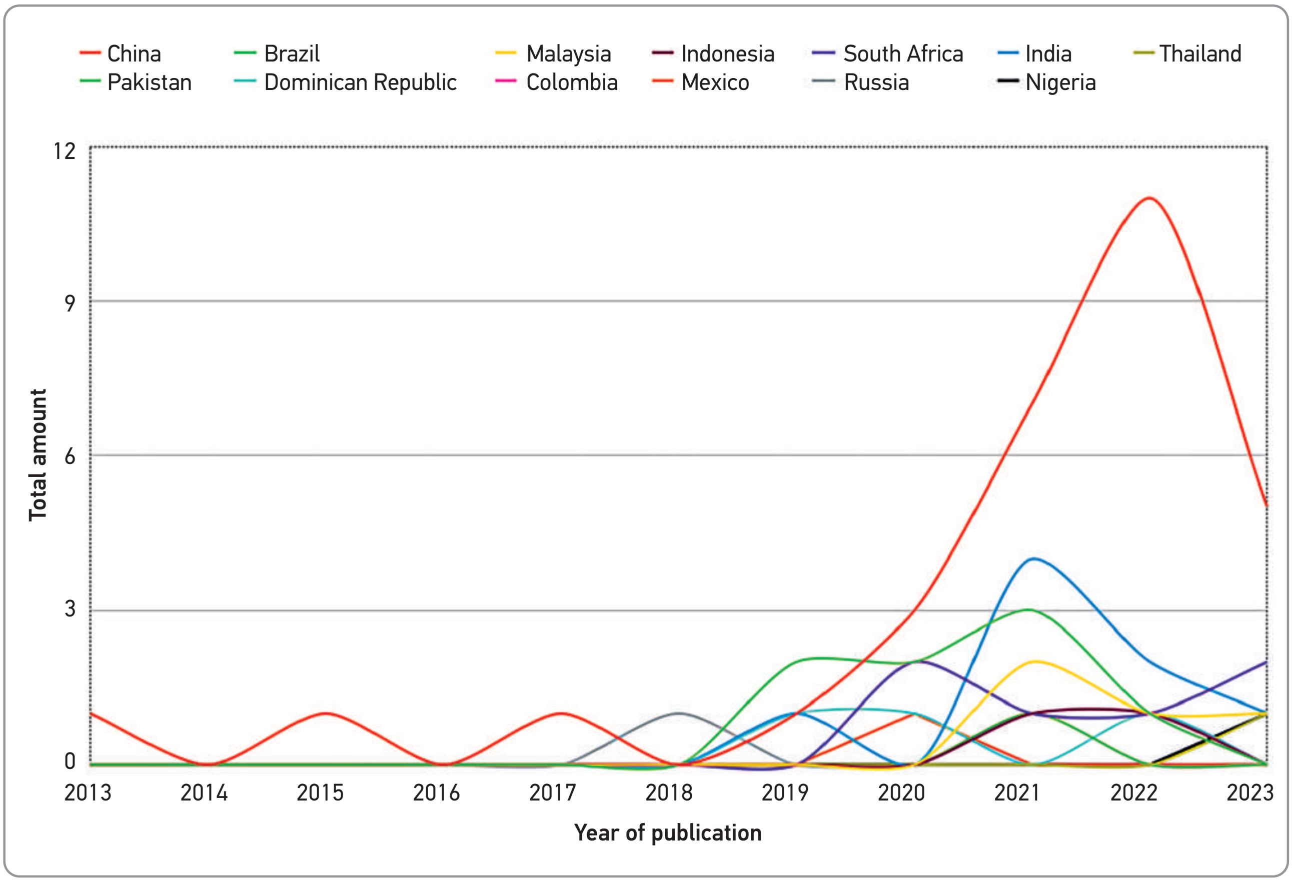

Figure 1. Number of scientific literature publications on cultured meat from different developing countries between 2013 and 2023

rence in the text. This analysis helped to identify central concepts, themes, and terms related to cultured meat, providing an overview of the research field. Table 3 shows the word cloud analysis steps.

The thematic network graph analysis explored the relationships and connections between research topics in selected articles (*Attride-Stirling,* 2001). This technique builds a thematic network map by using network analysis software. Each node in the graph represents a specific research topic, and edges represent relationships between issues based on co-occurrence patterns. Such analysis helps to reveal the interdependencies and linkages between different research areas within a research field, providing further insight into the complex relationships and dynamics within a domain. Table 4 shows the topic network analysis steps.

The integrated use of topic analysis, word cloud analysis, and topic network graph analysis allowed us to analyze and interpret the research literature on cultured meat comprehensively. By applying these three techniques, we were able to identify major themes, key concepts, and their interrelationships, providing a holistic view of the field of study. This integrated approach enhances the understanding of the research domain, generates valuable insights, and informs subsequent discussions and conclusions.

3. Results and Discussion

As shown in Table 5, the literature covers consumer perceptions of sustainable food technologies, neophobia of cultured meat, acceptance of cultured meat among consumers in different countries, the environmental impact of meat products, Muslim perceptions of cultured meat and its halal status, perspectives for cultured meat, etc.

Regarding developing country distribution, China was the most frequent country from which research originated in this literature review, and Chinese researchers covered multiple research topics. Other developing countries that have conducted studies include Brazil, South Africa, Indonesia, Malaysia, Pakistan, Thailand, and others (Figure 1).

Regarding the time distribution, the publication years of these studies were mainly concentrated between 2021 and 2023 (Figure 1). Among them, 2022 was the year with the highest number of publi-

Table 5. Scientific literature analyzed in the present study

Article Topics	Country	Reference
Perception and acceptance	Nigeria	*Owokoniran et al*. (2024)
Consumer acceptance of sustainable food technologies	India	*Giacalone & Jaeger* (2023)
Cell culture media optimization and cost reduction	China	*Gomez Romero & Boyle* (2023)
Challenges of bringing cultured meat to the market	China	*Xiang & Zhang* (2023)
Neophobia scale	South Africa	*Tsvakirai et al*. (2023)
Consumer segmentation and motives	China	*Wang & Scrimgeour* (2023)
Role of environmental messages on food technology acceptance	China	*Zheng et al*. (2023)
Consumer perceptions	Africa	*Ngah et al*. (2023)
Consumer attitudes and intentions	China	*Li et al*. (2023)
Appraisal from Muslim scholars' perspectives	Malaysia	*Burhanuddin et al*. (2023)
Consumer acceptance	Thailand	*Siripat & Srivardhana* (2023)
Consumer acceptance and production of in vitro meat	India China	*Kantono et al*. (2022)
Perspectives of meat eaters on cultured beef	South Africa	*Falowo et al*. (2022)
Commercialization of cultured meat products	Asia-Pacific region	*Ye et al*. (2022)
Consumer willingness to pay	China, Brazil and Dominican Republic	*Rombach et al*. (2022)
Porcine muscle stem cells for cultured meat production	China	*Li et al*. (2022)
Proliferation of porcine muscle stem cells for cultured meat production	China	*Fang et al*. (2022)
Regulating the commercialization of cell-cultured meat	China	*Li, Fu & Li* (2022)
Cost of large-scale production of cell-cultured meat	China India	*Garrison, Biermacher & Brorsen* (2022)
Indonesian Muslim communities' prospects	Indonesia	*Qotadah et al*. (2022)
Quality evaluation of cultured meat with plant protein scaffold	China	*Zheng et al*. (2022)
Identity labels	China	*Ortega et al*. (2022)
Halal status	Malaysia	*Kashim et al*. (2022)
Trends and public acceptance	India	*Kamalapuram et al*. (2021)
Trends and ideas in technology, regulation and public acceptance of cultured meat	China	*Guan et al*. (2021)
Food attributes	Brazil	*de Oliveir et al*. (2021)
Consumer adoption	South Africa	*Szejda et al*. (2021)
Consumers' valuation of cultured meat	China	*Rao et al*. (2021)
Cultural concepts of meat and future predictions	China, India and Colombia	*Hansen et al*. (2021)

Article Topics	Country	Reference
Attitudes and perceptions	Pakistan	*Ahsan, Khan & Ahmad* (2021)
Attitudes and perceptions	Brazil	*Munz Fernandes et al*. (2021)
Effect of smooth muscle cells on cultured meat quality	China	*Zheng et al*. (2021)
Muslim consumers' attitudes	Malaysia	*Hamdan et al*. (2021a)
Muslim consumers and the replacement of livestock slaughter with cultured meat	Malaysia	*Hamdan et al*. (2021b)
Preferences and willingness to pay for meat alternatives	India	*Arora, Brent & Jaenicke* (2020)
Technology landscaping in the Indian meat sector	India	*Sen et al*. (2021)
Undergraduate students' perceptions	Indonesia	*Virginia et al*. (2021)
Consumers' attitudes	Brazil	*Chriki et al*. (2021)
Chinese consumers and their appetite	China	*Dempsey & Bryant* (2020)
Consumer acceptance of cultured meat	Brazil Dominican Republic	*Bryant & Barnett* (2020)
Naturalness, disgust, trust, and food neophobia	China, Mexico, South Africa	*Siegrist & Hartmann* (2020)
Consumer acceptance	China	*Zhang et al*. (2020)
Animal production	Brazil	*Heidenmann et al*. (2020)
Consumer perceptions	India, China	*Bryant et al*. (2020)
Food security of alternative dietary proteins	Dominican Republic	*Gómez-Luciano, Vriesekoop & Urban* (2019)
Consumer willingness to pay	Brazil	*Gómez-Luciano et al*. (2019)
Highly educated consumers' attitudes	Brazil	*Valente et al*. (2019)
Clean cultured meat for today's future	Russia	*Hoogenkamp* (2018)
The cross-cultural perspective	China	*Bekker et al*. (2017)
The environmental prospects	China	*Sun et al*. (2015)

cations, indicating that research in this field is continuing to develop.

The literature provides findings on consumer acceptance of new sustainable food technologies and cultured meat, research perspectives from different countries, and the influences of religion and culture on food choices (Table 5).

3.1 Thematic Analysis Results

According to the themes, research on consumer purchase intentions, attitudes, beliefs, and cognition occupied a large proportion of the collected literature (Table 5). This suggests that consumer acceptance and attitudes toward cultured meat are essential concerns in the study. Studies in multiple countries and regions, including India, South Africa, China, and Africa, have investigated and analyzed consumers' acceptance of cultured meat. These studies explored consumers' knowledge level, willingness to purchase, attitudes, and perceptions toward plant-based meat products.

Second, research on culture and religion has been deserving of attention. Consumer purchase intentions, attitudes, beliefs, and perceptions proved to be essential concerns in cultured meat research. Research shows differences in consumer acceptance of new sustainable food technologies. These differences could be related to consumers' desire for naturalness, disgust, trust in food, awareness, and understanding of alternative meat products. Individual

Table 4. Thematic analysis results from the analyzed scientific literature

Theme	Sub-themes
Consumer Acceptance	Consumer acceptance of sustainable food technologies Consumer attitudes and intentions Perception and acceptability Consumer perceptions Highly educated consumers' attitudes Consumer willingness to purchase
Market Promotion and Commercialization	Commercialization of cultured meat products Regulating the commercialization of cell-cultured meat
Environmental, Ethical, and Health Factors	Ethical, ecological, and health factors influencing the acceptance of cultured meat Environmental prospects of cultured meat Food security of alternative dietary proteins
Cultural and Religious Factors	Neophobia Scale Muslim communities' perspectives Perspectives of meat eaters
Technology and Production Factors	Cell culture cost Porcine muscle stem cells Quality evaluation Smooth muscle cells
Public Acceptance and Trends	Trends and public acceptance Trends and ideas in technology, regulation, and public acceptance Cultural concepts Future predictions

values, cultural background, and social factors also impacted consumer attitudes toward cultured meat products.

Second, cultural and religious factors played different roles in cultured meat research in different countries and regions. In some countries, especially those with strict religious regulations on food preparation, religious factors play a significant role in the acceptance of cultured meat. For example, Shariah and Sufi scholars' assessment of halal cultured meat was given attention in the Malaysian study. This suggests that the influence of religious factors on the acceptance of sophisticated meat products by local consumers is significant in this country. However, studies in other developing countries did not specifically emphasize religious factors, possibly because religion would have little influence on the local acceptance of cultured meat.

These findings provide important insights into research into cultured meat in developing countries. Understanding consumer purchase intentions and attitudes and the influence of culture and religion on the acceptance of cultured meat will help us better understand the promotion and adoption of cultured meat in these countries and regions. These findings have significant reference value for developing the cultured meat industry and formulating promotional strategies.

3.2 Word cloud analysis results

In the cultured meat studies, words that appeared more frequently included "Cultured", "Meat", "Consumer", "Research", "Product", and "Animal cell." These words highlight the core themes of the studies, namely consumer acceptance of cultured meat products, the development of research, and the characteristics of related products (Figure 2).

"China" occurred frequently, reflecting the importance of China in cultured meat research and development. China's investment and innovation in cultured meat have significantly impacted the development of the global cultured meat industry. Relat-

Figure 2. Word cloud analysis results concerning scientific literature originating from developing countries and focusing on cultured meat

ed words included "Technology", "Alternative", and "Plant-based", reflecting China's aggressive efforts to promote cultured meat technology, find alternatives, and develop plant-based meat products.

"South Africa" was another country that stood out in the research on cultured meat, demonstrating the importance of South Africa in this area and consumer acceptance. The South African studies covered consumer acceptance of cultured meat products, purchase intentions, and marketing strategies. Associated words were "Neophobia" (fear of new things), "Quality", and "Welfare" (animal welfare), highlighting South Africa's focus on the quality of cultivated meat products and animal welfare (Figure 2).

Other terms such as "India", "Brazil", "Halal", "Education", and "Safety" also reflected the importance of these countries and fields in cultured meat research (Figure 2). These countries play an important role in consumer acceptance of cultured meat, related regulations and standards, religious factors, and education and safety.

3.3 Word Network Analysis Results

Based on the text analysis and thematic lexical network map analysis of research on cultured meat in developing countries, we found strong links between these themes. The following professional explanations can illustrate this result (Figure 3).

The strong connection between consumers and meat reflects the importance of consumers in the meat product sector. Consumer attitudes significantly impact the acceptance and market performance of cultured meat. Consumer attitudes and preferences towards meat products influence their willingness and purchase decisions for cultured meat.

The declassified connection between China and meat can be attributed to China's important position in the meat industry and consumer market. As one of the world's largest meat consumers, China is vital in researching and developing cultured meat. The deciphering of this link may indicate that China's investment and innovation in cultured meat technology have achieved remarkable results.

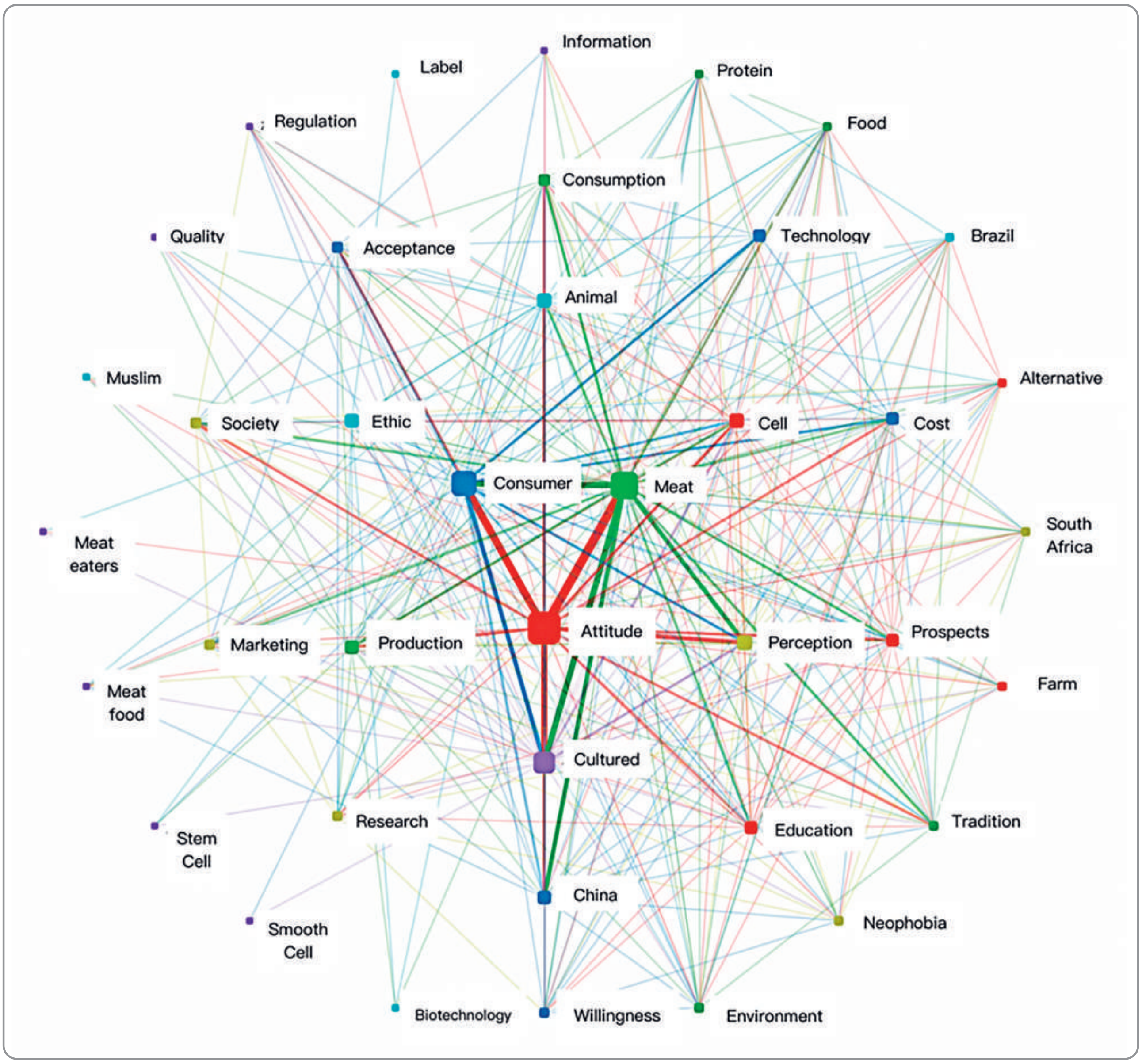

Figure 3. Word Network Analysis Results concerning the scientific literature originating from developing countries and focusing on cultured meat

The substantial tie between attitudes and perceptions, and perspectives suggests that consumers' attitudes toward cultured meat are closely related to their awareness and understanding of the technology (Figure 3). Consumer attitudes are influenced by their awareness and knowledge horizons about cultured meat, which could be affected by education, information access, and scientific research dissemination.

The strong link between attitude and society reflects the critical role of social factors in shaping consumer attitudes toward cultured meat (Figure 3). Social values, cultural traditions, and social identity can affect consumers' acceptance and attitude toward cultured meat.

The intense relationship between attitude and acceptance suggests that consumers' attitudes significantly impact their acceptance of cultured meat products (Figure 3). Positive consumer attitudes toward cultured meat tend to drive them to be more willing to try and purchase the product, while negative attitudes can hinder acceptance.

Finally, the vital link between attitude and tradition suggests that traditional culture influences consumers' attitudes and acceptance of new meat products (Figure 3). Traditional factors, such as cultural background, religious beliefs, and food habits, likely can shape consumer attitudes towards cultured meat, and so these factors need to be considered in strategies for promoting and adopting cultured meat.

It should be noted that different developing countries have differing research priorities. Taking China, Brazil, and South Africa as examples, their frequent support of or involvement in cultured meat research is closely related to the importance of these countries in meat production and consumption (*Bryant & Barnett*, 2020; *Heidemann* et al., 2020). These countries have large populations and significant meat markets, so research on meat production, consumption, and alternatives is of great economic and social importance.

3.4 Challenges and Opportunities for Cultured Meat in Developing Countries

The deployment of cultured meat technologies in developing countries presents several challenges and opportunities. First, one of the challenges is the cost and feasibility of cultured meat technology. The cultured meat production process requires a lot of capital, technical facilities, and expertise, which could be a considerable challenge for some developing countries (*Bhat, Kumar & Fayaz*, 2015). Finding innovative methods and technologies to reduce production costs and introducing locally adapted cultured meat production models will be vital in addressing this issue (*Chriki & Hocquette*, 2020).

Second, cultural and religious factors are also a significant challenge. Consumers' cultural and religious background influences the acceptance of cultured meat technology. Cultural and religious factors present a potential challenge to the acceptance of cultured meat technology in developing countries. Consumers' cultural and religious backgrounds deeply influence their attitudes and beliefs toward food choices, including their acceptance of new technologies. Research conducted in Malaysia highlighted the importance of cultural and religious beliefs, particularly among Muslim populations, in determining the acceptance of cultured meat (*Burhanuddin et al.*, 2023). Halal certification, aligning with Muslims' religious dietary requirements, played a crucial role in cultured meat gaining acceptance in Malaysia. Similarly, in Indonesia, a study emphasized the influence of religious perspectives on the perception of cultured meat. The research focused on the opinions of Muslim communities and revealed that the views of Islamic scholars on the permissibility of cultured meat affected consumer acceptance (*Hamdan et al.*, 2021b). Moreover, traditional food practices and cultural attachments to specific meat products also pose challenges. Research conducted in India demonstrated that consumers' deep-rooted connection to traditional meat-based dishes limited their willingness to adopt alternative options like cultured meat (*Kamalapuram et al*., 2021).

Additionally, food safety and regulatory oversight is a significant challenge. Developing countries could have weak links in food safety and legal supervision, and there are difficulties in supervising and controlling new food technologies.

In developing countries, cultured meat technology has multiple opportunities and strong links with the Sustainable Development Goals. First, cultured meat can create opportunities for gender equality. While traditional livestock farming is often dominated by men, cultured meat technology offers a gender-independent means of producing meat, promoting gender equality and opportunities for women to participate in the agricultural sector. The new food pathway contributes to achieving gender equality in the Sustainable Development Goals.

Second, cultured meat technology can help address the environmental and sustainability challenges faced by traditional livestock farming (*Kumar et al.,* 2021). Developing countries face problems such as limited land resources, water shortages, and climate change. Compared with livestock farming, cultured meat technology can provide a more environmentally friendly and sustainable method of meat production, reducing dependence on natural resources.

Third, cultured meat technology can contribute to food safety and the stability of the food supply (*Bryant & Barnett,* 2020). Developing countries often face challenges such as unstable food supply chains, food safety issues, and the spread of infectious diseases. Compared with livestock production, cultured meat technology can provide a more controllable and predictable production process, reduce the risk of food contamination and animal diseases, and improve food supply security, reliability, and safety.

In addition, cultured meat technology can also create decent jobs and economic growth (*Dupont-Inglis & Borg,* 2018). Developing the cultivated meat industry requires various professional and technical personnel, bringing new employment opportunities and investment to the local economy. The promotion of cultured meat technology can also promote the development of related industrial chains, including cell culture technology, food processing, and supply chain management, and is likely to bring opportunities for economic growth and technology transfer to developing countries.

The combination of tradition and modernity may be a promising direction when exploring sustainable meat-eating patterns in developing countries. Developing countries have rich traditional meat diet cultures as part of their unique cultural heritage. Preserving and passing on the value of traditional meat-based diets helps maintain cultural diversity and fosters community cohesion. At the same time, modern technology has played an important role in meat production and is now poised to provide more sustainable solutions in this area. Combining tradition and modernity, developing countries can explore the application of modern technology in the production and supply chain of traditional meat diets to improve efficiency and to reduce resource consumption and environmental impacts. Such a combination can meet the needs of local consumers for a traditional meat diet while keeping in mind the goal of sustainable development. In this process, attention to community participation, policy support, and scientific and technological innovation is vital to ensuring the successful implementation of sustainable meat diets and providing healthy, diverse, and sustainable meat choices for people in developing countries.

4. Conclusion

Through comprehensive analysis, including thematic analysis, word cloud visualization, and word network matrix, essential insights into cultured meat and its impact on developing countries were derived.

Thematic analysis reveals in the overall picture of cultured meat the importance of farming, consumer attitudes and acceptance, technological advancements, and environmental impacts. These themes highlight the multidimensional nature of the cultivated meat industry and its importance in addressing pressing challenges in the food sector. The word cloud further emphasizes the prominence of topics such as consumer behavior, research and development, and the production and consumption of meat substitutes.

The word network matrix visualizes the interconnections and frequencies between different keywords. It demonstrates the close relationship between words such as “farmed”, “meat”, “consumer,” “research” and “product”, indicating the interconnectedness and focus of our research. Furthermore, the word network highlights the importance of technology, market analysis, environmental concerns, and cultural factors in shaping the discussion about cultured meat.

The analysis also reveals the specific focus of research in different developing countries. Research in China, Brazil, and South Africa focuses on particular areas specific to each country, which reflects the research priorities and development directions of each country in the field of cultured meat.

Overall, this study provides important insights into and understanding of cultured meat and its development in developing countries. The findings of this study provide valuable information for relevant stakeholders, policymakers, and academia to advance the sustainable development and application of the cultured meat industry. This study provides a basis for further exploring the potential and development path of the cultivated meat industry and will help guide future research and policy formulation.

Održivo okruženje za veštačko/kultivisano meso u zemljama u razvoju: mogućnosti, izazovi i održivi izgledi

Wenxuan Guo i Dawan Wiwattanadate

INFORMACIJE O RADU

Ključne reči:
Veštačko/kultivisano meso
Zemlje u razvoju
Alternative mesu
Održivo meso

APSTRAKT

Ova studija je imala za cilj da sveobuhvatno ispita istraživanja koja su bila usmerena na dobijanje veštačkog/kultivisanog mesa u zemljama u razvoju tokom protekle decenije, fokusirajući se na njegove mogućnosti i izazove za održive sisteme proizvodnje mesa. Metod istraživanja uključivao je kombinaciju pregleda literature i analize tekstova. Studija je otkrila da se istraživanje kultivisanog mesa u zemljama u razvoju fokusiralo na stavove i prihvatanje potrošača, kulturne faktore, kao i politiku i regulativu. Kupovne namere, stavovi i nivo znanja potrošača značajno utiču na promociju i usvajanje kultivisanog mesa. Istovremeno, kulturni faktori, verski propisi i izazovi održivosti su takođe važni faktori koji utiču na razvoj kultivisanog mesa u zemljama u razvoju. Štaviše, razvoj i implementacija politike i regulatornih okvira su kritični za podsticanje razvoja održivih sistema mesa. Kombinacijom pregleda literature i analize tekstova, ova studija pruža dubinski pogled na istraživanje kultivisanog mesa u zemljama u razvoju tokom protekle decenije. Nalazi sugerišu da su stavovi potrošača, kulturni faktori i izazovi održivosti centralne teme u istraživanju kultivisanog mesa u zemljama u razvoju. Međutim, urađeno je relativno malo istraživanja o društvenoj prihvatljivosti, ekonomskoj izvodljivosti i usvajanju tehnologije. Ovi nalazi pružaju važan uvid kreatorima politike, istraživačima i relevantnim zainteresovanim stranama u formulisanju politika i strategija za unapređenje održivih sistema ishrane.

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

Acknowledgment: The authors would like to express their gratitude to reviewers and editors who have contributed to this research.

Ethical approval: No ethical approval was obtained because this is a retrospective literature review article.

References

Ahsan, M., Khan, M. R., & Ahmad, T. (2021). Attitudes and Perceptions Towards Cultured Meat Among General Population in Pakistan. *ASEAN Journal of Science and Engineering Education*, 2 (1), 111–122, https://doi.org/10.17509/ajsee.v2i1.38766

Arora, R. S., Brent, D. A., & Jaenicke, E. C. (2020). Is India ready for alt-meat? Preferences and willingness to pay for meat alternatives. *Sustainability*, 12 (11), 4377.

Attride-Stirling, J. (2001). Thematic Networks: An Analytic Tool for Qualitative Research. *Qualitative Research*, 1 (3), 385–405, https://doi.org/10.1177/146879410100100307

Bekker, G. A., Fischer, A. R. H., Tobi, H., van Trijp, H. C. M., & van der Fels-Klerx, H. J. (2017). Meet Meat: An Explorative Study on Meat and Cultured Meat as Seen by Chinese, Ethiopians and Dutch. *Appetite*, 114, 82–92, https://doi.org/10.1016/j.appet.2017.03.009

Bhat, Z. F., Kumar, S., & Fayaz, H. (2015). In vitro meat production: Challenges and benefits over conventional meat production. *Journal of Integrative Agriculture*, 14 (2), 241–248.

Gomez Romero, S., & Boyle, N. (2023). Systems biology and metabolic modeling for cultivated meat: A promising approach for cell culture media optimization and cost reduction. *Comprehensive Reviews in Food Science and Food Safety*, 10.1111/1541-4337.13193. Advance online publication, https://doi.org/10.1111/1541-4337.13193

Bryant, C., & Barnett, J. (2020). Consumer acceptance of cultured meat: An updated review (2018–2020). *Applied Sciences*, 10 (15), 5201.

Bryant, C., et al. (2020). Corrigendum: A Survey of Consumer Perceptions of Plant-Based and Clean Meat in the USA, India, and China. *Frontiers in Sustainable Food Systems*, 4, 86, https://doi.org/10.3389/fsufs.2020.00086

Burhanuddin, I. H., et al. (2023). Cultured Meat: An Appraisal from the Fiqh and Sufi Views of Muslim Scholars. *Malaysian Journal of Syariah and Law*, 11 (1), https://doi.org/10.33102/mjsl.vol11no1.373

Chriki, S., & Hocquette, J. F. (2020). The myth of cultured meat: A review. *Frontiers in Nutrition*, 7, 7, https://doi.org/10.3389/fnut.2020.00007

Chriki, S., et al. (2021). Brazilian consumers' attitudes towards so-called 'cell-based meat'. *Foods*, 10 (11), 2588, https://doi.org/10.3390/foods10112588

Dempsey, C., & Bryant, C. J. (2020). Cultured meat: Do Chinese consumers have an appetite? https://doi.org/10.31219/osf.io/pjm83

Domingo, J. L., & Nadal, M. (2017). Carcinogenicity of consumption of red meat and processed Meat: A review of scientific news since the IARC decision. *Food and Chemical Toxicology*, 105, 256–261, https://doi.org/10.1016/j.fct.2017.04.028

Dupont-Inglis, J., & Borg, A. (2018). Destination bioeconomy–The path towards a smarter, more sustainable future. *New Biotechnology*, 40, 140–143.

Falowo, B. A., et al. (2022). Perspectives of meat eaters on the consumption of cultured beef (in vitro production) from the eastern cape of South Africa. *Frontiers in Sustainable Food Systems*, 6, https://doi.org/10.3389/fsufs.2022.924396

Fang, J., et al. (2022). Vitamin C enhances the ex vivo proliferation of porcine muscle stem cells for cultured meat production. *Food & Function*, 13 (9), 5089–5101.

Garrison, G. L., Biermacher, J. T., & Brorsen, B. W. (2022). How much will large-scale production of cell-cultured meat cost? *Journal of Agriculture and Food Research*, 10, 100358.

Gerhardt, C., Suhlmann, G., Ziemßen, F., Donnan, D., Warschun, M., & Kühnle, H. J. (2020). How will cultured meat and meat alternatives disrupt the agricultural and food industry?. *Industrial Biotechnology*, 16 (5), 262–270.

https://doi.org/10.1089/ind.2020.29227.cge

Giacalone, D., & Jaeger, S. R. (2023). Consumer acceptance of novel sustainable food technologies: a multi-country survey. *Journal of Cleaner Production*, 408, 137119, https://doi.org/10.1016/j.jclepro.2023.137119

Gómez-Luciano, C. A., et al. (2019). Consumers' willingness to purchase three alternatives to meat proteins in the United Kingdom, Spain, Brazil and the Dominican Republic. *Food Quality and Preference*, 78, 103732, https://doi.org/10.1016/j.foodqual.2019.103732

Gómez-Luciano, C. A., Vriesekoop, F., & Urbano, B. (2019). Towards food security of alternative dietary proteins: A comparison between Spain and the Dominican Republic. *Amfiteatru Economic*, 21 (51), 393–407.

Guan, X., et al. (2021). Trends and ideas in technology, regulation and public acceptance of cultured meat. *Future Foods*, 3, 100032, https://doi.org/10.1016/j.fufo.2021.100032

Guerrero, A., et al. (2013). Some Factors That Affect Ruminant Meat Quality: From the Farm to the Fork. Review. *Acta Scientiarum. Animal Sciences*, 35 (4), 10.4025/Actascianimsci.V35i4.21756.

Hadi, J., & Brightwell, G. (2021). Safety of alternative proteins: technological, environmental and regulatory aspects of cultured meat, plant-based meat, insect protein and single-cell protein. *Foods*, 10 (6), 1226. 10.3390/foods10061226.

Hamdan, M. N., et al. (2021a). Cultured Meat: Islamic and other religious perspectives. *UMRAN — International Journal of Islamic and Civilizational Studies*, 8 (2), 11–19. 10.11113/umran2021.8n2.475.

Hamdan, M. N., et al. (2021b). Will Muslim consumers replace livestock slaughter with cultured meat in the market? *Trends in Food Science & Technology,* 109, 729–732. 10.1016/j.tifs.2021.01.034.

Hansen, J., et al. (2021). Exploring cultural concepts of meat and future predictions on the timeline of cultured meat. *Future Foods*, 4, 100041. 10.1016/j.fufo.2021.100041.

Heidemann, M. S., et al. (2020). Critical perspective of animal production specialists on cell-based meat in Brazil: From bottleneck to best scenarios. *Animals*, 10 (9), 1678. 10.3390/ani10091678.

Hoogenkamp, B. H. (2018). Clean cultured meat for today's future. *Fleischwirtschaft International*, 2, 42–46.

Hopkins, P. D. (2015). Cultured meat in Western media: The disproportionate coverage of vegetarian reactions, demographic realities, and implications for cultured meat marketing. *Journal of Integrative Agriculture*, 14 (2), 264–272. 10.1016/s2095-3119(14)60883-2.

Kashim, M. I. A. M., et al. (2022). Scientific and Islamic perspectives in relation to the Halal status of cultured meat. *Saudi Journal of Biological Sciences*, 30 (1), 103501. 10.1016/j.sjbs.2022.103501.

Kamalapuram, S. K., et al. (2021). Cultured meat prospects for a billion! *Foods,* 10 (12), 2922. 10.3390/foods10122922.

Kantono, K., et al. (2022). Consumer acceptance and production of In vitro meat: a review. *Sustainability*, 14 (9), 4910.

Ngah, M. K., et al. (2023). Consumer perception of 'artificial meat' in the educated young and urban population of Africa. *Frontiers in Nutrition,* 10. 10.3389/fnut.2023.1127655.

Kumar, P., et al. (2021). In-Vitro Meat: A promising solution for sustainability of meat sector. *Journal of Animal Science and Technology*, 63 (4), 693–724. 10.5187/jast.2021.e85.

Li, H., et al. (2023). Will cultured meat be served on Chinese tables? A study of consumer attitudes and intentions about cultured meat in China. *Meat Science,* 197, 109081. 10.1016/j.meatsci.2022.109081.

Li, M., et al. (2022). An efficient and economical way to obtain porcine muscle stem cells for cultured meat production. *Food Research International,* 162, 112206.

Mancini, M. C., & Antonioli, F. (2020). To what extent are consumers' perception and acceptance of alternative meat production systems affected by information? The case of cultured meat. *Animals*, 10 (4), 656. 10.3390/ani10040656.

Munz Fernandes, A., et al. (2021). Consumption behavior and purchase intention of cultured meat in the capital of the 'State of Barbecue,' Brazil. *British Food Journal*, 123 (9), 3032–3055. 10.1108/bfj-08-2020-0698.

Ortega, D. L., et al. (2022). Identity labels as an instrument to reduce meat demand and encourage consumption of plant based and cultured meat alternatives in China. *Food Policy*, 111, 102307. 10.1016/j.foodpol.2022.102307.

Philip, R. K. (2020). Word cloud analysis and single word summarisation as a new paediatric educational tool: results of a neonatal application. *Journal of Paediatrics and Child Health*, 56 (6), 873–877. 10.1111/jpc.14760.

Qotadah, H. A., et al. (2022). Cultured meat for Indonesian Muslim communities: A review of Maslahah and prospect. *Al-Istinbath : Jurnal Hukum Islam*, 7 (2), 337. 10.29240/jhi.v7i2.5476.

Rombach, M., et al. (2022). Is cultured meat a promising consumer alternative? Exploring key factors determining consumer's willingness to try, buy and pay a premium for cultured meat. *Appetite*, 179, 106307. 10.1016/j.appet.2022.106307.

Sen, A. R., et al. (2021). Technology landscaping in Indian meat sector to meet the future demand and strengthening business. *Journal of Meat Science*, 16. 1–6. 10.5958/2581-6616.2021.00001.3.

Sheng, J., et al. (2023). The role of environmental-related message on consumer acceptance of novel food production technology: an experimental investigation on artificial meat products. *Environmental Science and Pollution Research*, 30 (8), 21238–21251, https://doi.org/10.1007/s11356-022-23597-2.

Siegrist, M., & Hartmann, C. (2020). Perceived naturalness, disgust, trust and food neophobia as predictors of cultured meat acceptance in ten countries. *Appetite*, 155, 104814, https://doi.org/10.1016/j.appet.2020.104814.

Siripat, K., & Srivardhana, T. (2023). Consumer acceptance of cultured meat in Thailand. Proceedings of the 24th National Graduate Conference, Command and General Staff College, Thailand, 22 May 2023.

Sun, Z., et al. (2015). The environmental prospects of cultured meat in China. *Journal of Integrative Agriculture*, 14 (2), 234–240, https://doi.org/10.1016/s2095-3119(14)60891-1.

Szejda, K., et al. (2021). South African consumer adoption of plant-based and cultivated meat: A segmentation study. *Frontiers in Sustainable Food Systems*, 5, 744199, https://doi.org/10.3389/fsufs.2021.744199.

Treich, N. (2021). Cultured meat: Promises and challenges. *Environmental and Resource Economics*, 79 (1), 33–61.

Tsvakirai, C. Z., et al. (2023). Development and validation of a cultured meat neophobia scale: industry implications for South Africa. *Scientific African*, 20, e01641, https://doi.org/10.1016/j.sciaf.2023.e01641.

Valente, J. P. S., et al. (2019). First glimpse on attitudes of highly educated consumers towards cell-based meat and related issues in Brazil. *PLOS ONE,* 14 (8), e0221129, https://doi.org/10.1371/journal.pone.0221129.

Virginia, J. A., et al. (2021). The perception of undergraduate students in Jakarta on the consumption of cultured meat. *Indonesian Journal of Life Sciences,* 3 (2).

Wang, O., & Scrimgeour, F. (2023). Consumer segmentation and motives for choice of cultured meat in two Chinese cities: Shanghai and Chengdu. *British Food Journal*, 125 (2), 396–414, https://doi.org/10.1108/bfj-09-2021-0987.

Xiang, N., & Zhang, X. (2023). The challenges of bringing cultured meat to the market. Nature *Reviews Bioengineering*, 1–2.

Rao, Y., Asioli, D., Shaosheng, J., & Nayga, R. M. (2021). Consumers' valuation for cultured meat: A multi-city choice experiment in China. In 2021 AAEA Annual Meeting. Austin, Texas, United States. Retrieved from https://doi.org/10.22004/ag.econ.313957.

Ye, Y., et al. (2022). Commercialization of cultured meat products: current status, challenges, and strategic prospects. *Future Foods,* 6, 100177, https://doi.org/10.1016/j.fufo.2022.100177.

Li, Y., Fu, X., & Du, L. (2022). Regulating the commercialization of cell-cultured meat: Practices in selected jurisdictions and their implications for China. *Synthetic Biology Journal*, 3 (1), 209–223. doi: 10.12211/2096-8280.2021-101

Zhang, M., et al. (2020). Consumer acceptance of cultured meat in urban areas of three cities in China. *Food Control*, 118, 107390, https://doi.org/10.1016/j.foodcont.2020.107390.

Zheng, Y.-Y., et al. (2022). Quality evaluation of cultured meat with plant protein scaffold. *Food Research International*, 161, 111818, https://doi.org/10.1016/j.foodres.2022.111818.

Zheng, Y.-Y., et al. (2021). Evaluation of the effect of smooth muscle cells on the quality of cultured meat in a model for cultured meat. *Food Research International*, 150, 110786, https://doi.org/10.1016/j.foodres.2021.110786

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

UDK: 638.162:577.1
ID: 133223433
https://doi.org/10.18485/meattech.2023.64.3.6

Review paper

Comparative overview of microelements and toxic elements in honey regarding the international criteria

Danka Spirić[1], Jelena Ćirić[1], Silvana Stajković[2], Mirjana Dimitrijević[2], Čaba Silađi[1], Srđan Stefanović[1] and Vesna Đorđević[1]*

[1] *Institute of Meat Hygiene and Technology, Kaćanskog 13, Belgrade, Serbia*
[2] *University of Belgrade, Faculty of Veterinary Medicine,Bulevar oslobodjenja 18, Belgrade, Serbia*

ARTICLE INFO

Keywords:
Honey
Microelements
Toxic elements
Legislative

ABSTRACT

Honey is source of energy for bees and natural sweet substance with many benefits in human consumption. It is also used as a part of apitherapy, because it is rich in carbohydrates enzymes, trace elements, organic acids, dextrins, phytochemicals (flavonoids, phenolic acids, essential oils), vitamins and even prebiotics oligosaccharides. The stated use of honey demands high quality and safety of honey and honey products. Criteria for quality of honey is precise and regulated in Codex Alimentarius, where are defined honey, types of honey and parameters for quality of honey. For European Union (EU) members Council Directive 2001/110/EC is in effect, for United States of America (USA) it is United States Standards for Grades of Extracted Honey Effective date May 23, 1985, for China it is National Standards of the People's Republic of China, GB 14963-2011, National Food Safety Standard, for Serbia Rulebook on quality and other requirements for honey, other bee products, preparations based on honey and other bee products (Pravilnik o kvalitetu meda i drugih proizvoda pčela („Sl. glasnik RS" 101/2015). Regarding microelements and toxic elements there are criteria for EU countries, similar to USA and China, defining criteria only for content of Pb in honey set to 1 mg/kg maximum residue level (MRL). National criteria for several microelements and toxic elements were present in our legislative, but over the time national criteria has been synchronized with EU criteria.

1. Introduction

Honey is complex natural product that is created by the collection of nectar by insects, mainly *Apis mellifera*. Honey bees are interacting with environment while collecting nectar, pollen and water, foraging up to 6 km from their hives. They are considered to be bioindicators, due their capacity to deposit microelements, contaminants and residues of pollutants in their bodies. They also bring nectar, pollen and water that contain diverse substances, including hazardous components, and store it in the hives. Honeybees are considered as cumulative bioindicators regarding deposition of minerals in their bodies. They have capacity to retain number of certain microelements above naturally present concentrations in their bodies. In the case of residue monitoring in bee bodies, these organisms are observed as effective bioindicators. Pesticide concentration in dead bees samples and mortality of honeybees are monitored during blooming season for misapplication detection of pesticides during plant production (*Calatayud-Vernich et al*., 2019). The presence and amount of microelements in honey can indicate the type of honey and its geographical origin. Microelements are stable and characteristic of the soil and melliferous flora. Honey bees have large area of habitat compared to their body size and they are reflecting nature with their mineral composition and composition of their products

***Corresponding author:** Danka Spiric, *danka.spiric@inmes.rs*

Paper received September 28th 2023. Paper accepted November 22nd 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

around hives up to 6 km during good weather (*Atanassova et al.*, *Bilandžić 2016; et al.*, 2019; *Bogdanov et al.*, 2007). From flower nectar as raw material to the final product, honey undergoes a complex process of sugar conversion by bee enzymes and maturation in combs. Presence and quantity of microelements in nectar depends on the mineral composition of the vegetation. There are metabolic processes of plants resulting in avoidance or tolerance of certain elements, including toxic elements. Plants have several evolution mechanisms for surviving in polluted environment, or to control the level of toxic elements intake.

2. Mineral composition of honey

From flower nectar as raw material to the final product, honey undergoes a complex process of sugar conversion by bee enzymes and maturation in combs. The mineral composition of nectar depends on the mineral composition of the vegetation. There are metabolic processes of plants resulting in avoidance or tolerance of certain microelements, including toxic elements. Plants have several evolution mechanisms for surviving in polluted environment, or to control the level of toxic elements intake. The major minerals in honey have nectar-producing plants origin. Mineral composition of honey indicates type of honey. Honeydew, dark and forest honey is richer in minerals comparing to monofloral honey. The presence of heavy metals (Pb and Cd) and toxic elements (Cr and As) in honeydew honey has been reported in some studies suggesting its origin from environmental, soil contamination, pest treatment, and unsuitable procedures in the processing and conservation of honey (*Atanassova et al*., 2016). Range of minerals in honey can be from 0,04% in pale honey, e.g., black locust to 0,20% in darker, forest honey (*Bogdanov et al*., 2007). Likewise, content of minerals in honey is reflection of environment, mineral content of soil, water, pollen and nectar of plants. Serbian Regulative is synchronized with (EU) 2023/915, setting **maximum residue level** (MRL) for Pb in honey, 0,1 mg/kg. Regarding data from different studies (Table 1), average values of Pb are considerably below MRL, except for higly contaminated mining areas from Kosovo* (*Kastrati et al*., 2023). Microelements are distributed in honey in sense that Zn is the most abundant compared to other elements, as potassium is the most abundant macroelement. Average content of minerals and toxic elements in honey from some studies is presented in Table 1.

3. Mechanisms of toxic element intake control

"Avoidance" is the first line of defence to restrain uptake of toxic elements and limit their distribution into plant tissues through root system. It consists of extracellular mechanisms, such as metal ion precipitation, and metal exclusion (*Dalvi and Bhalerao*, 2013). Exposure to heavy metals, can cause excretion of organic acids and amino acids by root system that make stable complexes that stay in soil and can´t enter the plant, or change the pH of soil and precipitations of heavy metals occurs. Existence of mycorrhizas can obstruct absorption of toxic elements into the plant, leaving them in rhizosphere by absorption, adsorption, or chelation. (*Dalvi and Bhalerao*, 2013). Embedding the heavy metals in the plant cell walls is another mechanism of heavy metal avoidance (*Memon and Schröder*, 2009). Cell wall has carboxylic groups of polygalacturonic acid are negatively charged and can bind heavy metals. In this way, the uptake of toxic elements into plant tissue is prevents thanks to the cell wall. Once the toxic element ions entry the cytosol, tolerance strategy is adopted by the plants to cope with the toxicity of accumulated metal ions. It is the second line of defence at intracellular level through various mechanisms such as inactivation, chelation, and compartmentalization of toxic element ions.

4. Potential health hazards resulting from honey consumption

Besides environmental concerns regarding honey element composition, quality control of honey is also important given the increase in total honey production and demands of the largest honey market of EU (*Bilandzic et al*., 2012). Parameters for honey quality are defined in Codex Alimentarius and transferred into national regulations. In that manner essential composition and quality factors are (moisture content, fructose and glucose content (and ratio), sucrose content, water insoluble solids content, free acidity, diastase activity, hydroxymethylfurfural, electrical conductivity), toxic elements, residues of pesticides and veterinary drugs, hygiene, declaring (CXS 12–1981). There are no specific national regulations regarding the presence of toxic elements, whose origin in honey is usually anthropogenic. A Codex Alimentarius statement is that honey shall be free from metals in amounts which may result in a hazard to human health and this statement is included in the

Table 1. Average content of microelements and toxic elements in honey from different studies, expressed as mg/kg

Honey, Contry of origin	Mark of microelements and toxic elements										Author
	Fe	Mn	Cu	Zn	Co	Ni	Pb	As	Cr	Cd	
Black locust, Italy	3.67–5.39	0.1–0.6	<0.05–0.05	<0.05	<0.05	0.51–066	<0.002–0.006	<0.01	0.66–0.74	<0.01	(Meli et al., 2018)
Wildflower, Italy	3.46–7.28	0.5–2.5	0.11–0.49	<0.5–1.6	<0.05	0.42–0.69	0.005–0.017	<0.001–0.01	0.53–0.96	<0.01	
Multiflower, Poland	<0.002–1.256		0.002–0.464	0.004–1.048	0.001–0.007	0.0022–0.266	Nt**	0.00008–0.004	0.003–0.0037	Nt	(Ligor et al., 2022)
Multiflower, Kosovo*	0.57–15	0.15–8.0	0.52–9.50	0.75–14	0.0042–0.240	0.024–1.2	0.05–2.1	0.0021–0.025	0.06–2.1	0.0098–0.27	(Kastrati et al., 2023)
Black locust, Serbia	1.57±1.58	1.55±6.01	0.22±0.12	2.8±11.3	0.11±0.31	0.067±0.056	Nt	Nt	0.068±0.089	0.003±0.007	(Jovetic et al., 2017)
Linden, Serbia	1.44±1.01	1.56±0.89	0.25±0.08	1.4±1.0	0.07±0.14	0.025±0.026	Nt	Nt	0.051±0.061	0.001±0.003	
Multiflower, Brasil	<0.72–47.0	0.29–4.62	<0.07–0.95	<1.1- 2.94	Nt	Nt	Nt	<1.6–3.25	Nt	<0.04–0.29	(Oliveira et al., 2019)
Multiflower, Croatia	1.3±1.1	2.1±4.8	0.37±0.3	1.4±1.4	0.019±0.01	0.193±0.108	0.009±0.019	<0.002	0.05±0.074	<0.001	(Bilandzic et al., 2019)
Black locust, Croatia	0.57±0.5	0.22±0.2	0.12±0.1	0.63±0.6	0.051±0.031	0.281±0.26	0.0078±0.012	<0.002	0.024±0.097	<0.001	
Linden, Croatia	1.3 ± 1.0	0.94±0.7	0.24 ± 0.2	0.63±0.2	0.099±0.006	<0.033	0.023±0.012	<0.002	<0.004	<0.001	
Linden, Serbia	2.25–5.59	0.21–1.12	Nd***–0.71	1.12–20.36	Nt	Nd	Nd	Nd	Nd	Nd-0.02	(Mracevic et al., 2020)
Multifloral, Serbia	0.79–3.54	0.31–2.05	Nd	0.77–7.68	Nt	Nd	Nd	Nd	Nd	Nd-0.15	
Black locust, Serbia	3.16–3.91	0.54–0.66	Nd	0.38–1.08	Nt	Nd-0.05	Nd	Nd	Nd	Nd-0.02	
Black locust, Serbia	1.3	Nt	0.147	1.57	Nt	Nt	0.004	0.004	Nt	0.003	(Ciric et al., 2020)
Black locust, Hungary	0.43	Nt	0.13	1.58	Nt	Nt	Nt	Nt	14.5	Nt	(Czipa et al., 2015)

Nt** – not tested; Kosovo* – This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence; Nd*** - not detected (bellow limit of detection)

Codex Alimentarius (*Codex Alimentarius*, 2001) and incorporated as well, in Regulation of countries. The Codex maximum level (ML) for a contaminant in a food or feed commodity is the maximum concentration of that substance recommended by the Codex Alimentarius Commission to be legally permitted in that commodity. For toxic elements considered by the Directive 96/23/EC, no limits have apparently been established (EC, 1996) in honey. The Directive 2001/110/EC of the EU Commission relating to honey includes some general and specific properties of honey composition but no guidelines with respect to the content of toxic elements (*European Commission*, 2001). The regulation EC 1881/2006, which set the maximum levels for certain contaminants in foodstuff, does not address honey bee products (*European Commission*, 2006), except for the ML of Pb (0.10 mg/kg). Consequently, there are currently no legal criteria to compare the results obtained in presented studies (Table 1). A recommendation from the Joint Food and Agriculture Organization of the United Nations and Worl Health Organization (FAO/WHO) Expert Committee on Food Additives (JECFA) concerning the maximum tolerable or allowable intake, based on a full evaluation of an proper toxicological database, should be the main basis for decisions by Codex member. However, to have a frame for comparison, the maximum limits of Pb and Cd permitted by EC Regulation 1881/06 in bivalve mollusks (1,5 ppm for Pb and 1 ppm for Cd) were taken as reference considering the characteristics of bioaccumulation in bees and annual per capita consumption of honey. Former legislation of Serbia had prescribed MRL values for certain elements in honey. According to the Rulebook (*Official Gazette of the FRY* 5/92, 11/92, 32/02, 25/10 and 28/11), the criteria for the MRL quantities were prescribed in honey, respectively for Pb, Cd, Zn, As, Cu and Fe are 0,5; 0,03; 10; 0,5, 1 and 20 mg/kg. These criteria are withdrawn due to alignment process of Serbian and EU regulative. Before EU regulative criteria, each country had its own MRLs for toxic elements in honey, e.g., Polish standards were 0,4–0,5 mg/kg for Pb, 0,1 mg/kg for Cd, and 10 mg/kg for Cu in pollen and honey. In Finland, criteria for toxic elements in honey as category of "other food" were 0,3 mg/kg for Pb, 0,1 mg/kg of Cd, 10 mg/kg of Cu, 0,5 mg/kg of Hg and 50 mg/kg of Zn (*Fakhimzadeh and Lodenius*, 2000).

China has established MRL value for lead in honey 1 mg/kg (CH18025), and Vietnam etsablished MRL for As to 1,0 mg/kg, for Cd to 1,0 mg/kg, for Pb to 2,0 mg/kg and for Hg to 0,05 mg/kg. Russian regulative regarding toxic elements is not revised since SSSR period, and does not have criteria for toxic elements in honey (*Dudarev et al*., 2019). USA Food and Drug Administration (FDA) has set general criteria for toxic elements in food: toxic elements as lead (as Pb), not more than 10 parts per million; arsenic (as As), not more than 3 parts per million, mercury (as Hg), not more than 1 part per million (CFR FDA, 2023). The reason for lack of MRLs in honey for toxic elements could be explained in several manners. Honey is nutritious and precious food used as sugar source, and minor component of meals. It is more important for major ingredients to have set and met MRL values. Honey as well as other foodstuff is rather studied in sense of intake per kg of body mass, that includes multielement approach and nutritive aspect. Studies and forming of different food databases enabled risk management and knowledge of what contaminants can be expected in certain food, including toxic elements. Though, it is expected to detect mercury in fishery products, so the limits are set for this group of foods, and probably honey is proven over the years that is not common grocery to accumulate mercury. Studies showed that mercury was not detected in any sample of bees or apiary products tested (*Spiric et.al*, 2019, *Ciric et al*., 2020). It is also important to consider that honey is source of energy in hive, and bees as well as other living creatures have tendency to decontaminate source of energy and life to enhance survival and wellbeing of next generations.

FDA organized Total Diet Study (TDS) to monitor toxic elements in the USA food supply from traders from all states. From testing 3,241 samples of 305 foods during 2018 through 2020, cadmium was reported in 61% of samples from the TDS survey, including 98% of vegetable samples and 28% of fruit samples. Predominant highest mean concentrations of cadmium were detected in sunflower seeds, spinach, potato chips, leaf lettuce, and French fries. Lead and arsenic were detected in 15% and 43% of the food samples. Arsenic was detected at higher levels than Cd. The highest concentrations of inorganic arsenic were reported for certain foods, including crisped rice cereal, white rice, and baby foods such as puffed snacks, dry rice cereal and multi-grain cereal (*USDA*, 2017). The Joint FAO/WHO Expert Committee on Food Additives has designed for Ni a Provisional Tolerable Weekly Intake (PTWI) of 2,45 mg (*JECFA*, 2006). For inorganic As, a PTWI of 1,05 mg. Value of 0,3 mg Hg was indicated as PTWI for a 70 kg person (*FAO/WHO*, 2010a). A Provisional Tolerable Monthly Intake (PTMI) of 1,75 mg was outlined for Cd (*FAO/WHO*, 2010b) and for Pb a PTWI of 1,75 mg was created. Therefore, although the honey samples are not completely pollution free, toxic element intake from honey is considerably bellow the recommended dose and, from this point of view, the consumption of these honey products is not considered dangerous for human health. (*Meli et al*., 2018). According to the standard values determined by Codex Alimentarius Commission, the maximum Fe value that can be found in sweet nutrients such as sugar and honey is reported as 15 µg/g. The maximum Pb value that must be found in sweet substances such as sugar and honey is determined as 0,3 µg/g by Codex Alimentarius Commission. According to the standards determined by the Codex Alimentarius Commission, the maximum Zn value that must be found in sweet nutrients such as sugar and honey is 5 µg/g.

5. Conclusion

Haevy metals and other toxic elements in honey are naturally occurring. They are found in smaller amount than in other bee products, because honey is the main source of energy for hive, so there is trend in minimizing exposure of beehive comunity to toxic elements through energy source. That sort of decontamination provides clean source of food for bees and healthy swarm of bees. Honey produced in that manner by bees is very desirable food product and ingredient, acceptable for pharmacy industry as well for nutrition of sensitive part of population, with the exception of children up to the age of one. Existing data from studies of toxic elements and haevy metals in honey show that their content is lower than ML values by Codex Alimentarius (Table 1).

Uporedna analiza međunarodnih kriterijuma u pogledu mikroelemenata i toksičnih elemenata u medu

Danka Spirić, Jelena Ćirić, Silvana Stajković, Mirjana Dimitrijević, Čaba Silađi, Srđan Stefanović i Vesna Đorđević

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

Ključne reči:
Med
Mikroelementi
Toksični elementi
Zakonska regulativa

A P S T R A K T

Med je osnovni izvor energije za pčele i prirodni zaslađivač za ljudsku ishranu. Koristi se i u apiterapiji, jer je bogat ugljenim hidratima, mikronutrijentima, vitaminima i prebioticima. Ovakva specifična upotreba zahteva visok kvalitet i bezbednost meda i proizvoda od meda. Kriterijumi za kvalitet meda su standardizovani i regulisani Codex Alimentariusom, gde su definisani med, vrste meda i granice kvaliteta meda. Za članice Evropske unije (EU) na snazi je Direktiva Veća 2001/110/EC, za Sjedinjene američke države (SAD) to su američki standardi za klasifikovanje meda koji su stupili na snagu 23. maja 1985., za Kinu su nacionalni standardi Narodne Republike Kine, GB 14963–2011, Nacionalni standard o bezbednosti hrane, za Srbiju Pravilnik o kvalitetu i drugim zahtevima za med, druge pčelinje proizvode, preparate na bazi meda i druge pčelinje proizvode (Pravilnik o kvalitetu meda i drugih proizvoda pčela („Sl. glasnik RS" 101/2015). Što se tiče toksičnih elemenata, postoje kriterijumi za zemlje EU, slični SAD i Kini, koji definišu kriterijume samo za sadržaj Pb u medu postavljen na 1 mg/kg maksimalni rezidualni nivo (MRL). Nacionalni kriterijumi za nekoliko toksičnih elemenata bili su prisutni u zakonodavstvu, ali su tokom vremena nacionalni kriterijumi sinhronizovani sa kriterijumima EU.

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

Acknowledgment: This paper was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project "Selected biological hazards to the safety/quality of food of animal origin and the control measures from farm to consumer" (31034).

References

Atanassova, J., Pavlova, D., Lazarova, M. & Yurukova L. (2016). Characteristics of Honey from Serpentine Area in the Eastern Rhodopes Mt., Bulgaria. *Biological Trace Element Research,* 173 (1), 247–258, doi: 10.1007/s12011-015-0616-9

Bilandžić, N., Sedak, M., Đokić, M., Bošković, A. G., Florijančić, T., Bošković, I., Kovačić, M., Puškadija, Z. & Hruškar, M. (2019). Element content in ten Croatian honey types from different geographical regions during three seasons. *Journal of Food Composition and Analysis*, 84, 103305.

Bogdanov, M., Haldimann, W., Luginbull & Gallmann, P. (2007). Minerals in honey; Environmental geographical and botanical aspects. *Journal of Apicultural Research*, 4690, 4, 269275.

Calatayud-Vernich, P., Calatayud, F., Simó, E., Pascual, Aguilar, J. A. & Picó, Y. (2019). A two-year monitoring of pesticide hazard in-hive: High honey bee mortality rates during insecticide poisoning episodes in apiaries located near agricultural settings. *Chemosphere*, 232, 471–480, https://doi.org/10.1016/j.chemosphere.2019.05.170.

Codex Alimentarius General standard for contaminants and toxins in food and feed cxs 193–1995 adopted in 1995 revised in 1997, 2006, 2008, 2009 amended in 2010, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019.

Codex Alimentarius Standard for honey cxs 12–19811 Adopted in 1981. Revised in 1987, 2001. Amended in 2019, 2022.

Czipa, N., Andrási, D. and Kovács, B. **(2015)**. Determination of essential and toxic elements in Hungarian honeys. *Food Chemistry*, 175, 536–542, https://doi.org/10.1016/j.foodchem.2014.12.018.

Ćirić, J., Đorđević, V., Trbović, D., Baltić, T., Branković Lazić, I., Matović, K., Janković, S. & Parunović, N. (2020). Risk assessment of toxic elements in acacia honey. *Meat Technology*, 61 (1), 70–74, https://doi.org/10.18485/meattech.2020.61.1.6

Dalvi, A. A. & Bhalerao, S. A. (2013). Response of plants towards heavy metal toxicity: an overview of avoidance, tolerance and uptake mechanism. Annals of Plant Sciences, 2, 362–368.

Dudarev, A., Chupakhin, V., Vlasov S. & Yamin-Pasternak, S. (2019). Traditional Diet and Environmental Contaminants in Coastal Chukotka III: Metals. *International Journal of Environmental Research and Public Health,* 16, 699, Doi.10.3390/ijerph16050699.

Đogo, Mračević, S., Krstić, M., Lolić, A. & Ražić S. **(2020).** Comparative study of the chemical com-position and biological potential of honey from different regions of Serbia. *Microchemical Journal*, 152, 104420, https://dx.doi.org/10.1016/j.microc.2019.104420

European Commission (2006). Commission Regulation No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.

European Commission (1996). Council Directive 96/23/CE of 29 April 1996 on measures to monitor certain substances and residues in live animals and animal products, Official Journal of the European Communities, Brussels, 23 May 1996.

European Commission (2001). Council Directive 2001/110/EC of 20 December 2001 relating to honey, Official Journal of the European Communities, Brussels, 12 January 2002.

Fakhimzadeh, K. & Lodenius M. (2000). Heavy metals in Finnish honey, pollen and honey bees. *Apiacta*, 35 (2), 85–95.

FAO/WHO, (2010a). Evaluation of Certain Food Additives and Contaminants. Seventy-second Report of the Joint FAO/WHO Expert Committee on Food Additives, Rome, February 16–25, 2010., WHO Technical Report Series No. 959 Geneva, Switzerland.

FAO/WHO (2010b). Evaluation of Certain Food Additives and Contaminants. Seventy-third Report of the Joint FAO/WHO Expert Committee on Food Additives, Geneve 2010., WHO Technical Report Series No. 960 Geneva, Switzerland.

FDA CFR — Code of Federal Regulations Title 21, Volume 3, TITLE 21–food and drugs chapter I–Food and Drug Administration Department of Health and Human Services subchapter b — food for human consumption (continued).

JECFA (Joint FAO/WHO Expert Committee on Food Additives) (2003). Summary and conclusions of the sixty-first meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), pp. 18–22. Available on http://www.who.int/pcs/jecfa/Summary61.pdf

Jovetić, M., Trifković, J., Stanković, D., Manojlović, D. & Milojković-Opsenica, D. (2017). Mineral Content as a Tool for the Assessment of Honey Authenticity. *Journal of AOAC International*, 100 (4), 862–870, doi:10.5740/jaoacint.17-0145

Kastrati, K., Sopaj, F., Tašev, K., Stafilov, T., Šajn**, R. & Paçarizi M. (2023).** Analysis of chemical elements in honey samples in the territory of Kosovo. *Journal of Food Composition and Analysis*, https://doi.org/10.1016/j.jfca.2023.105505.

Ligor, M., Kowalkowski, T. & Buszewski, B. (2022). Comparative Study of the Potentially Toxic Elements and Essential Microelements in Honey Depending on the Geographic Origin. *Molecules*, 2627 (17), 5474, doi: 10.3390/molecules27175474.

Mejías, E. & Garrido, T. (2017). Analytical Procedures for Determining Heavy Metal Contents in Honey: A Bioindicator of Environmental Pollution. InTech. doi: 10.5772/66328

Meli, M. A., Fagiolino, I., Desideri, D. & Roselli, C. (2018). Essential and toxic elements in honeys consumed in Italy. *Journal of Toxicology and Environmental Health*, Part A, 1–12, doi:10.1080/15287394.2018.1520160

Memon, A. R. & Schroder, P. (2009). Metal Accumulation in Plants and Its Implication in Phytoremediation. *Environmental Science Pollution*, 16 (2), 162–175.

Oliveira, S. S., Alves, C. N, Morte, E. S. B, de Freitas, A. S. Jr., Araujo, R.G.O., Santos, D.C.M.B. (2019). Determination of essential and potentially toxic elements and their estimation of bio accessibility in honeys. *Microchemical Journal,* 151, https://doi.org/10.1016/j.microc.2019.104221.

Spiric, D., Ciric, J., Djordjevic, V., Nikolic, D., Jankovic S., Nikolic A., Petrovic, Z., Katanic N. & Teodorovic V. (2019). Toxic and essential element concentrations in different honey types. International Journal of Environmental Analytical Chemistry, 99 (5), DOI: 10.1080/03067319.2019.1593972

USDA: National Food Safety Standard Maximum Levels of Contaminants in Foods CH18025 (2021), https://www.fsis.usda.gov/sites/default/files/media_file/2021-02/GB-2762-2017.pdf, unofficial translation

Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S. & Chen, Z. (2020). Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. *Frontiers in Plant Science*, 11, doi:10.3389/fpls.2020.00359.

meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade
https://doi.org/10.18485/meattech.2023.64.3.7

Withdrawal statement by Editorial of Meat Technology

The article “On-farm killing as a method to minimize pre-slaughter stress: a qualitative analysis from Switzerland“ by Lisa Märcz, Anna Francesca Corradini, Eugenio Demartini and Michael Gibbert, pp 432–437, doi:10.18485/meattech.2023.64.2.83, published in Meat technology 64/2 2023 dedicated to 62nd International Meat Industry Conference-meatcon2023 is withdrawn, since according to the opinion of the authors, the procedure for pub- lishing in the Meat technology was not appropriate.

The Editorial team of the journal acted in accordance with the journal’s Editorial policy during the process of submmision, review and acceptance of publishing this article, however at the insistence of the authors, the article will be withdrawn. We conclude that this is the best way to this dispute.

Link to the withdrawal article: https://doi.org/10.18485/meattech.2023.64.2.83

Published in Meat technology 64/3 2023, page 141.

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.

CONCLUSION: 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.

REFERENCES: (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.

Example:

- 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

---

In Meat technology 63/2 2022, on page 1, Muhamed Smailovic is written incorrectly, it shoulwwd be Muhamed Smajlović. On the same page, next to the name Željko Sladojević, instead of Republic of Srpska, should be written Bosnia and Herzegovina.

All corrections were made in the Meat technology 64/1 2023 issue.


carnex
svaki dan je dobar dan

Koraci naše tradicije odjekuju kvalitetom

Kompanija Zlatiborac je osnovana s idejom da se kroz neprekidnu modernizaciju i primenu savremenih tehnologija zadrži tradicionalni koncept proizvodnje zlatiborskih suvomesnatih proizvoda. Specifičnost regije i klimatskih uslova sela Mačkat, prirodan proces sušenja mesa na ruži vetrova i dimljenja na bukovom drvetu, uz primenu jedinstvene recepture, doprineli su da se izdvojimo ne samo na domaćem, već i na inostranim tržištima.

Poslovni proces se odvija u okviru savremenih kapaciteta i opreme, na 40.000 m^2 proizvodnog prostora, uz ispunjavanje najvažnijih standarda i sertifikata za kvalitet i bezbednost hrane: HACCP, IFS, EAC. Proizvodni portfolio se neprekidno unapređuje, a sadržan je u dve kategorije, trajnih i polutrajnih suvomesnatih proizvoda. Proizvodi su dostupni u tri vrste pakovanja, vakuumu, rinfuzu i zaštitnoj atmosferi.

Zlatiborac brend se posebno izdvaja po komparativnim prednostima u odnosu na konkurenciju, te u segmentu „slajs-pakovanja", o čijim funkcionalnim benefitima neprekidno edukuje svoje potrošače, zauzima lidersku poziciju na tržištu. Kao proizvođač, „Zlatiborac" je jedini koji svoje suvomesnate proizvode seče tanko i koso, pod uglom od 38 stepeni.

Sveobuhvatnu pažnju poklanjamo čistoći i higijeni, a u prostoru „bela soba" u kome nastaju upravo ovi slajs-proizvodi vlada apsolutni princip kontrolisanja strujanja vazduha koji eliminiše svako prisustvo neželjenih čestica, baš kao u hirurškoj sali. Besprekorne uslove obezbeđujemo filtracijom vazduha, merenjem i regulacijom prečišćavanja, dok se vazduh u našim „belim sobama" u potpunosti promeni čak 18 puta u toku jednog sata.

Godinama unazad, „Nemačko poljoprivredno društvo" (DLG), kao vodeća evropska institucija za bezbednost i unapređenje kvaliteta hrane nagrađuje zlatiborac proizvode najvišim ocenama i medaljama za kvalitet. Ova posebna nagrada dodeljuje se proizvođačima koji su u prethodnih pet godina ostvarili natprosečan uspeh u takmičenju, a „Zlatiborac" je prva kompanija s naših prostora koja je dobila ovo važno priznanje. Kontinuirana posvećenost kvalitetu proizvoda i stalna ulaganja u tehnološki proces koji prati važne svetske standarde u prehrambenoj industriji doneli su „Zlatiborcu" ovo svetsko priznanje koje jasno govori da su tradicionalne recepture sušenja suvomesnatih delikatesa sinonim za kvalitet i na svetskom tržištu. Do kraja 2022. godine dodeljeno je ukupno 95 zlatnih i 40 srebrnih DLG medalja.

U „Zlatiborcu" danas radi više od 650 ljudi koji svojom marljivošću i posvećenošću doprinose ostvarivanju korporativne misije, negujući vrednosti integriteta, doslednosti, usmerenosti na rezultate i kreativnosti. U dodiru tradicije i jedinstvenog prirodnog ambijenta nastali su izvorni proizvodi, a u kompaniji ponosno ističemo da je tradicija garancija našeg umeća, a priroda izvor naše snage. Život u skladu s prirodom je jedna od osnovnih odrednica naše korporativne kulture.

U godinama koje dolaze, nastavićemo da ostvarujemo naše ciljeve u povećanju obima proizvodnje, povećanju udela na domaćem i inostranom tržištu, u osvajanju novih tržišta, unapređenju kvaliteta i bezbednosti proizvoda, uz očuvanje životne sredine.

Misija „Zlatiborca" je stvaranje stabilne, organizovane i snažne kompanije, koja će stalnim inovacijama, ulaganjem u kvalitet, tehnologiju, opremu, edukaciju i obuku zaposlenih, stvoriti proizvod koji će svojim istaknutim karakteristikama odgovoriti potrebama i željama zahtevnih savremenih potrošača.

Hvala vam na poverenju.

Matijević
INDUSTRIJA MESA NOVI SAD
Kukuruz, pšenica, ječam soja, suncokret, šećerna repa...
Agronom
KONTROLA
· Rodnost
· Kvalitet
· NON GMO
KONTROLA
tehnolog stočarstva
Vlaga ·
Toksini ·
Proteini ·
STOČNA HRANA
SA NAŠIH FARMI
ušna markica A-01 000001
GODIŠNJE KLANJE
300.000 Tovljenika
10.000 Junadi
7.000.000 Pilića
INDUSTRIJA MESA MATIJEVIĆ
Veterinar
KONTROLA
Tehnolog proizvodnje
KONTROLA
kvaliteta proizvoda
100 KAMIONA
Godišnja otprema robe: 45.000 t
162 PRODAJNA OBJEKTA
matijevic.rs
Industrija mesa "Matijević" doo, 21 000 Novi Sad, Rumenački put 86

NOVO

OD PILEĆEG FILEA I BATAKA

Tako fina Patelina

Natur
ZA BATU
ZA MAMU
ZA DEKU
ZA SEKU
ZA TATU
ZA BAKU
PROIZVEDENO U SRBIJI
SVI VOLE
Domaće
Perutnina Ptuj


YUHOR
Još od 1902.
YUUHOOR!
Dobar ukus
na dobrom glasu