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# COOKED-EMULSIFIED RABBIT MEAT SAUSAGES: A POTENTIAL SOLUTION TO INCREASE RABBIT MEAT CONSUMPTION

*Petar Sikimić[1], Dragan Vasilev[1], Branislav Vejnović[2], Slaviša Stajić[3], Nikola Stanišić[4], Nikola Čobanović[1], Nevena Grković[1], Branko Suvajdžić*[1]*

***Address(es):*** Dr Branko Suvajdžić, Assistant Professor,
[1] University of Belgrade, Faculty of Veterinary Medicine, Department of Food Hygiene and Technology, Bulevar oslobodjenja 18, 11000 Belgrade, Serbia.
[2] University of Belgrade, Faculty of Veterinary Medicine, Department of Economics and Statistics, Bulevar oslobodjenja 18, 11000 Belgrade, Serbia.
[3] University of Belgrade, Faculty of Agriculture, Department of Animal Source Food Technology, Nemanjina 6, 11080, Belgrade – Zemun, Serbia.
[4] Institute of Animal Husbandry Belgrade – Zemun, Autoput Beograd-Zagreb 16, 11000 Belgrade, Serbia.

*Corresponding author: brankos@vet.bg.ac.rs

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## ABSTRACT

The aim of this research was to develop cooked-emulsified rabbit meat sausages with or without reduced fat content and to assess the impact of completely replacing rabbit adipose tissue with inulin on the sausage quality and acceptability, while also considering sustainability aspects. Accordingly, two groups of rabbit meat sausages were produced: the RM group (rabbit meat sausages with regular fat content) and the RMI group (rabbit meat sausages with added inulin as a fat substitute). Additionally, two control groups were included: the P group (pork sausages with regular fat content) and the PI group (pork sausages with added inulin as a substitute for back fat). Chemical, microbiological, and sensory analyses were conducted, along with instrumental color and texture determination of the experimental sausages. In terms of chemical composition, rabbit meat sausages had significantly higher moisture content ($P<0.05$), similar protein content ($P>0.05$), and significantly lower fat content ($P<0.05$) compared to their pork counterparts. TVC and LAB counts significantly increased during storage across all experimental groups ($P<0.05$), while sulfite-reducing clostridia, *Salmonella* spp., and *Listeria monocytogenes* were not detected. Rabbit meat sausages exhibited similar lightness and yellowness ($P>0.05$) but had a significantly lower redness value than pork sausages ($P<0.05$). In terms of textural parameters, rabbit meat sausages had significantly lower values for hardness, gumminess, and chewiness than their pork equivalents ($P<0.05$).There was no significant difference in total sensory scores between rabbit meat sausages and pork sausages throughout the analysed period ($P>0.05$). In conclusion, the formulation of RMI sausages has an advantage over the RM formulation in terms of technological and nutritional aspects.

**Keywords:** rabbit meat, cooked-emulsified sausages, inulin, reduced fat content, functional food

## INTRODUCTION

Rabbit meat is regarded as a healthful due to its high levels of easily digestible protein rich in essential amino acids, low fat and cholesterol content, low sodium but high phosphorus levels, and abundant B vitamins, particularly vitamin B12 (**Dalle Zotte & Szendro, 2011; Dalle Zotte & Cullere, 2019; Honrado *et al.*, 2022**). For this reason, it is recommended in the diets of children, pregnant women, the elderly, and individuals with health conditions such as obesity, diabetes, hypertension, and cardiovascular diseases (**Składanowska-Baryza & Stanisz, 2019; Siddiqui *et al.*, 2023**). Unfortunately, rabbit meat consumption remains limited due to consumers' socio-demographic characteristics, nationality, perception of rabbits as pets, and attitudes toward rabbit husbandry methods and welfare, as well as sensory properties and price of rabbit meat (**Siddiqui *et al.*, 2023**).

The rabbit meat industry is currently going through a challenging time due to insufficient consumption of rabbit meat, structural flaws, criticism of the welfare conditions, and other ethical issues (**Cullere & Dalle Zotte, 2018**). According to data retrieved from **FAOSTAT (2022)**, global rabbit meat production declined by 39.75% between 2012 and 2022. A decreasing trend was observed across all continents except Africa, where rabbit meat production increased by 24.06% due to enhanced production in Egypt (**FAOSTAT, 2022**). The global decrease in rabbit meat production was primarily influenced by the decline in China's output (-56%), as the world's leading producer (**FAOSTAT, 2022**). As the world's second-largest producer, North Korea maintained a stable level of rabbit meat production, while the European Union recorded a 48.61% decline. Accordingly, there is an immediate need for innovative strategies to increase the consumption of rabbit meat and guarantee the industry's viability. Creating novel, healthier rabbit meat products, can be an effective way to draw in new customers, especially those who are concerned about their health (**Cullere & Dalle Zotte, 2018; Suvajdžić *et al.*, 2023**). Cooked-emulsified rabbit meat sausages could be a solution, considering that this type of sausages is widely used in human diets worldwide (**Mohammadpourfard *et al.*, 2021**). Due to its nutritional profile and technological properties, rabbit meat could be an excellent raw material for producing cooked-emulsified sausages, especially value-added ones that align with modern consumer demands for healthy foods (**Suvajdžić *et al.*, 2023**). Considering that rabbits have a low quantity of adipose tissue, which is necessary for sausage production, replacing it with functional ingredients like vegetable fibers could be effectively due to their technological and dietary benefits (**Petracci & Cavani, 2013; Suvajdžić *et al.*, 2023**). A potential solution is inulin, a plant-based polysaccharide, which is widely utilized in the food industry (**Bajčić *et al.*, 2023**). Inulin exhibits thermal stability during heat processing and has strong potential as both a fat replacer and a prebiotic. In heat-treated sausages, it enhances the water-holding capacity and stability of low-fat meat batters, thereby reducing cooking loss without adversely affecting the sensory properties of the final product (**Vasilev *et al.*, 2017**). Inulin is not digested in the human gastrointestinal tract, instead reaching the large intestine unchanged, where it serves as food for beneficial bacteria, promoting their growth and activity as a prebiotic (**Vasilev *et al.*, 2017; Bajčić *et al.*, 2023**). The health-promoting properties of inulin are attributed to its low energy value, which is approximately 1–1.5 kcal per gram (**Alaei *et al.*, 2018**); its beneficial effects on lipid and calcium metabolism; and its role in body weight regulation and the reduction of cardiovascular disease risk (**Bakirhan & Karabudak, 2021**). Additionally, inulin plays an active role in colorectal cancer prevention through its positive modulation of colonic microbiota, reduction of reactive oxygen species, and inhibition of colonic carcinogenesis (**Shoaib *et al.*, 2016; Bakirhan & Karabudak, 2021**). Replacing adipose tissue with inulin reduces the fat content in cooked-emulsified sausages, thereby lowering their energy value and enhancing their functional characteristics. Therefore, the aim of this research was to develop cooked-emulsified rabbit meat sausages with or without reduced fat content and to assess the impact of completely replacing rabbit adipose tissue with inulin on the sausage quality and acceptability, while also considering sustainability aspects.

## MATERIAL AND METHODS

### Sausage production

The subject of this research was cooked-emulsified rabbit meat sausages with or without inulin (Fibruline, COSUCRA, Warcoing, Belgium) as a substitute for fat tissue. The sausages were produced in the Experimental Meat Processing Room at the Faculty of Veterinary Medicine, University of Belgrade, under identical production conditions and using the same technological procedures. Two groups of cooked-emulsified rabbit meat sausages were produced: the RM group (rabbit meat sausages with regular fat content) and the RMI group (rabbit meat sausages with added inulin as a fat substitute). Additionally, two control groups were included: the P group (pork sausages with regular fat content) and the PI group (pork sausages with added inulin as a substitute for back fat). The composition of the experimental sausages is shown in Table 1.

**Table 1** Composition of the experimental sausages

| Filling ingredients | Experimental sausages | | | |
|---|---|---|---|---|
| | P | PI | RM | RMI |
| Rabbit meat (%) | / | / | 60 | 60 |
| Rabbit fat tissue (%) | / | / | 20 | / |
| Pork I category (%) | 60 | 60 | / | / |
| Back fat (%) | 20 | / | / | / |
| Inulin (%) | / | 4 | / | 4 |
| Ice (%) | 20 | 36 | 20 | 36 |
| Spices and phosphate mix (%) | 1 | 1 | 1 | 1 |
| Nitrite salt (%) | 1.7 | 1.7 | 1.7 | 1.7 |

Meat and fat tissue used in the production of the cooked-emulsified sausages were obtained from rabbits and pigs slaughtered in a registered slaughterhouses, adhering to animal welfare, and principles of good manufacturing and good hygiene practices. Rabbit meat and adipose tissue (submandibular, scapular, and perirenal) were manually separated from the whole chilled carcasses immediately before preparing the sausage filling. In the production of control sausage groups (P and PI), first-category pork was used, as well as pig back fat for the P sausage group. The filling for each group of experimental sausages was prepared separately in a cutter (Maxima cutter deluxe 9L, Maxima, Mijdrecht, Netherlands) and stuffed into previously cleaned, washed, and salted small pork casings (Ø = 28 mm), which were desalted just before stuffing by soaking in lukewarm water. The prepared sausages were properly labeled and hung on rods inside the chamber for the smoking and heat treatment (UKM JUNIOR 04, Mauting, Valtice, Czechia). Beech wood shavings were used to produce smoke. Hot smoking with pasteurization was applied as the heat treatment process, which lasted until the core temperature of the product reached +72 °C. After that, the experimental sausages were cooled (0–4°C) and then vacuum-packed using a vacuum packaging machine (VAC-STAR S-210 DBV, VAC-STAR AG, Sugiez, Switzerland). The vacuum-packed sausages were stored for the next 30 days at a temperature of 0–4 °C. The sausages were analysed immediately after production (day zero) and after 15 and 30 days of product storage.

### Chemical analysis

The chemical composition of experimental sausages was analyzed on day zero using standard methods described below. The dry matter content of the tested products was determined using the gravimetric method according to **SRPS ISO 1442:1998**. The total fat content was determined using the Soxhlet method (**SRPS ISO 1443:1992**). The meat protein content was established using the reference method SRPS **ISO 937:1992**. According to this method, the nitrogen content of the sample was first determined and then multiplied by a factor of 6.25 to calculate the meat protein content. The ash content was determined in accordance with the reference method **SRPS ISO 936:1999**. The chloride content was determined using the Volhard method (**SRPS ISO 1841-1:1999**), while the nitrite content was analyzed using the reference method **SRPS ISO 2918:1999**.

### Microbiological analysis

To evaluate the dynamics of microbiota development following pasteurization and throughout the storage of cooked-emulsified sausages, the Total Viable Count (TVC), Lactic Acid Bacteria (LAB) count, and sulfite-reducing clostridia count were investigated using standard methods: **ISO 4833-1:2013**, **ISO 15214:1998**, and **ISO 15213:2023**, respectively. Investigation of *Salmonella* spp. and *Listeria monocytogenes* presence was conducted according to the standard methods **ISO 6579-1:2017** and **ISO 11290-1:2017**, respectively. The number of microorganisms was expressed as a log CFU/g of sample.

### Instrumental measurement of color

The color of the experimental sausages was determined using a colorimeter (NR110, 3NH Technology Co., Ltd, Shenzhen, China) under D-65 lighting, with a standard viewing angle of 2° and an 8 mm aperture on the measuring head. Prior to each measurement, the colorimeter was calibrated using the standard procedure as per the manufacturer's instructions. Values were presented according to the CIE L*a*b* system ($L^*$ – lightness, $a^*$ – redness, $b^*$ – yellowness, $C^*$ – chroma, and $h^*$– hue angle). The measurements were performed at room temperature (20 ± 2 °C). The color parameters were measured on fresh cross-sections of the experimental sausage samples, with at least 6 measurements per sample being taken.

### Texture profile analysis (TPA)

Regarding the texture profile analysis (TPA), samples were taken from the center of the sausage, 12 mm in height and 16 mm in radius. Six samples from each treatment were used, following the procedure outlined by **Stajić *et al.* (2018)** with slight modifications: TPA was performed using the universal texture analyzer (TA.XT Plus; Stable Micro System, Ltd., Godalming, United Kingdom). Samples were compressed twice to 50% of their original height, with a compression aluminium platen of 25 mm (P/25) and a 5 kg load cell. The pre-test speed was 60 mm/min, the test speed was 60 mm/min, and the post-test speed was 300 mm/min. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience were evaluated and obtained using the available computer software (Stable Micro Systems, Godalming, United Kingdom).

### Sensory analysis

The sensory analysis of the experimental sausages was conducted in three replicates by a panel consisting of 7 selected and trained assessors (**ISO 8586:2023**) in the Sensory Testing Laboratory at the Department of Food Hygiene and Technology, Faculty of Veterinary Medicine, University of Belgrade. The quantitative descriptive analysis was used as a method of choice. The following product attributes were evaluated: external appearance; appearance and composition of the cross-section; color and color stability; odor and taste; texture. Each of the listed attributes was evaluated by a 5-point scale (with the possibility of semi-scores), where each score represented a specific level of quality as follows: 5 – typical, optimal level of quality, 4 – slight deviations from optimal quality, 3 – moderate defects in quality, 2 – pronounced defects in quality, 1 – atypical properties, unacceptable product. Experimental sausages were labeled with a three-digit randomized code and were independently evaluated by panelists in randomized order. Panelists used bread and water to cleanse their palates between samples.

### Statistical analysis

The statistical processing of experimental data was performed using GraphPad Prism software version 7 (GraphPad, San Diego, CA, USA). The normality of the data distribution was tested using the Shapiro-Wilk test. Since the data were normally distributed (Shapiro-Wilk test: $P>0.05$), groups were compared using a two-factor analysis of variance (ANOVA) with repeated measurements in one factor, followed by post-hoc comparisons using the Tukey's test. The differences between groups in moisture, protein, fat, ash, NaCl, and nitrites content were assessed using one-way ANOVA, followed by post hoc comparisons using the Tukey's test. The results are presented as mean and standard deviation. A significance level of $P \leq 0.05$ was selected as the threshold for statistical significance in all tests.

## RESULTS

### Chemical composition

The chemical composition of cooked-emulsified sausages, analysed immediately after production, is summarized in Table 2. Rabbit meat sausages had a significantly higher moisture content than pork sausages ($P<0.05$). Moisture content was also significantly higher in sausages with inulin addition ($P<0.05$). No significant difference in protein content was observed between P and RM sausages or between PI and RMI sausages ($P>0.05$). However, RM sausages had a significantly higher protein content than RMI sausages ($P<0.05$). On the other hand, rabbit meat sausages had a significantly lower fat content than their pork counterparts ($P<0.05$). In addition, RMI sausages had the highest ash content ($P<0.05$). Furthermore, rabbit meat sausages had a significantly lower NaCl content and a higher nitrite content than pork sausages ($P<0.05$).

**Table 2** Chemical composition of cooked-emulsified sausages

| Parameter | Group | | | | *P* value |
|---|---|---|---|---|---|
| | P | PI | RM | RMI | |
| Moisture (%) | 63.21±0.39$^{A}$ | 71.17±0.43$^{B}$ | 69.38±0.28$^{C}$ | 72.73±0.14$^{D}$ | <0.0001 |
| Protein (%) | 15.75±0.07$^{AB}$ | 15.38±0.11$^{AC}$ | 16.14±0.01$^{B}$ | 14.96±0.72$^{C}$ | 0.0001 |
| Fat (%) | 18.48±0.66$^{A}$ | 2.38±0.02$^{B}$ | 10.89±0.09$^{C}$ | 2.01±0.02$^{D}$ | <0.0001 |
| Ash (%) | 2.74±0.06$^{A}$ | 2.84±0.07$^{AB}$ | 2.58±0.03$^{B}$ | 2.88±0.10$^{C}$ | <0.0001 |
| NaCl (%) | 1.76±0.01$^{A}$ | 1.77±0.03$^{A}$ | 1.72±0.02$^{B}$ | 1.73±0.01$^{B}$ | 0.0018 |
| Nitrites (mg/kg) | 12.99±0.70$^{A}$ | 12.37±0.58$^{A}$ | 37.37±2.05$^{B}$ | 38.12±0.45$^{B}$ | <0.0001 |

**Legend:** $^{ABC}$Different uppercase letters in the superscript within the same row indicate a significant difference between groups ($P<0.05$).

### Microbiota

The results of the microbiological analysis are shown in Figure 1. At the beginning of the experiment, the TVC and LAB count were <1 log CFU/g in all experimental sausage groups but significantly increased over time ($P<0.05$). At the end of analysed period, the TVC in the cooked-emulsified rabbit meat sausages ranged from 4.67±0.01 to 4.80±0.13 log CFU/g, while LAB count reached 3.87±0.08 log CFU/g (RM) and 4.07±0.08 log CFU/g (RMI). The TVC and LAB count in rabbit meat sausages were slightly higher than in pork sausages, but no significant difference was observed ($P>0.05$). The presence of sulfite-reducing clostridia, *Salmonella* spp., and *Listeria monocytogenes* was not detected during the experiment.

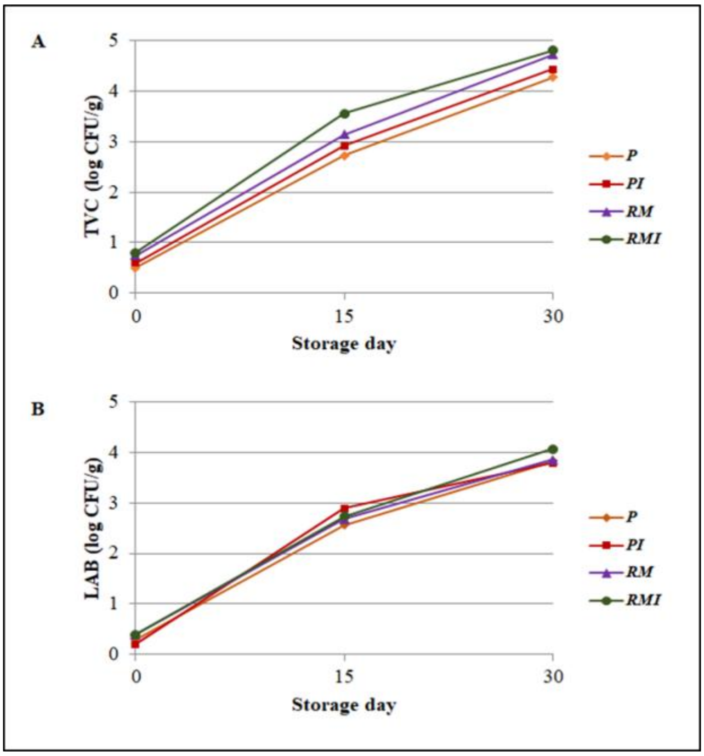

**Figure 1** TVC (A) and LAB count (B) during the storage of the cooked-emulsified sausages

### Instrumental color parameters

The instrumental color parameters of cooked-emulsified sausages are shown in Table 3. Sausages with inulin addition had a significantly higher *L** value than those with fat tissue ($P<0.05$). During the experimental period, rabbit meat sausages had a significantly lower *a** value than their pork equivalents ($P<0.05$). Over time, yellowness (*b**) increased in all experimental groups, but the increase was significant only in sausages with added fat tissue ($P<0.05$). On the other hand, rabbit meat sausages had a significantly lower *C** value than pork sausages ($P<0.05$). Among all sausage groups, RMI sausages had the highest *h** value during the analysed period.

### Texture parameters

The texture parameters of cooked-emulsified sausages are presented in Table 4. Rabbit meat sausages had significantly lower hardness, gumminess, and chewiness values than their pork counterparts ($P<0.05$). By the end of the experiment, the hardness, gumminess, and chewiness values had significantly increased in rabbit meat sausages ($P<0.05$). On the other hand, the adhesiveness, cohesiveness, springiness, and resilience values of all experimental groups did not change significantly during storage ($P>0.05$). Additionally, replacing fat tissue with inulin affected all textural parameters of the reformulated sausages ($P<0.05$), except for adhesiveness in PI sausages and both adhesiveness and cohesiveness in RMI sausages ($P>0.05$)

### Sensoryanalysis

The results of the quantitative descriptive analysis are presented in Figure 2. In terms of sensory properties, the experimental sausages were similar, with a significant difference observed only in texture. Compared to the other experimental groups, RM sausages had significantly lower texture scores ($P<0.05$). The scores for external appearance significantly decreased over time only in the PI and RMI sausages ($P<0.05$). On the other hand, the scores for cross-section appearance, color, texture, odor, and flavor also decreased until the end of the experiment, but significantly only in the RMI sausage group ($P<0.05$). Throughout the experiment, no significant differences were observed in the total sensory scores among the cooked-emulsified sausages ($P>0.05$). However, total sensory scores significantly decreased in all sausage groups by the end of the experiment ($P<0.05$).

**Table 3** Instrumental color parameters of cooked-emulsified sausages

| Parameter | Day | Group | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|
| | | P | PI | RM | RMI | Group | Time | G × T |
| *L** | 0 | 71.48±1.14$^{Aa}$ | 76.57±1.09$^{Ba}$ | 71.24±1.41$^{Aa}$ | 77.03±1.93$^{Ba}$ | < 0.0001 | 0.0539 | 0.4837 |
| | 15 | 70.71±1.18$^{Aa}$ | 74.28±1.13$^{Bab}$ | 70.36±0.99$^{Aa}$ | 77.44±2.22$^{Ca}$ | | | |
| | 30 | 70.61±0.53$^{Aa}$ | 73.75±1.56$^{Bb}$ | 69.71±2.85$^{Aa}$ | 77.25±2.05$^{Ca}$ | | | |
| *a** | 0 | 8.77±0.36$^{Aa}$ | 8.59±0.32$^{Aa}$ | 6.85±0.65$^{Bab}$ | 6.05±1.06$^{Ba}$ | < 0.0001 | 0.1532 | 0.0053 |
| | 15 | 8.57±0.80$^{Aa}$ | 8.02±0.21$^{Aa}$ | 7.64±0.56$^{Ba}$ | 5.39±0.61$^{Ca}$ | | | |
| | 30 | 8.77±0.39$^{Aa}$ | 8.38±0.43$^{Aa}$ | 6.22±0.80$^{Bb}$ | 5.56±0.53$^{Ba}$ | | | |
| *b** | 0 | 6.94±0.47$^{Aa}$ | 7.05±0.11$^{Aa}$ | 5.97±0.45$^{Ba}$ | 7.55±0.60$^{Aa}$ | 0.0024 | 0.0013 | 0.2058 |
| | 15 | 7.38±0.51$^{Aab}$ | 7.19±0.23$^{Aa}$ | 6.58±0.43$^{Aab}$ | 7.13±0.90$^{Aa}$ | | | |
| | 30 | 7.76±0.33$^{Ab}$ | 7.28±0.29$^{Aa}$ | 6.98±0.74$^{Ab}$ | 7.86±1.21$^{Aa}$ | | | |
| *C** *(Chroma)* | 0 | 11.18±0.54$^{Aa}$ | 11.11±0.25$^{Aa}$ | 9.11±0.53$^{Ba}$ | 9.69±1.09$^{Bab}$ | < 0.0001 | 0.1922 | 0.0093 |
| | 15 | 11.28±0.85$^{Aa}$ | 10.82±0.39$^{Aa}$ | 10.10±0.40$^{Bb}$ | 8.96±0.82$^{Ca}$ | | | |
| | 30 | 11.71±0.45$^{Aa}$ | 11.08±0.49$^{Aa}$ | 9.38±0.78$^{Bab}$ | 10.05±0.27$^{Bb}$ | | | |
| *h** *(Hue angle)* | 0 | 38.33±1.28$^{Aa}$ | 39.39±1.18$^{Aa}$ | 41.14±3.77$^{Aa}$ | 51.52±3.09$^{Ba}$ | < 0.0001 | < 0.0001 | 0.0410 |
| | 15 | 41.01±1.65$^{Aa}$ | 41.88±0.56$^{Aa}$ | 40.77±3.29$^{Aa}$ | 52.84±4.71$^{Bab}$ | | | |
| | 30 | 41.50±1.14$^{Aa}$ | 41.00±1.47$^{Aa}$ | 48.32±4.75$^{Bb}$ | 56.40±2.99$^{Cb}$ | | | |

**Legend:** $^{ABC}$Different uppercase letters in the superscript within the same row indicate a significant difference between groups ($P<0.05$). $^{abc}$Different lowercase letters in the superscript within the same column indicate a significant difference between values within the same group over the storage days ($P<0.05$). G × T - Group × Time interaction.

**Table 4** Texture parameters of cooked-emulsified sausages

| Parameter | Day | Group | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|
| | | P | PI | RM | RMI | Group | Time | G×T |
| Hardness (g) | 0 | 2055.85±305.71$^{Aa}$ | 1937.66±244.44$^{ABa}$ | 1719.85±197.32$^{Ba}$ | 1201.67±82.52$^{Ca}$ | < 0.0001 | < 0.0001 | 0.4303 |
| | 15 | 2290.13±246.45$^{Ab}$ | 2030.12±185.30$^{Ba}$ | 1856.66±204.93$^{Bab}$ | 1512.79±325.95$^{Cb}$ | | | |
| | 30 | 2484.57±237.12$^{Ab}$ | 2105.29±231.42$^{Ba}$ | 2004.85±155.55$^{Bb}$ | 1593.74±154.51$^{Cb}$ | | | |
| Adhesiveness (g·s) | 0 | -30.64±11.28$^{Aa}$ | -24.48±9.50$^{ABa}$ | -14.43±7.65$^{Ba}$ | -18.59±8.67$^{ABa}$ | 0.0010 | 0.8863 | 0.5215 |
| | 15 | -22.42±13.61$^{Aa}$ | -26.12±13.29$^{Aa}$ | -16.41±12.10$^{Aa}$ | -19.71±15.11$^{Aa}$ | | | |
| | 30 | -25.78±19.04$^{ABa}$ | -25.13±17.02$^{ABa}$ | -12.58±8.15$^{Aa}$ | -26.31±14.13$^{Ba}$ | | | |
| Springiness | 0 | 0.87±0.02$^{ACa}$ | 0.81±0.05$^{Ba}$ | 0.90±0.03$^{Ca}$ | 0.85±0.02$^{Aa}$ | < 0.0001 | 0.3336 | 0.2062 |
| | 15 | 0.87±0.03$^{Aa}$ | 0.78±0.03$^{Ba}$ | 0.91±0.03$^{Ca}$ | 0.84±0.05$^{Aa}$ | | | |
| | 30 | 0.88±0.03$^{Aa}$ | 0.80±0.02$^{Ba}$ | 0.93±0.03$^{Ca}$ | 0.84±0.05$^{Da}$ | | | |
| Cohesiveness | 0 | 0.74±0.04$^{Aa}$ | 0.68±0.05$^{Ba}$ | 0.72±0.06$^{ABa}$ | 0.68±0.04$^{Ba}$ | 0.0002 | 0.0278 | 0.2973 |
| | 15 | 0.75±0.03$^{Aa}$ | 0.69±0.03$^{Ba}$ | 0.75±0.04$^{Aa}$ | 0.73±0.05$^{ABa}$ | | | |
| | 30 | 0.72±0.09$^{ABa}$ | 0.70±0.04$^{Aa}$ | 0.76±0.04$^{Ba}$ | 0.72±0.04$^{ABa}$ | | | |
| Gumminess | 0 | 1517.06±190.25$^{Aa}$ | 1299.78±92.05$^{Ba}$ | 1240.83±141.27$^{Ba}$ | 821.62±75.92$^{Ca}$ | < 0.0001 | < 0.0001 | 0.6934 |
| | 15 | 1718.64±216.61$^{Ab}$ | 1401.46±150.34$^{Bab}$ | 1395.52±145.77$^{Bab}$ | 1098.33±223.32$^{Cb}$ | | | |
| | 30 | 1794.77±285.32$^{Ab}$ | 1482.07±222.52$^{Bb}$ | 1532.65±145.60$^{Bb}$ | 1150.98±140.66$^{Cb}$ | | | |
| Chewiness (g) | 0 | 1315.67±153.82$^{Aa}$ | 1048.82±83.04$^{Ba}$ | 1113.82±148.28$^{Ba}$ | 697.01±75.57$^{Ca}$ | < 0.0001 | < 0.0001 | 0.3976 |
| | 15 | 1493.87±209.86$^{Ab}$ | 1090.81±126.13$^{Ba}$ | 1269.89±141.37$^{Cab}$ | 926.17±200.23$^{Bb}$ | | | |
| | 30 | 1572.62±237.96$^{Ab}$ | 1179.91±192.88$^{Ba}$ | 1420.49±143.53$^{Ab}$ | 967.79±142.98$^{Cb}$ | | | |
| Resilience | 0 | 0.42±0.04$^{Aa}$ | 0.35±0.04$^{Ba}$ | 0.42±0.05$^{Aa}$ | 0.35±0.03$^{Ba}$ | < 0.0001 | 0.1190 | 0.3231 |
| | 15 | 0.42±0.03$^{Aa}$ | 0.34±0.03$^{Ba}$ | 0.44±0.03$^{Aa}$ | 0.38±0.04$^{Ca}$ | | | |
| | 30 | 0.42±0.06$^{Aa}$ | 0.35±0.04$^{Ba}$ | 0.45±0.03$^{Aa}$ | 0.38±0.04$^{Ba}$ | | | |

**Legend:** $^{ABC}$Different uppercase letters in the superscript within the same row indicate a significant difference between groups (P<0.05). $^{abc}$Different lowercase letters in the superscript within the same column indicate a significant difference between values within the same group over the storage days (P<0.05). G × T - Group × Time interaction.

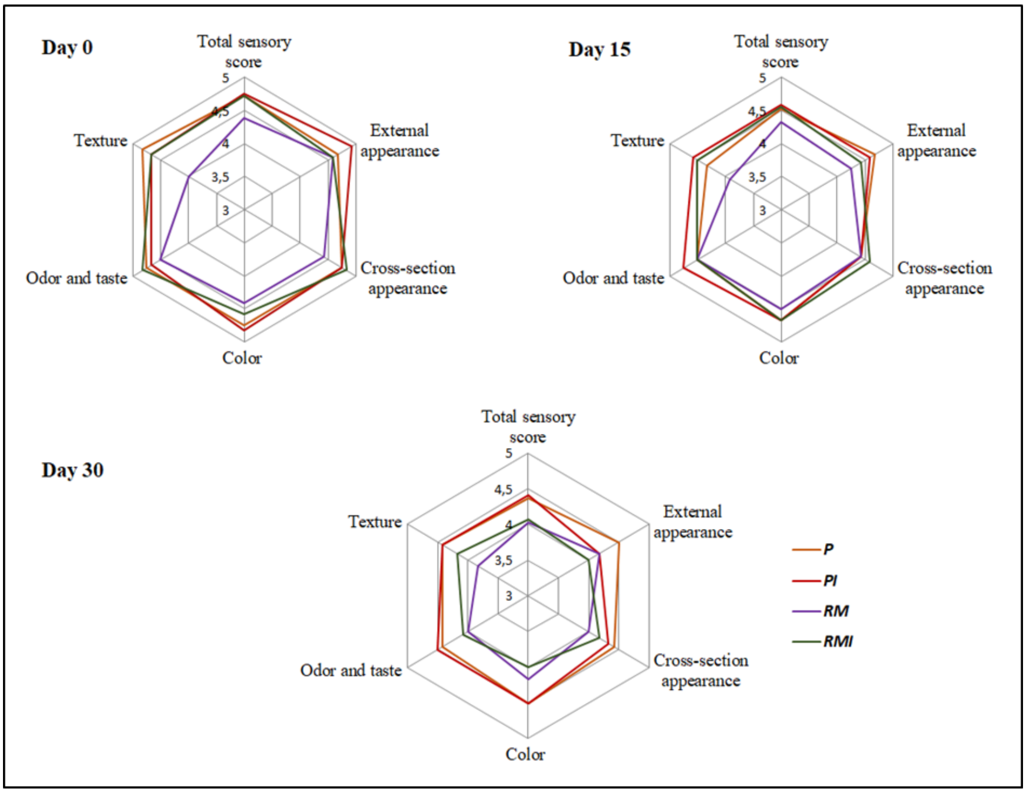

**Figure 2** Sensory properties of the cooked-emulsified sausages

## DISSCUSION

### Chemical composition

The moisture content of the cooked-emulsified sausages was significantly higher in the rabbit meat sausages compared to the equivalent pork sausages (P<0.05). This finding can be explained with higher moisture content in rabbit meat compared to other livestock and poultry meat (**Deng *et al.*, 2024**). The higher moisture content is also determined in sausages with inulin addition (P<0.05), since more water was added due to the inulin dissolution. This finding is in accordance with results **Šojić *et al.* (2011)** and **Petričević *et al.* (2022)**, who determined that fat tissue replacement with inulin significantly increases water content. The higher moisture content in these modified sausages did not negatively impact filling stability or product quality, as evidenced by the sensory analysis results (Figure 2). On the other hand, no significant difference was observed between the P and RM sausages, as well as PI and RMI sausages regarding protein content (P>0.05). This finding is not surprising, considering that fresh rabbit meat and pork had a similar protein content, which, depending on the carcass part, amounts 18.6–22.4% (**Dalle Zotte & Szendrő, 2011**) and 18–22% (**Lebret & Čandek-Potokar, 2022**), respectively. However, RM sausages had a significantly higher protein content compared to RMI sausages (P<0.05). This difference can be ascribed to the addition of rabbit adipose tissue in the formulation of the RM sausages, which was permeated with connective tissue, whose collagen content finally led to the higher protein content in the RM sausages. Despite the difference, the meat protein content in both sausage groups was consistent with literature data on rabbit meat frankfurters (**Polak *et al.*, 2023**). On the other hand, a significantly lower fat content was determined in RM sausages compared to P sausages as the control group. This finding can be explained with the quality of the rabbit adipose tissue. As previously mentioned, rabbit adipose tissue is very permeated with connective tissue, which ultimately can reduce the fat content and increase the protein content in the sausage chemical composition. Additionally, compared to pork, rabbit meat has lower content of intramuscular fats, which ranges from 1.8 g/100 g to 8.8 g/100 g, depending on the carcass part (**Dalle Zotte & Cullere, 2019**). This statement also explains a significantly lower fat content in the RMI sausages compared to the PI sausages (P<0.05). The RMI sausages had a significantly higher ash content compared to other sausage groups (P<0.05). This finding is in line with the results of **Alaei *et al.* (2018)**, who found that inulin addition in sausage formulations enhanced their ash content. On the other hand, rabbit meat sausages had a significantly lower NaCl content and higher nitrite content compared to pork sausages (P<0.05), even though the same amount of the nitrite salt was added to each sausage group. As known, during the sausage production, added nitrites react with myoglobin, leading to the formation of the nitrosyl-myoglobin (**Suvajdžić *et al.*, 2023**). Compared to other animal species, rabbit meat contains a lower amount of myoglobin (0.02% of wet muscle weight) (**Carrillo-Lopez *et al.*, 2021**), and, consequently, less nitrite was spent in the reaction with myoglobin in rabbit meat sausages compared to the pork sausages, which could explain the higher amount of residual nitrites in rabbit meat sausages. Additionally, nitrite content in all experimental sausage groups was lower than added, considering that the level of these reactive compounds decreases during the sausage production and storage, through reactions with sausage ingredients (**Mićović *et al.*, 2021**).

### Microbiota

At the beginning of the experiment, the TVC and LAB count were <1 log CFU/g in all experimental sausage groups (Figure 1). During storage, the TVC and LAB count significantly increased in all experimental sausage groups (P<0.05). According to the literature data, bacteria that survive pasteurization, along with secondary contaminants, multiply during the storage of meat products (**Vuković, 2020**). Over time, their population can reach 7 log CFU/g, a level commonly considered the spoilage threshold (**Kameník *et al.*, 2015**). At the end of the analyzed period, the TVC in the cooked-emulsified rabbit meat sausages ranged from 4.67±0.01 to 4.80±0.13 log CFU/g, which is below the mentioned spoilage threshold of 7 log CFU/g. LAB are the primary microorganisms responsible for the spoilage of cooked meat products, as they can survive in vacuum packaging, where their metabolic products cause acidification and product deterioration (**Kameník *et al.*, 2015**). At the end of the analyzed period, the LAB count in cooked-emulsified rabbit meat sausages ranged from 3.87±0.08 to 4.07±0.08 log CFU/g, which was slightly higher than in the pork control sausages. In all experimental sausage groups, LAB counts remained below 7 log CFU/g, which is considered as the upper acceptability limit for cooked sausages (**Feng *et al.*, 2013**). The presence of sulfite-reducing clostridia, *Salmonella spp.*, and *Listeria monocytogenes* was not detected, which is crucial for ensuring product safety.

### Instrumental color parameters

Regarding the color parameters (Table 3), no significant difference in lightness ($L^*$) was found between the rabbit meat sausages and their pork equivalents (P>0.05). The lightness of rabbit meat sausages from present study was in accordance with findings of **Polak *et al.*, 2023**. According to **Ignacio *et al.*, 2019**, the lightness of meat products increases significantly with the addition of rabbit meat, while the redness significantly decreases. On the other hand, sausages with inulin addition were lighter (higher $L^*$ value) compared to sausages with fat tissue (P<0.05). **Polak *et al.*, 2023** also determined a higher $L^*$ value in the rabbit meat frankfurters with reduced back fat content. In contrast, **Pintado *et al.*, 2021** reported that products with reduced fat content are darker than standard sausages. During the analyzed period, the RM and RMI sausages had a significantly lower $a^*$ (redness) value compared to cooked-emulsified pork sausages (P<0.05). This finding can be explained by the low myoglobin content in rabbit meat, which limits the development of nitrosyl-myoglobin, a pigment that affects the product color (**Suvajdžić *et al.*, 2023**). According to **Ignacio *et al.*, 2019**, rabbit meat is high in polyunsaturated fatty acids, which are prone to oxidation. The products of this process lead to the formation of metmyoglobin and, consequently, a decrease in redness. However, rabbit meat is low in iron, which acts as a pro-oxidant, so lipid oxidation is less pronounced than in red meats (**Cullere & Dalle Zotte, 2018**). Moreover, the total replacement of fat by inulin in pork and rabbit meat cooked-emulsified sausages led to a decrease in redness, which is in accordance with findings of **Bajčić *et al.*, 2023**. Compared to results of **Polak *et al.*, 2023**, rabbit meat sausages from present study had a lower $a^*$ and $b^*$ values. The differences can be ascribed to the fact that **Polak *et al.*, 2023** used ground red pepper and curry as spices in the production of rabbit meat frankfurters, which influenced the product's color, enhancing both redness and yellowness. During the storage, the yellowness ($b^*$ value) increased in all experimental groups, but significantly only in sausages with fat tissue addition (P<0.05). On the other hand, rabbit meat sausages had a significantly lower $C^*$ value compared to pork sausages (P<0.05), which was significantly increased to the end of experiment (P<0.05). Compared to other sausage groups, the RMI sausages had the highest $h^*$ value during the analyzed period. According to **Alaei *et al.*, 2018**, a higher inulin level led to a consistent increase in the Hue angle.

### Texture parameters

In terms of texture (Table 4), rabbit meat sausages had significantly lower hardness than their pork equivalents (P<0.05). According to the literature, rabbits have finer muscle fibers, resulting in more tender meat and a better chewing experience (**Deng *et al.*, 2024**). Additionally, fat replacement by inulin significantly decreased the hardness value in the PI and RMI sausages (P<0.05), which is in accordance with results of **Mendez Zamora *et al.*, 2015**. **Alaei *et al.*, 2018** state that a reduced fat content and lack of pressure-resistant lattices in the sausages may be the primary factors contributing to the decrease in the force needed to compress sausage samples. During the storage, the hardness value significantly increased in all experimental groups, except in the PI group (P<0.05). On the other hand, the adhesiveness and cohesiveness of all experimental groups did not significantly change during the storage (P>0.05). Additionally, fat replacement by inulin decreased the cohesiveness value in the reformulated sausages. It is well known that fats possess high elasticity, allowing them to form strong lattices that help retain substances in sausage formulations (**Alaei *et al.*, 2018**). Removing fat from the formulation led to a loss of elasticity and cohesiveness in the samples (**Alaei *et al.*, 2018**). However, this loss was partially compensated by the added inulin. Among the experimental sausages, the RM sausages had the highest springiness and resilience values during the entire analyzed period. This finding could be related to incomplete filling homogenization due to the use of adipose tissue, which was much permeated with connective tissue whose fibers probably contributed to the increase in the mentioned textural parameters. Springiness and resilience values did not significantly change by the end of the experiment in any of the analyzed sausage groups (P>0.05). A statistically significant difference was determined in gumminess between rabbit meat sausages and equivalent pork sausages (P<0.05). Cooked-emulsified rabbit meat sausages were less gummy than pork counterparts. Additionally, fat replacement by inulin significantly decreased the gumminess value in the reformulated sausages (P<0.05). Since gumminess is a product of hardness and cohesiveness, the determined decrease in these textural parameters directly influenced it (**Alaei *et al.*, 2018**). Until the end of the experiment, the gumminess value significantly increased in all experimental groups (P<0.05), which is related to the increase in hardness. Rabbit meat sausages had a significantly lower chewiness value compared to equivalent pork sausages (P<0.05). According to the literature, hardness, cohesiveness, and springiness are mathematically combined to determine chewiness, which represents the time required to consistently chew a food sample until it reaches a swallowable consistency (**Olorode & Adedeji, 2023**). Considering that RM sausages had higher cohesiveness and springiness values than other sausage groups, a lower hardness value positively impacted their chewiness. On the other hand, sausages with inulin addition had significantly lower chewiness values compared to the P and RM sausages (P<0.05). According to **Alaei *et al.*, 2018**, higher inulin levels in reformulated sausages improved the chewability of their samples. During the storage, the chewiness value significantly increased in all experimental groups, except in the PI group (P<0.05). The replacement of rabbit adipose tissue with inulin positively affected the textural parameters of cooked-emulsified rabbit meat sausages. It has been demonstrated that rabbit adipose tissue is not suitable for the production of cooked-emulsified sausages and is also very difficult to obtain in the required amounts, especially for industrial sausage production, due to its naturally low amount on rabbit carcass (**Dalle Zotte & Cullere, 2019**).

### Sensory analysis

Regarding sensory properties (Figure 2), the experimental sausages met the requirements of the Regulation on the quality of minced meat, meat semi-products, and meat products (Official Gazette of the Republic of Serbia No. 50/2019 and 34/2023). The P, PI, RM, and RMI sausages were firm and juicy, maintaining their shape without releasing liquid under light pressure. The casing fit well around the filling; however, small folds in the casing resulted in lower scores for external appearance. The scores for external appearance significantly decreased only in the PI and RMI sausages during the analyzed period (P<0.05). The filling of the experimental sausage was homogeneous, with a uniform and stable pink color, showing no signs of gel or fat separation. An inhomogeneous cross-section appearance was observed in the RM sausages, which is a consequence of incomplete filling homogenization due to the use of rabbit adipose tissue. Sausages with inulin addition were a shade brighter compared to sausages with fat tissue, which is in accordance with results of the instrumental measurement of color. Both groups of rabbit meat sausages had distinctive odors and tastes that were acceptable for all panelists. Based on available scientific literature, heat treatment leads to the release of volatile compounds, creating the distinctive odor and taste of rabbit meat products (**Deng *et al.*, 2024**). A significant difference between experimental sausage groups was observed only in texture. Compared to other experimental groups, the RM sausages had significantly lower scores for texture (P<0.05), since they were a little tough during chewing. This sensory impression is in accordance with the results of the instrumental texture parameters (Table 4). In addition, sensory parameters such as cross-section appearance (no statistically significant difference), color (no significant difference), and texture (with a significant difference) were significantly improved with fat replacement by inulin in both rabbit and pork sausages, which is in accordance with previous findings (**Šojić *et al.*, 2011**; **Mendez Zamora *et al.*, 2015**). Until the end of the experiment, the scores for cross-section appearance, color, texture, odor, and flavor of experimental sausages decreased, but significantly only in the RMI sausage group (P<0.05). Among P, PI, RM, and RMI sausages, no significant difference in total sensory scores was observed during the experiment (P>0.05). However, total sensory scores significantly decreased in all experimental groups over time (P<0.05). Despite this decline, all products maintained scores above 4.0, indicating satisfactory sensory quality.

## Practical implications

The production of cooked-emulsified rabbit meat sausages represents a sustainable and innovative strategy to valorize this nutritionally excellent but underutilized raw material. Additionally, cooked-emulsified rabbit meat sausages could be a potential solution to increase rabbit meat consumption which is obviously low in many countries (**Siddiqui *et al.*, 2023**). Processing rabbit meat into cooked-emulsified sausages enables the production of sensory-appealing, nutritionally valuable, and ready-to-eat products that can be more easily incorporated into individual diets. Considering the nutritional profile of rabbit meat, cooked-emulsified rabbit meat sausages are suitable for the diets of children, pregnant women, the elderly, and individuals with specific health conditions (**Składanowska-Baryza & Stanisz, 2019; Siddiqui *et al.*, 2023**). The addition of ingredients such as inulin further enhances the nutritional, functional, and technological properties of the cooked-emulsified rabbit meat sausages. Moreover, replacing fat with inulin solves the problem of the limited amount of adipose tissue in rabbits and does not adversely affect the sensory properties of the product. This innovation can support rabbit meat processors to diversify their offer with value-added products and meet the nutritional needs of health-conscious consumers.

## CONCLUSIONS

The research results confirmed the hypothesis that rabbit meat is an excellent raw material for producing cooked-emulsified sausages, particularly value-added ones that meet modern consumer demands for healthy foods. During this study, it was demonstrated that rabbit adipose tissue is not suitable for the production of cooked-emulsified sausages. Moreover, obtaining the required amounts of rabbit adipose tissue for industrial sausage production could be challenging. Total fat replacement with inulin as a prebiotic, improved the quality of cooked-emulsified rabbit meat sausages by enhancing their functional characteristics. Based on the findings of this study, it can be concluded that the formulation of RMI sausages has an advantage over the RM formulation in terms of technological and nutritional aspects. Due to its dietetic properties, RMI sausages could attract new customers and be incorporated into the diets of individuals with specific health conditions.

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