

Copyright: The author/s
This work is licensed under a CC-BY 4.0 license
(*) Corresponding author
Peer review method: Double-blind
Original research article
DOI: 10.20544/HORIZONS.1.1.24.P11
Section B



ENHANCING QUALITY AND EXTENDING SHELF LIFE: THE ROLE OF γ -IRRADIATED BLACK PEPPER (*PIPER NIGRUM*) IN MORTADELLA PRESERVATION DURING COLD STORAGE

Vladimir Kitanovski

Faculty of Technological Sciences, Mother Teresa University - Skopje

ORCID ID: <https://orcid.org/0000-0002-5547-6765>

Email: vladimir.kitanovski@unt.edu.mk

Nora Limani Bektashi*

Faculty of Technological Sciences, Mother Teresa University - Skopje

ORCID ID: <https://orcid.org/0000-0002-0291-2623>

Email: nora.limani@unt.edu.mk

Olga Popovska

Faculty of Technological Sciences, Mother Teresa University - Skopje

ORCID ID: <https://orcid.org/0000-0002-0707-8762>

Email: olga.popovska@unt.edu.mk

Suzana Jordanovska

Faculty of Technological Sciences, Mother Teresa University - Skopje

ORCID ID: <https://orcid.org/0000-0001-9344-1427>

Email: suzana.jordanovska@unt.edu.mk

Sani Demiri

Faculty of Technological Sciences, Mother Teresa University - Skopje

ORCID ID: <https://orcid.org/0000-0001-7756-3758>

Email: sani.demiri@unt.edu.mk

Irina Mladenoska

Faculty of Technology and Metallurgy, Ss. Cyril and Methodius University - Skopje

ORCID ID: <https://orcid.org/0000-0003-4517-7179>

Email: irinaetf@t.mk

Hristina Spasevska

Faculty of Electrical Engineering and Informational Technology, Ss. Cyril and Methodius University - Skopje

ORCID ID: <https://orcid.org/0000-0003-3566-7596>

Email: hristina@feit.ukim.edu.mk

Abstract

*The aim of this study was to assess the impact of incorporating γ -irradiated black pepper (*Piper nigrum*) at the maximum approved radiation dose of 10 kGy on the quality characteristics and shelf-life of sliced mortadella bologna-type sausage (IBP) stored at 4 ± 2 °C for 21 days in vacuum packaging. The sterility of the black pepper grains was confirmed using the standard*

microbiological agar plate method, revealing < 0.01 log cfu/g microbial activity, a state maintained after the pepper's addition at 1.5% of the total sausage mass. This led to an extended lag phase in microbial growth within the IBP samples during storage, positively influencing various sensory and biochemical parameters. Statistically significant improvements ($p \leq 0.05$) in hardness and color intensity were observed by the 14th day, enhancing overall appearance and resulting in lower TVB-N values due to decreased microbial activity. These findings suggest that γ -irradiated black pepper can enhance the quality and extend the shelf-life of mortadella bologna-type sausages during cold storage in normal atmosphere packaging.

Keywords: γ -irradiated black pepper, mortadella bologna type sausage, quality characteristics, cold storage shelf-life.

INTRODUCTION

Hot-cured sausages constitute a significant portion of the meat products in the European market, particularly in the Western Balkan countries. Among these, mortadella is recognized as a high-quality product. It is well established that during shelf life, changes occur in sensory, biochemical, and microbiological characteristics Fernandez-Lopez et al., (2003); (2005); Indzhelieva et al., (2015). Among chemical indicators, biogenic amines—particularly putrescine and cadaverine—have been proposed as markers for determining meat quality Ivanov et al., (2016). These processes of quality deterioration significantly reduce the nutritional value of sausages Dragoev et al., (2016). Additives used in the processing of meat products, such as nitrates and nitrites, can delay rancidity Rysha et al., (2021).

The primary microorganisms present in raw meat and meat products include aerobic bacteria such as *Pseudomonas* spp., *Bacillus* spp., and facultative anaerobes like *Escherichia* spp., *Brochothrix* spp., *Lactobacillus* spp., *Salmonella* spp., and *Staphylococcus* spp. Viuda-Martos et al., (2010). The presence of these undesirable microorganisms can lead to serious foodborne illnesses, posing significant health risks to humans. Additionally, they can cause the production of ammonia, trimethylamine (TMA), and dimethylamine (DMA) in spoiled meat Cai et al., (2011).

Lipid oxidation is one of the most critical issues affecting the chemical deterioration of meat during cold storage Choe & Min, (2009). It leads to a decline in quality characteristics, reviewed through a multistage system perspective, beginning with a decrease in nutritional properties, including the loss of essential fatty acids, which can negatively impact sensory characteristics and cause deterioration in flavor, texture, and color Pratt et al., (2011).

In response to these challenges, the meat industry continuously works on developing effective additive combinations to ensure product safety while also striving to enhance the nutritional and quality characteristics of processed meat products Doménech-Asensi et al., (2013).

γ -ray irradiation of food is emerging as a potential solution for pre-treating additives in processed meat products Suhaj, (2006). The primary expectations from these pre-treatments include reducing microbial growth and extending the lag phase, which in turn can result in an extended shelf life of meat products.

Irradiation is an effective form of food preservation that prolongs shelf life and reduces spoilage Saeideh et al., (2021). It can be achieved using low-dose, medium-dose, or high-dose levels of radiation. Low-dose irradiation (<2 kGy) is used to delay the aging of vegetables and fruits; medium-dose irradiation (between 1 and 10 kGy) is used to reduce the levels of pathogenic organisms, similar to pasteurization; and high-dose irradiation (>10 kGy) is used to achieve

sterility Morehouse & Komolprasert, (2004).

The Directive 1999/3/EC states that foods and food ingredients from an established list (covering 25 countries) can be treated with γ -rays with a maximum absorption of up to 10 kGy for dried aromatic herbs, spices, and vegetable seasonings. The FDA limit for culinary herbs, seeds, spices, vegetable seasonings, and blends of these aromatic vegetable substances is up to 30 kGy Code of Federal Regulation, (2004).

Based on this, the objective of the study was to evaluate the effect of gamma-irradiated black pepper (10 kGy) on the quality characteristics and shelf life of mortadella under household cold storage conditions (4 ± 2 °C).

MATERIALS AND METHODS

Twelve Experimental design. Research work in this article was divided in two main pillars. First the irradiation of whole black pepper grains was made and then the microbial analyses for evaluation of black pepper sterility was made.

The preparation of samples, precisely mortadella sausages was made in two groups. Control group (C) and experimental group (IBP) with total mass of 5 kg.

Manufacturing process was done on traditional way known for mortadella with just whole grains of black pepper.

Meat as percentage of 100%: contained 65% lean meat and 35% backfat; during emulsification meat never extended 2 °C, 15% water (ice w/w) was added and as Additives: 3% potato starch, 0.5% sodium ascorbate, 0.15% sodium nitrite, as Spices: commercial spices 1.5% and 15 grams (1.5%) whole black pepper grains.

Fat cubes and black pepper were added after emulsification phase and the whole mix was just stirred on low speed.

Mixture was filled in laminate polyethylene-polyvinyl dichloride sausage casings and thermally processed for 3 hours on 75–80 °C.

Next step was cooling with running water for one hour and then transferred into refrigerator for 6 hours, while the temperature decreases to 1 °C on the surface. The whole sausages were sliced and packed in a minimal vacuum sealing pressure of 5 mbar. Tabletop vacuum machine model VA-400 from Jiangsu Tenglong Packing Machinery Co., Ltd was used.

One difference between the control and experimental sample was the use of γ -irradiated black pepper in the experimental samples of mortadella.

Mortadella sausages were manufactured at Andonov dool Sveti Nikole, North Macedonia.

γ -irradiation and microbial analyses of black pepper grains. Irradiation is a non-thermal technique for decontamination.

For this study, samples of black pepper were obtained from the food processing factory AD Vitaminka Prilep, North Macedonia.

Samples were irradiated by ^{60}Co γ -rays at absorbed dose of 10 kGy. The material was irradiated at the Vinča Institute of Nuclear Sciences, University of Belgrade (Belgrade, Republic of Serbia).

The conventional agar plate method was used as a standard microbiological method, in order to evaluate the effect of irradiation on TVC at black pepper samples in the laboratory of Ss. Cyril and Methodius University, Faculty of Technology and Metallurgy, Skopje, North Macedonia.

Sensory evaluation. Discriminative, or difference testing, methods were used to determine

differences in specific attributes like appearance, color intensity, shine, odor, acid taste, hardness and juiciness of mortadella using the Degree of Difference method with 5 points where 1 is very large difference from initial stage and 5 is no difference. This means that at the initial phase the grades were all 5 and during the storage they will decrease ASTM, (1986).

Preparation of samples for physicochemical analysis. Average laboratory samples were prepared by homogenization. From every group average laboratory sample was taken and then, the quantity required was calibrated, as described in the appropriate methods for research.

pH value was measured directly with the use of bevel needle pH electrode of digital pH meter BIOBASE Benchtop (PRC) pH/mV 210.

Acid value was measured using free fatty acids as an indication of hydrolytic rancidity of extracted fat according to the Bligh & Dyer, (1959) modified by Gheisari (2011). FFA in the fat extracted from a mortadella sample was determined by titration with a solution of 0.1 N potassium hydroxide (KOH) and with phenolphthalein as an indicator. The acid value (or free fatty acid content) was determined by AOAC method 940.28 AOAC, (2012).

Peroxide value POV was determined spectrophotometrically based on the oxidation of Fe^{2+} to Fe^{3+} in the presence of hydroperoxides and the formation of a colored complex between obtained Fe^{3+} and SCN^- as described by Hornero-Méndez et al., (2001). The absorbance at 470 nm was measured against the water blank sample (correction of the spectrum baseline at 670 nm was performed). The absorbance was measured by spectrophotometer SPUV 1000 DLAB (DLAB Scientific Co., Ltd. Beijing Airport Economic Core Zone, Shunyi District, Beijing 101318, China).

TBARS was determined using the method of (Botsoglou et al., 1994), following recommendations of Jebelli et al., (2012). A 2 g sample was transferred into a 25 mL centrifugated tube, and volumes of 5% aqueous TCA (8 cm³), and 0.8 mL BHT in hexane (5 cm³) were successively added. The content of the tube was Ultra-Turraxed for 30 s at high speed and centrifugated for 3 min at 3000 g, and the top hexane layer was discarded. The bottom aqueous layer was made to a 10 mL volume with a 5% TCA, and 2.5 cm³ aliquot was pipetted into a screw-capped tube to which a volume (1.5 cm³) of 0.8% aqueous TCA was added. Following incubation for 30 min at 70°C, the tube was cooled under tap water, and reaction mixture was submitted to third-derivative spectrophotometry against blank reaction mixture. Aliquots of standard solutions were pipetted into screw-capped tubes and diluted to 2.5 cm³ volume with 5% TCA. A 1.5 cm³ 0.8% TCA was added in each tube and the reaction was carried out as prescribed. Calibration curves were constructing by plotting values of peak height at 521.5 nm were measured using single ray spectrophotometer SPUV 1000 DLAB (DLAB Scientific Co., Ltd. Beijing Airport Economic Core Zone, Shunyi District, Beijing 101318, China), as they are printed on the instrumental chart in arbitrary units, versus known concentration of MDA in the final reaction mixtures. MDA in samples was calculated using formula:

$$MDA = \frac{16 \cdot C \cdot V}{W} \mu g/kg$$

C is the MDA concentration (mg/cm³) in the sample extracts according to the calibration curve,

V is a dilution factor of sample extract (cm³) if any, and

W is the weight (kg) of the sample.

The total volatile basic nitrogen TVB-N was determined according to the method described by Goulas & Kontominas, (2005). The 5 g to 10 g of laboratory samples was measured. They, were put in distillation flask with 200 cm³ of distillate water, to which were added litmus paper, 10 cm³ of liquid paraffin, 2 g of magnesium oxide mixed with 25 cm³ to 30 cm³ of distillate water. The reaction needed an alkaline reaction (litmus paper supposed to be blue). The distillation

equipment which was used containing: steamer, distillation flask, Liebig condenser, and receiving flask. The 20 cm³ to 30cm³ of H₂SO₄ were put, and 3–5 drops of methyl rot as an indicator were added. After that the samples were titrated in the receiving flask with 0.1N NaOH until changing the color from red to yellow.

Microbiological analysis. Decimal dilutions were performed and 1 mL was removed from each dilution and cultured by the pour plate technique on plate count agar for mesophilic and psychrotrophic counts in triplicate according to the method of Ercolini et al., (2009). The total mesophilic aerobic bacteria count was incubated 72 h at 28 °C. Psychrotrophic count (PTC) was determined in a similar method to that for TVC, except, plates were incubated at 7 °C for 10 days.

Statistical analysis. Obtained data was run in triplicate and results were reported as mean values $\pm$ standard deviation (SD). Data were subjected to analysis of variance (one-way ANOVA Excel 5.0). A p-value less than 0.05 ($p \leq 0.05$) was considered statistically significant.

RESULTS

γ -irradiation of black pepper gave the expected results and at the microbial analyses sterility of black pepper grains was obtained. Similar results were obtained by Horvatova et al., (2007) who spotted significant differences in the antioxidant activity of black pepper grains irradiated with EU limit doses of 10 kGy.

First and very important, results in sensory evaluation showed that irradiation did not have unpleasant impact on aromatic components of black pepper and it is impossible to sense without detection methods Bayram & Delincée, (2004). These findings are in accordance with the obtained results of Balamatsia et al., (2006) who examined the effect of low-dose radiation on microbiological, chemical, and sensory characteristics of chicken meat stored aerobically at 4 °C. At, first day the highest scores were adopted. During storage examined indicators in sensory evaluation showed decreasing trend and at the 21st day of storage they were unacceptable.

Significant differences were detected at the 14th day (presented on Fig. 1 and Fig. 2 below) in favor of experimental sample for hardness and color intensity which led to significant score in overall appearance. We assume that significant differences in sensory parameters were caused due to higher presence of oxidation indicators like FFA and POV and we think that even bigger impact had higher TVB-N values and higher values of microbiological parameters that were obtained on the analyses of the 14th day of storage.

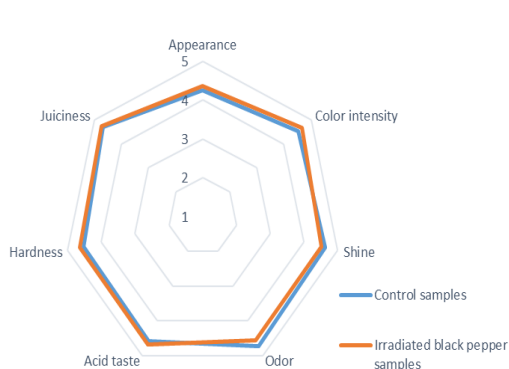


Figure 1. Sensory score at the 7th day of storage at 4 $\pm$ 2 °C

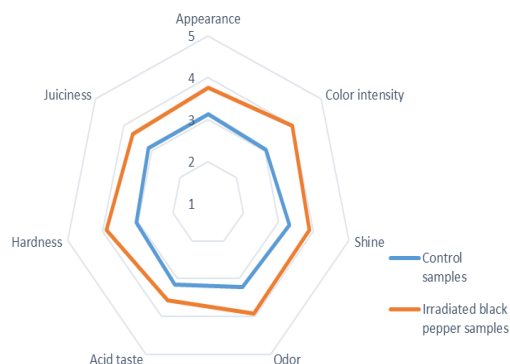


Figure 2. Sensory score at the 14th day of storage at 4 $\pm$ 2 °C

Similar results, regarding significance of sensory score in favor of mortadella's treated with different techniques for increasing antioxidant activity of ingredients and extending shelf life were reported by Thales Leandro et al., (2021); Lee et al., (2008); Kumar et al., (2015).

In mortadella, pH values ranged from 6.42 (initially) to 7.29 and did not show any pattern of increase or decrease (Table 1). The pH values of such products can be expected to be relatively high, attributable to presence of sodium additives Dutra et al., (2017). Values of FFA (a measure of fat status and quality) showed steady increase level during storage and they increased 0.41 to 3.48 at the end of storage for control samples and from 0.78 to 3.37 at the end of storage for IBP samples. This pattern might suggest use of FFA percentage as an analytical indicator to judge the fat quality of mortadella. Al-Abdullah (2004) obtained approximate results for FFA levels of beef and sheep mortadella.

Peroxide value showed increasing trend till the 14th day and reached 0.289 milliequivalents of active oxygen for control and 0.256 for experimental samples then decreased to 0.121 for control and 0.129 for experimental group at the end of cold storage on the 21st day. This variation in PV was due to Hydroperoxide formation is higher than decomposition; therefore, its accumulation in tissue, results with an increased peroxide value. When concentration is high following the breakdown into smaller molecules, the peroxide value decreases.

Absence of significance between samples can be explained because irradiation process does not have antioxidative effect and cannot have effect on primary lipid oxidation processes. Similar results were obtained by Dutra et al., (2017), they examined combined effects of γ -radiation doses and sodium nitrite content on the lipid oxidation and color of mortadella.

Malondialdehyde concentration showed steady increase throughout whole storage time in both samples without significant differences, reaching 0.88 and 0.94 mg/kg for control and irradiated samples respectively. TBARS results in our analyses differ compared to Abdel-Khalek, El-Aziz & Ibrahim (2022); Arshad et al. (2019); Islam et al. (2019); Ham et al. (2017); Li et al. (2017); Yan et al. (2024) who investigated lipid oxidative changes during storage of chicken and pork irradiated meat and detect significant changes in γ -irradiated samples. Our opinion is that γ -radiation of only the main spice black pepper it is not strong enough to cause undesirable changes of the lipid oxidation processes during cold storage of mortadella.

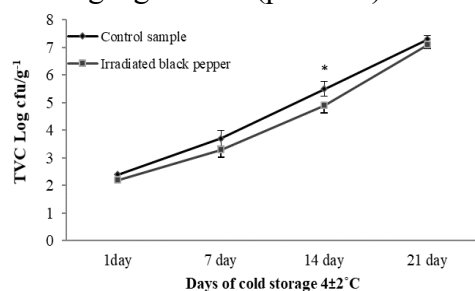
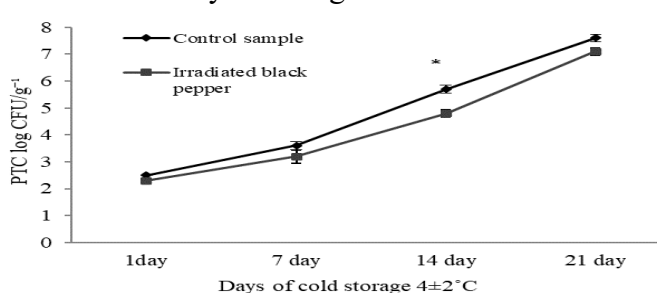
For estimating meat freshness or shelf-life, TVB-N as a product of microbial decarboxylase activity was investigated. TVB-N values showed higher significant differences in control sample on the 14th day of storage, but were below the recommended value of 40 mg N/100 g. In our study, increase of the total viable count were followed by subsequent increases of TVB-N content and many authors stated a clear relationship between the microbiological quality and levels of TVB-N formation Cilla et al., (2006); Bekhit et al., (2021).

Table 1. Analyses of physico-chemical parameters of whole mortadella sausage cuts stored for three weeks at $4 \pm 2^\circ\text{C}$

Examined Parameter	Day 1 Control sample	Day 7 Control sample	Day 14 Control sample	Day 21 Control sample	Day 1 IBP sample	Day 7 IBP sample	Day 14 IBP sample	Day 21 IBP sample
pH value	6.42 ^a ±0.04	7.13 ^b ±0.03	7.21 ^c ±0.05	6.91 ^b ±0.03	6.38 ^a ±0.05	7.09 ^b ±0.02	7.11 ^b ±0.04	6.97 ^b ±0.03
FFA (% oleic acid)	0.81 ^{ab} ±0.01	1.36 ^{ba} ±0.03	2.97 ^{ca} ±0.02	3.48 ^d ±0.04	0.78 ^{ab} ±0.02	1.23 ^{ba} ±0.04	2.85 ^{ca} ±0.03	3.37 ^d ±0.03
Peroxide value (mEq/O ₂ g lipid)	0.027 ^{bc} ±0.01	0.111 ^{cb} ±0.01	0.289 ^{ac} ±0.02	0.121 ^{da} ±0.01	0.031 ^{bc} ±0.01	0.107 ^{cb} ±0.02	0.256 ^{ac} ±0.02	0.129 ^{da} ±0.02
TBARS, mg MDA/kg	0.13 ^c ±0.02	0.19 ^{ca} ±0.03	0.37 ^{cb} ±0.03	0.88 ^{cd} ±0.04	0.14 ^c ±0.02	0.23 ^{ca} ±0.03	0.41 ^{cb} ±0.03	0.94 ^{cd} ±0.08
TVB-N (mg N/100 g sample)	12.32 ^e ±0.11	18.68 ^{ea} ±0.39	37.24 ^{*de} ±0.67	51.23 ^{eb} ±1.25	11.24 ^e ±0.13	16.79 ^{ea} ±0.35	28.92 ^{*f} ±0.61	47.35 ^{eb} ±1.17

Data were expressed as Mean of three readings for each replicate ($n = 3$) ± SD. a, b, c, d, e, f - different letters indicated that values of the means in the same rows and columns are significantly different (* $p < 0.05$)

The initial values of total viable counts TVC for mesophilic and psychrophilic microorganisms (presented on the Fig. 3 and Fig 4. below) started with 2.4 log cfu/g and 2.2 log cfu/g for experimental sample. Until seventh day of storage bacterial growth was lagging. Exponential growth started at eight day of cold storage and on the 14th day significantly higher values of 5.5 log cfu/g for control sample were obtained. Similar results for microbial status were reported by Almeida et al., (2015), who examined effect of jabuticaba peel extract on microbial stability of Bologna-type sausages during refrigerated storage. Although critical value of 5.7 log cfu/g was not exceeded in all samples, which was not case on the last day of storage where samples showed amounts above 7 log cfu/g. TVC results were in agreement with the obtained PTC results showing significant ($p \leq 0.05$) differences at the 14th day of storage.

**Figure 3.** Total viable counts of mesophilic microorganisms**Figure 4.** Total viable counts of psychrophilic microorganisms

TVB-N values were significantly lower at IBP samples, and this was in accordance with microbial status of mesophilic and psychrophilic counts which were significantly lower for IBP samples on the 14th day of storage. We assume that lower amounts of microorganisms are due to irradiation of black pepper and the smaller value from the initial stage so when exponential growth of microorganisms started the differences between values increased and become significant.

CONCLUSION

The overall quality of Bologna-type mortadella sausages showed decreasing trend and limited changes during short-term refrigerated storage. Flavor loss was evident at the beginning of storage while textural changes appeared mostly at the final stage of storage. Trained panelist spotted significant differences on the 14th day in favor of IBP samples for hardness and color intensity which led to significant score in overall appearance. In agreement with this, more examined parameters showed significant differences at the 14th day of storage in favor of IBP samples.

In summary, it might be concluded that γ -irradiation of black pepper (*Piper Nigrum*) gave the expected results and at the microbial analyses, sterility of black pepper grains was obtained. This led to significant changes in some sensory, bio-chemical and microbial examined parameters which can be considered as an improvement in quality characteristics and shelf life of Bologna-type mortadella sausages.

REFERENCES

1. Abdel-Khalek H.H., El-Aziz A.B.A. & Ibrahim S. Safety achievement and shelf-life prolongation of poultry breast meats by polylactic acid active packaging and gamma-irradiation. *International Food Research Journal*, 2022, 29(5): 1053–1066. <https://doi.org/10.47836/ifrj.29.5.08>
2. Alaa El-Din A.B., Benjamin W.B.H., Stephen G. G., David L.H. Total volatile basic nitrogen (TVB-N) and its role in meat spoilage: A review. *Trends in Food Science & Technology*, 2021, 109: 280-302. <http://dx.doi.org/10.1016/j.tifs.2021.01.006>
3. Al-Abdullah B. Beef and sheep mortadella: formulation, processing and quality aspects. *International Journal of Food Science & Technology*. 2004, 39: 177-182. <https://doi.org/10.1046/j.0950-5423.2003.00763.x>
4. Almeida P.L., de Lima S.N., Costa L.L., de Oliveira C.C., Damasceno K.A., dos Santos B.A., Campagnol P.C.B. Effect of jabuticaba peel extract on lipid oxidation, microbial stability and sensory properties of Bologna-type sausages during refrigerated storage. *Meat Science*, 2015, 110: 9-14. <http://dx.doi.org/10.1016/j.meatsci.2015.06.012>.
5. AOAC (2012) Official Method 940.28. *Methods of Analysis of AOAC International*. (19th edn), AOAC International, Rockville, MD.
6. Arshad M. S., Amjad, Z., Yasin, M., Saeed, F., Imran, A., Sohaib, M., Anjum, F. M., & Hussain, S. Quality and stability evaluation of chicken meat treated with gamma irradiation and turmeric powder. *International Journal of Food Properties*, 22 (1), 154–172. <https://doi.org/10.1080/10942912.2019.1575395>
7. ASTM (1986). *Physical requirements. Guidelines for sensory evaluation laboratories*, STP 913. Philadelphia, PA: American Society for Testing and Materials.
8. Balamatsia C.C., Rogga K., Badeka A., Kontominas M.G., Sawaidis I.N. Effect of low-dose radiation on microbiological, chemical, and sensory characteristics of chicken meat stored aerobically at 4 °C. *Journal of Food Protection*, 2006, 69(5): 1126-1133. <http://dx.doi.org/10.4315/0362-028x-69.5.1126>
9. Bayram G., Delincée H. Identification of irradiated Turkish foodstuffs combining various physical detection methods. *Food Control*, 2004, 15: 81–91. [https://doi.org/10.1016/S0956-7135\(03\)00018-5](https://doi.org/10.1016/S0956-7135(03)00018-5)
10. Bligh E.G., Dyer, W.J. A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 1959, 37(8): 911-917. <http://dx.doi.org/10.1139/o59-099>
11. Botsoglou NA, Fletouris DJ, Papageorgiou GE, Vassilopoulos VN, Mantis AJ, Trakatellis AG. A rapid,

- sensitive, and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissues, food, and feedstuff samples. *J. Agric. Food Chem.* 1994; 42: 1931-1937. <http://dx.doi.org/10.1021/jf00045a019>
12. Cai J., Chen Q., Wan X., Zhao J. Determination of total volatile basic nitrogen (TVB-N) content and Warner–Bratzler shear force (WBSF) in pork using Fourier transform near infrared (FT-NIR) spectroscopy. *Food Chemistry*, 2011, 126: 1354-1360. <http://dx.doi.org/10.1016/j.foodchem.2010.11.098>
13. Choe E., Min D.B. Mechanisms of antioxidants in the oxidation of foods. *Comprehensive Reviews in Food Science and Food Safety*, 2009, 8: 345–358. <https://doi.org/10.1111/j.1541-4337.2009.00085.x>
14. Cilla I., Martínez L., Beltrán J.A., Roncalés P. Dry-cured ham quality and acceptability as affected by the preservation system used for retail sale. *Meat Science*, 2006, 73(4):581-589. <https://doi.org/10.1016/j.meatsci.2006.02.013>.
15. Code of Federal Regulation: 21CFR179: Irradiation in the production, processing and handling of food, Title 21 (Vol. 3). Revised as of April 1, 2004.
16. Directive 1999/3/EC of the European Parliament and of the Council of 22 February 1999 on the establishment of a Community list of foods and food ingredients treated with ionising radiation. Special edition in Bulgarian: Chapter 13 Volume 026 P. 63 – 65.
17. Doménech-Asensi G., García-Alonso F.J., Martínez E., Santaella M., Martín-Pozuelo G., Bravo S., Periago M. Effect of the addition of tomato paste on the nutritional and sensory properties of mortadella. *Meat Science*, 2013, 93(2): 213-219. <https://doi.org/10.1016/j.meatsci.2012.08.021>
18. Dragoev, S.G., Balev, D.K., St. Nenov, N., Vassilev, K.P. and Vlahova-Vangelova, D.B. Antioxidant capacity of essential oil spice extracts versus ground spices and addition of antioxidants in Bulgarian type dry-fermented sausages. *European Journal of Lipid Science and Technology*, 2016, 118(10):1450-1462. <https://doi.org/10.1002/ejlt.201500445>
19. Dutra M.P., Cardoso G.P., Fontes P.R., Silva D.R.G., Pereira M.T., Ramos A.L.S., Ramos E.M. Combined effects of gamma radiation doses and sodium nitrite content on the lipid oxidation and color of mortadella. *Food Chemistry*, 2017, 237:232-239. <https://doi.org/10.1016/j.foodchem.2017.05.108>.
20. Ercolini D., Russo F., Nasi A., Ferranti P., Villani F. Mesophilic and psychrotrophic bacteria from meat and their spoilage potential in vitro and in beef. *Applied and Environmental Microbiology*, 2009, 75(7): 1990-2001. <https://doi.org/10.1128/AEM.02762-08>
21. Fernandez-Gines J.M., Fernandez-Lopez J., Sayas-Barbera E., Sendra E., Perez- Alvarez J.A. Effect of storage conditions on quality characteristics of bologna sausages made with citrus fibre. *Journal of Food Science*, 2003, 68(2), 710–715. <https://doi.org/10.1111/j.1365-2621.2003.tb05737.x>
22. Fernandez-Lopez, J., Sayas-Barbera, M. E., Navarro, C., Sendra, E., & Perez-Alvarez, J. Antioxidant and antibacterial activities of natural extracts: Application on cooked meat balls. *Meat Science*, 2005, 69, 371–380. <https://doi.org/10.1016/j.meatsci.2004.08.004>
23. Gheisari H.R. Correlation between acid, TBA, peroxide and iodine values, catalase and glutathione peroxidase activities of chicken, cattle and camel meat during refrigerated storage. *Veterinary World*, 2011, 4:153-157. <https://doi.org/10.1016/10.5455/vetworld.2011.153-157>
24. Goulas A.E., Kontominas M.G., Effect of salting and smoking method on the keeping quality of chub mackerel (*Scomber japonicus*): biochemical and sensory attributes. *Food Chemistry* 2005, 93: 511-520. <https://doi.org/10.1016/j.foodchem.2004.09.040>
25. Ham, Y. K., Kim, H. W., Hwang, K. E., Song, D. H., Kim, Y. J., Choi, Y. S., Song, B. S., Park, J. H., & Kim, C. J. (2017). Effects of irradiation source and dose level on quality characteristics of processed meat products. *Radiation Physics and Chemistry*, 130, 259–264. <https://doi.org/10.1016/j.radphyschem.2016.09.010>
26. Hornero-Méndez D., Gálvez A.P., Mínguez M.M.I. A rapid spectrophotometric method for the determination of peroxide value in food lipids with high carotenoid content. *Journal of the American Oil Chemists' Society*, 2001, 78(11):1151-1155. <https://doi.org/10.1007/s11746-001-0404-y>
27. Horváthová J., Suhaj M., Polovka M., Brezová V., Šimko P. The influence of gamma-irradiation on the formation of free radicals and antioxidant status of oregano (*Origanum vulgare* L.). *Czech Journal of Food*

- Sciences, 2007, 25(3):131-143. <http://dx.doi.org/10.17221/741-CJFS>
28. Indzhelieva, D., Valkova, K., Kuzelov, A., Andronikov, D. The impact of starter culture on the pH and the content of lactic and volatile fatty acids in boiled-smoked sausages. *Tehnologija mesa*, 2015, 56(1):34-40. <https://doi.org/10.5937/tehmesa15010341>
29. Islam, A., Sadakuzzaman, M., Hossain, M. A., Hossain, M. M., & Hashem, M. A. (2019). Effect of gamma irradiation on shelf life and quality of indigenous chicken meat. *Journal of the Bangladesh Agricultural University*, 17(4), 560–566. <https://doi.org/10.3329/jbau.v17i4.44626>
30. ISO 17410:2002. Microbiology of food and animal feeding stuffs-Horizontal method for the enumeration of psychrotrophic microorganisms.
31. Ivanov G., Ivanova I., Slavchev A., Vassilev K. Biogenic Amines and Their Role as Index of Freshness in Chicken Meat. *Journal of Applied Life Sciences International*, 2015, 3(2):55-62. <https://doi.org/10.9734/JALSI/2015/18326>
32. Jebelli Javan A, Ghazvinian K, Mahdavi A, Javaheri Vayeghan A, Staji H, Khaligh G. The effect of dietary Zataria multiflora Boiss. essential oil supplementation on microbial growth and lipid peroxidation of broiler breast fillets during refrigerated storage. *J Food Process Pres.* 2012; 37: 881-888. <http://dx.doi.org/10.1111/j.1745-4549.2012.00714.x>
33. Kumar Y., Yadav D.N., Ahmad T., Narsaiah K. Recent trends in the use of natural antioxidants for meat and meat products. *Comprehensive Reviews in Food Science and Food Safety*, 2015, 14(6): 796–812. <https://doi.org/10.1111/1541-4337.12156>
34. Lee M.A., Han D.J., Jeong J.Y., Choi J.H., Choi, Y.S., Kim, H.Y. Effect of kimchi powder level and drying methods on quality characteristics of breakfast sausage. *Meat Science*, 2008, 80(3): 708–714. <http://dx.doi.org/10.1016/j.meatsci.2008.03.010>
35. Li, C., He, L., Jin, G., Ma, S., Wu, W., & Gai, L. (2017). Effect of different irradiation dose treatment on the lipid oxidation, instrumental color and volatiles of fresh pork and their changes during storage. *Meat Science*, 128, 68–76. <https://doi.org/10.1016/j.meatsci.2017.02.009>
36. Milan S. (2006). Spice antioxidants isolation and their antiradical activity: A review. *Journal of Food Composition and Analysis*, 2006, 19: 531-537. <http://dx.doi.org/10.1016/j.jfca.2004.11.005>
37. Morehouse K.M., Vanee K. Book: Irradiation of Food and Packaging: An Overview. In: *Irradiation of Food and Packaging*. American Chemical Society, 2004, pp 1-11. ISBN13: 9780841238695eISBN: 9780841219809
38. Pratt D.A., Tallman K.A., Porter N.A. Free radical oxidation of polyunsaturated lipids: New mechanistic insights and the development of peroxy radical clocks. *Accounts of Chemical Research*, 2011, 44(6):458-671. <http://dx.doi.org/10.1021/ar200024c>
39. Rysha, A., Kastrati, G., Jurkovic, J., & Kabashi-Kastrati, E. Evaluation of the residual nitrite concentrations of locally produced and imported meat products in Kosovo. *Journal of the Hellenic Veterinary Medical Society*, 2022, 73(3): 4505–4510. <https://doi.org/10.12681/jhvms.27604>
40. Saeideh E., Berengi-Ardestani S., Elham K., Mohsen B., Mohammad Ali S., Effect of storage time on the microbial and physicochemical properties of gamma irradiated turmeric powder under various atmospheres of packaging. *Radiation Physics and Chemistry*, 2021, 187: <http://dx.doi.org/10.1016/j.radphyschem.2021.109580>
41. Thales Leandro C.O., Stephan Malfitano C., Rodrigo de Araújo S., Milene Aparecida A., Maria das Graças C., Eduardo Mendes R., Roberta Hilsdorf P. Antioxidant effects of *Satureja montana* L. essential oil on TBARS and color of mortadella-type sausages formulated with different levels of sodium nitrite. *International Journal of Food Science and Technology*, 2021, 45(2):204-212. <http://dx.doi.org/10.1016/j.lwt.2011.09.006>
42. Viuda-Martos M., Ruiz-Navajas Y., Fernández-López J., Pérez-Álvarez J.A. Effect of added citrus fibre and spice essential oils on quality characteristics and shelf-life of mortadella. *Meat Science*, 2010, 85(3): 568-576. <http://dx.doi.org/10.1016/j.meatsci.2010.03.007>
43. Yan, Y., Zhu, X., Lu, A., Yang, X., Yu, J., Qu, J., Zhu, M., & Wang, W. (2024). Effect of ^{60}Co - γ -irradiation on the degradation of β -agonists residues and the quality of fresh pork during refrigeration. *Food Control*, 110362. <https://doi.org/10.1016/j.foodcont.2024>