Use of inulin-collagen suspension for the total replacement of pork backfat in cooked-emulsified sausages

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Summary

Total replacement of pork backfat with inulin-collagen suspension in the production of cooked-emulsified sausages was investigated. Four groups of sausages were produced: control sausages (backfat 25 %), Series A (backfat 15 %, inulin 4 %, and collagen 0.7 %), Series B (backfat 7.5 %, inulin 4 %, and collagen 1.2 %) and Series C (inulin 4 % and collagen 1.65 %). Physico-chemical properties, chemical composition, fatty acid profile, lipid oxidation parameters, colour, textural and sensory parameters were determined. The results showed that total replacement of pork backfat with inulin-collagen suspension is possible, considering that the low-fat Series C sausages had acceptable sensory properties, lower free fat content (8.5 ± 1.8 g·kg^{-1}), lower cholesterol content (462.3 ± 49.3 mg·kg^{-1}) and higher content of carbohydrates-prebiotics (74.6 ± 8.4 g·kg^{-1}) than the control sausages. Series C sausages also had lower polyunsaturated, higher monounsaturated and a similar saturated fatty acids contents compared to the control product. Total fat replacement led to a decrease in values of lightness and redness but did not influence yellowness or the texture parameters. Regarding quality parameters, sausages with partially replaced pork backfat were not superior to those with total fat replacement.

Keywords

cooked-emulsified sausages; fat replacement; inulin; collagen; quality

In the last few decades, the increased prevalence of obesity and cardiovascular diseases have been linked to the widespread consumption of “fast food” [1]. A common feature of all “fast food” forms, including cooked-emulsified sausages, is the high content of animal fats, which are an important source of cholesterol and saturated fatty acids, having also an unfavourable ratio of omega-6 to omega-3 fatty acids (*n*-6/*n*-3) [2]. The increased intake of cholesterol and saturated fatty acids is recognized as a risk factor for cardiovascular diseases, which are a common cause of death in developed countries. On the other hand, consumers‘ awareness of the adverse effects of “fast food” on their health is growing, so they more often decide to buy foods with reduced fat content. Therefore, the food industry is directing its production to reduced-fat or low-fat products without compromising their sensory characteristics [1]. Several studies of re-formulation of cooked-emulsified sausages were based on the fat replacement with substituents such as carrageenans, vegetable oils, rice bran, inulin or collagen [3]. Among them, inulin and collagen demonstrated favourable technological properties [4].

Inulin is a plant polysaccharide that is widely used in the food industry due to its technological and functional characteristics. In meat products, inulin can be added in the form of a gel or a powder. The significance of its use is manifold. In terms of sensory properties, inulin does not influence the product‘s aroma but has a beneficial effect on consistency. Its white colour corresponds to the colour of adipose tissue, so it can be successfully used as a substitute. Inulin is not digested in the human gastrointestinal tract but, in its unchanged form, reaches the large intestine and serves as a nutrient for beneficial

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species of bacteria, favouring their growth and reproduction [4]. This characteristic classifies inulin as a prebiotic. In addition to the prebiotic effect, inulin has a beneficial effect on digestion, calcium resorption and bone mineralization in adolescents. However, due to the risk of bloating and diarrhea in consumers, the amount of inulin in products should not exceed 4 % [5].

The other substance, collagen, is often used in the production of cooked sausages in order to achieve better stability of the stuffing and as a partial substitute for backfat [3]. Collagen is added in small quantities, its content in the product proteins should not exceed 20 % [6]. Moreover, some research indicates that collagen hydrolysates are suitable ingredients in functional food products as they show biological activities such as antihypertensive, immunomodulatory or neuroactive, serve hormonal regulation and take part in cartilage matrix synthesis, helping to reduce pain in osteoarthritis patients [7]. However, collagen, depending on its source, can be a carrier of microorganisms such as clostridia, the spores of which are resistant to pasteurization [8].

Taking into account the favourable technological properties of inulin and the fact that collagen is an integral part of the connective tissue stroma of adipose tissue, it can be assumed that the combination of inulin as an "imitation of fat" and collagen as an "imitation of connective tissue stroma" could be successfully used as a substitute for pork backfat in the production of the cooked-emulsified sausages. Thus, this study aimed to investigate the effects of partial and total replacement of pork backfat with inulin-collagen suspensions on the quality and sustainability of cooked-emulsified sausages.

MATERIALS AND METHODS

Preparation of cooked-emulsified sausages

Cooked-emulsified sausages were manufactured in a private processing plant. Four groups of sausages were produced according to the following recipes:

- Control group: first-category pork 50 %, backfat 25 %, ice 21 %, starch 2 %, nitrite salt 1.7 % and spices 0.4 %.
- Series A: first-category pork 50 %, backfat 15 %, ice 27 %, inulin 4 % (Fibruline Instant, Cosucra, Warcoing, Belgium), starch 2 %, collagen 0.7 % (bovine collagen powder BPS 90; Protein Slovakia, Liptovský Mikuláš, Slovakia), nitrite salt 1.7 % and spices 0.4 %.
- Series B: first-category pork 50 %, backfat 7.5 %, ice 34 %, inulin 4 % (Fibruline Instant), starch 2 %, collagen 1.2 % (BPS 90), nitrite salt 1.7 % and spices 0.4 %.
- Series C: first-category pork 50 %, ice 41 %, inulin 4 % (Fibruline Instant), starch 2 %, collagen 1.65 % (BPS 90), nitrite salt 1.7 %, and spices 0.4 %.

The meat batter was prepared in a bowl-cutter by first chopping the cooled meat and frozen backfat, then adding nitrite salt and a half of the ice followed by starch, then the mass was further chopped (bowl cutter speed 70 Hz) until the mixture reached 8 °C. The other half of the ice was then added, followed by inulin and collagen, providing the suspension formation during further comminution and homogenization until the mass temperature reached 9 °C. The stuffing was filled into artificial casings with a diameter of 55 mm and a length of 20 cm. The prepared sausages were pasteurized at 78 °C in a chamber until 72 °C in the centre of the sausages was reached. After pasteurization, the sausages were initially cooled under a water shower (water temperature 15 °C) and transferred into a chilling chamber (air temperature 2 °C) until the core temperature of the sausages fell below 4 °C. Afterwards, the sausages were stored in a storage chamber at 4 °C until the end of the study. Sampling was conducted immediately after production and cooling as well as on days 20, 34 and 55 of storage. All analyses were completed on six samples from each group in two replicates. Each sample consisted of a whole sausage.

Physico-chemical analyses

The pH value was determined by pH-meter Testo 205 (Testo, Lenzkirch, Germany). Before measuring, the pH meter was calibrated using standard phosphate buffers. The pH-meter probe was inserted in three places on the sausage cross section, and the result included the mean value of those three measurements. Water activity (a_w) was determined with an a_w-meter FAst/1 (GBX Scientific Instruments, Romans sur Isere, France). The procedure included filling a chopped sausage sample into a measuring cup (2/3 of its height), placing it in the measuring part of the probe and the measurement (by 20 °C) lasted until the equilibrium was established. The result for each sausage sample included the mean value of three measurements.

Chemical analyses

Chemical composition of the experimental sausages was determined according to standard methods. The moisture content was determined by drying samples at 105 °C [9]. Free fat content was determined according to SRPS ISO 1444 [10]. Protein content was determined by the Kjeldahl method and using a multiplication factor of 6.25 [11]. Collagen content was calculated by multiplying the hydroxyproline content by a factor of 8 [12] and then the proportion of collagen in meat proteins was calculated. Ash content was determined by mineralization of samples at 550 ± 25 °C [13]. NaCl content was obtained according to the modified Volhard method [14]. The contents of nitrites and total phosphorus were determined according to SRPS ISO 2918 [15] and SRPS ISO 13730 [16], respectively. Acid value was expressed as grams of oleic acid per kilogram of fat based on titration with 0.1 mol·l^{-1} NaOH [17]. Determination of thiobarbituric acid reactive substances (TBARS value) was performed according to Tarladgis et al. [18] and Holland [19]. TBARS values were calculated against a standard curve of malonaldehyde (MDA) and expressed as milligrams of MDA per kilogram of sample.

Cholesterol content was determined by high performance liquid chromatography with photodiode array detection (HPLC-PDA). Sample preparation was according to the AOAC 994.10 method [20], tailored in the final step to HPLC determination. The chromatographic system was an Alliance 2695 separation module with photodiode array detector 2996 (Waters, Milford, Massachusetts, USA). The mobile phase consisted of HPLC-grade methanol and ultrapure water (ASTM, Type I). Cholesterol content determination was performed in gradient separation mode on a reversed phase column Kinetex C18 (150 mm × 4.6 mm × 2.6 μm, 100 Å, Phenomenex, Torrance, California, USA).

Fatty acids determination was performed after extraction of free fat from samples according to SRPS ISO 1444 [10]. The extracted fat was converted to fatty acid methyl esters (FAME) by using 0.25 mol·l^{-1} trimethylsulfonium hydroxide (TMSH) in methanol [21] as described by Spirić et al. [22]. FAME were analysed by capillary gas chromatography on a Shimadzu 2010 gas chromatograph (Shimadzu, Kyoto, Japan) equipped with a flame ionization detector and a capillary column HP-88 (100 m × 0.25 mm × 0.20 μm; J&W Scientific, Folsom, California, USA). Components were identified by comparing relative retention times of FAME peaks with peaks of Supelco 37 Component FAME mix standard (Supelco, Bellefonte, Pennsylvania, USA).

Determination of sugars was conducted using ion chromatography with pulse amperometric detection. The system consisted of an 858 Professional sample processor, 930 Compact IC Flex with Oven/Deg and IC Amperometric detector (all from Metrohm, Herisau, Switzerland). The separation column was Metrosep Carb 2 250/4 (Metrohm) and separation of mono- and disaccharides was isocratic. The mobile phase consisted of 100 mmol·l^{-1} sodium hydroxide and 10 mmol·l-1 sodium acetate solution in accordance with the original method reported by Metrohm [23].

Colour analysis

Instrumental colour parameters of experimental cooked-emulsified sausages were determined by ChromaMeter CR-400 (Minolta, Tokyo, Japan), using a D-65 light source, a 2° standard observer angle and an 8 mm aperture in the measuring head. Values were presented according to the CIE $L^*a^*b^*$ system (L^* – lightness, a^* – redness, b^* – yellowness). The measurements were performed at room temperature (20 ± 2 °C) immediately after the sausages were cut.

Texture profile analysis

Texture profile analysis (TPA) was performed using the universal texture determination instrument TA XP (Stable Micro System, Godalming, United Kingdom). Samples were taken from the centre of the sausages, 22 mm in diameter and 20 mm in height, heated to room temperature (20 ± 2 °C) and compressed to 50 % of their initial height using a 75 mm aluminium compression plate (P/75) and a 5 kg load cell. Pretest speed, test speed and post-test speed were all 1 mm·s^{-1}. Hardness, adhesiveness, springiness, cohesiveness, gumminess and chewiness were evaluated using the Exponent software (Stable Micro Systems, Goldalming, United Kingdom).

Sensory analysis

Sensory analysis of the experimental cooked-emulsified sausages was performed by quantitative descriptive analysis in accordance with the standard method ISO 6564 [24]. Six experienced panelists participated in the quantitative descriptive analysis. Before the evaluation, the panel leader discussed with the panelists and defined the characteristics of each tested attribute, which included external appearance, cross-sectional appearance, colour, smell, taste and texture. Sensory characteristics of the experimental sausages were evaluated by a 5-point scale (with the possibility of semi-scores) 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. Panelists evaluated the products independently and the sausage series were randomly assigned.

Statistical analysis

Statistical analysis was conducted using the software JMP Statistical Discovery 10 (SAS Institute, Cary, North Carolina, USA). Results were analysed by one-way ANOVA followed by a post-hoc Tukey-Kramer test. Statistical significance was considered at $p < 0.05$. The results were presented as mean ± standard deviation.

RESULTS AND DISCUSSION

Physico-chemical parameters

The a_w values of all experimental product groups were identical (0.95 ± 0.01) despite different stuffing formulations in terms of the amount of added water (Tab. 1). This can be explained by the good water-binding capacities of collagen [3] and inulin [4]. Water activity remained unchanged during storage and the measured values were in the range common for cooked-emulsified sausages (0.95–0.97) [25].

At the beginning of storage, the lowest pH was determined in Series A sausages (5.89 ± 0.02), while Series C had the highest pH (6.04 ± 0.03). During storage, pH of all sausages increased but stayed in the range that is common for cooked sausages (6.1–6.3) [25]. At the end of storage, the control sausages had a significantly higher pH than all modified sausages ($p < 0.05$). Lower pH values in Series A, B, and C could be related to the addition of inulin and in accordance with the findings of other authors who stated that cooked sausages with added inulin [4] or fibre [25] were more acidic.

Chemical parameters

The chemical composition, carbohydrate content and fatty acids profile of experimental sausages are shown in Tab. 2. The chemical composition of the products differed significantly in terms of fat content ($p < 0.05$). Compared to control sausages, the fat content was reduced by 58 % in Series A, but by 80 % in Series B, and by 97 % in Series C. Thanks to the reduced fat content, the Series A and B products could bear the nutritional statement “fat reduced” as allowed by Regulation EC No. 1924/2006 [26] considering that these products contained by 30 % less fat than a similar product of normal composition. On the other hand, Series C products could bear the statement “low fat” because they contained less than 3 % fat.

The cholesterol contents in sausages from Series B (470.6 ± 20.3 mg·kg^{-1}) and C (462.3 ± 49.3 mg·kg^{-1}) were significantly lower ($p < 0.05$) than in the control group (558.7 ± 12.7 mg·kg^{-1}). Due to the reduction in the fat content, and since fat usually contains cholesterol at approximately 830 mg·kg^{-1} [27], this result is logical. However, a greater reduction in cholesterol content in Series C sausages, made without added pork backfat, was not expected because meat itself contains approximately 630 mg·kg^{-1} cholesterol [28].

Regarding the meat protein content, which ranged from 117.5 ± 2.9 g·kg^{-1} in the control to 123.4 ± 0.4 g·kg^{-1} in Series B, no significant differences were found ($p > 0.05$) and these values ranged within the range common for emulsified cooked sausages [25]. However, significant variations were found regarding the relative collagen content, as a significant parameter of sausage quality [6]. The collagen/proteins ratio increased proportionally with the addition of inulin-collagen suspension. Consequently, Series C had the highest collagen/proteins ratio, which amounted to

Tab. 1. Physico-chemical parameters of cooked-emulsified sausages.

Parameter	Storage time [d]	Control	Series A	Series B	Series C
a_w	0	0.950 ± 0.002 ^{a}	0.950 ± 0.002 ^{a}	0.950 ± 0.001 ^{a}	0.952 ± 0.001 ^{a}
	20	0.950 ± 0.002 ^{a}	0.949 ± 0.001 ^{a}	0.952 ± 0.001 ^{a}	0.953 ± 0.001 ^{a}
	34	0.949 ± 0.006 ^{a}	0.951 ± 0.001 ^{a}	0.948 ± 0.001 ^{a}	0.949 ± 0.001 ^{a}
	55	0.947 ± 0.005 ^{a}	0.948 ± 0.001 ^{a}	0.948 ± 0.001 ^{a}	0.949 ± 0.001 ^{a}
pH	0	5.94 ± 0.03 ^{b}	5.89 ± 0.02 ^{c}	5.97 ± 0.01 ^{b}	6.04 ± 0.03 ^{a}
	20	6.06 ± 0.02 ^{a}	5.88 ± 0.01 ^{c}	5.97 ± 0.01 ^{b}	6.07 ± 0.01 ^{a}
	34	6.11 ± 0.01 ^{a}	6.01 ± 0.01 ^{c}	6.04 ± 0.01 ^{b}	6.10 ± 0.01 ^{a}
	55	6.19 ± 0.01 ^{a}	6.05 ± 0.01 ^{d}	6.10 ± 0.00 ^{c}	6.15 ± 0.01 ^{b}

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.

Tab. 2. Chemical composition, carbohydrate content and fatty acid profile of cooked-emulsified sausages.

Parameter	Control	Series A	Series B	Series C
Chemical composition				
Fat [g·kg^{-1}]	254.8 ± 4.0 ^{a}	105.8 ± 8.9 ^{b}	50.1 ± 7.0 ^{c}	8.5 ± 1.8 ^{d}
Cholesterol [mg·kg^{-1}]	558.7 ± 12.7 ^{a*}	506.8 ± 63.4 ^{ab}	470.6 ± 20.3 ^{b}	462.3 ± 49.3 ^{b}
Protein [g·kg^{-1}]	117.5 ± 2.9 ^{a}	121.7 ± 1.0 ^{a}	123.4 ± 0.4 ^{a}	118.7 ± 8.1 ^{a}
Collagen/proteins ratio [%]	3.7 ± 0.3 ^{d}	6.2 ± 0.3 ^{c}	8.6 ± 0.1 ^{b}	10.3 ± 0.3 ^{a}
Water [g·kg^{-1}]	606.9 ± 2.8 ^{d}	648.9 ± 1.4 ^{c}	715.3 ± 2.9 ^{b}	773.4 ± 1.7 ^{a}
NaCl [g·kg^{-1}]	18.6 ± 1.5 ^{a}	18.0 ± 0.2 ^{ab}	17.2 ± 0.1 ^{b}	17.3 ± 0.2 ^{b}
Ash [g·kg^{-1}]	22.6 ± 1.7 ^{b}	24.2 ± 1.5 ^{ab}	25.6 ± 0.3 ^{a}	25.0 ± 0.7 ^{a}
Phosphorus (P_2O_5) [g·kg^{-1}]	5.70 ± 0.33 ^{a}	5.72 ± 0.09 ^{a}	5.71 ± 0.14 ^{a}	5.72 ± 0.13 ^{a}
Carbohydrate profile				
Total carbohydrates [g·kg^{-1}]	9.1 ± 4.0 ^{c}	99.4 ± 10.6 ^{a}	85.6 ± 9.6 ^{ab}	74.6 ± 8.4 ^{b}
Total sugars [g·kg^{-1}]	2.2 ± 0.1 ^{b}	4.5 ± 0.3 ^{a}	4.7 ± 0.2 ^{a}	4.7 ± 0.1 ^{a}
Fructose [g·kg^{-1}]	0.0 ± 0.0 ^{c}	0.9 ± 0.1 ^{a}	0.8 ± 0.1 ^{ab}	0.7 ± 0.1 ^{b}
Glucose [g·kg^{-1}]	2.2 ± 0.1 ^{b}	2.4 ± 0.2 ^{a}	2.4 ± 0.2 ^{a}	2.7 ± 0.1 ^{a}
Saccharose [g·kg^{-1}]	0.0 ± 0.0 ^{b}	1.3 ± 0.1 ^{a}	1.5 ± 0.1 ^{a}	1.3 ± 0.2 ^{a}
Fatty acid profile				
Total *n*-3 FA [g·kg^{-1}]	10.0 ± 1.2 ^{a}	10.5 ± 1.0 ^{a}	10.1 ± 1.2 ^{a}	5.1 ± 0.2 ^{b}
Total *n*-6 FA [g·kg^{-1}]	163.5 ± 4.8 ^{a}	132.0 ± 14.5 ^{b}	134.3 ± 15.5 ^{b}	78.7 ± 4.1 ^{c}
n-6/*n*-3 FA	16.5 ± 1.6 ^{a}	13.1 ± 0.3 ^{b}	13.9 ± 3.0 ^{b}	15.5 ± 1.2 ^{ab}
SFA [g·kg^{-1}]	351.4 ± 2.5 ^{b}	403.1 ± 34.7 ^{a}	388.8 ± 38.7 ^{a}	372.4 ± 3.0 ^{ab}
MUFA [g·kg^{-1}]	472.8 ± 6.9 ^{b}	447.9 ± 17.9 ^{b}	463.4 ± 28.0 ^{b}	540.5 ± 5.6 ^{a}
PUFA [g·kg^{-1}]	173.6 ± 6.7 ^{a}	146.0 ± 17.1 ^{b}	145.6 ± 12.6 ^{b}	84.5 ± 3.4 ^{c}

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.
FA – fatty acids, SFA – saturated fatty acids, MUFA – monounsaturated fatty acids, PUFA – polyunsaturated fatty acids.

10.3 ± 0.3 %. However, despite this, the collagen/proteins ratio in Series C was below the maximum prescribed limit of 20 % [6]. In addition, the importance of collagen in the diet and the potential positive effects its intake has on human health was also described [7].

The water content in the experimental sausages increased in proportion to the amount of added water that was necessary for the formation of the inulin-collagen suspension. Compared to the control sausages, Series A sausages contained by 6.9 %, Series B by 17.9 % and Series C by 27.4 % more water. However, the higher water content in these modified products did not adversely affect the stability of the stuffing or the product quality, as shown by the results of the texture profile analysis (Tab. 5) and sensory analysis (Tab. 6). It is known that inulin has good technological properties in terms of water binding and the formation of stable gels [4]. Additionally, collagen contributes to the stuffing stability of cooked sausages [3].

Although the NaCl content was significantly lower ($p < 0.05$) in Series B (17.2 ± 0.1 g·kg^{-1}) and Series C (17.3 ± 0.2 g·kg^{-1}) sausages compared to the control group (18.6 ± 1.5 g·kg^{-1}), these values were within the limits common to this type of product [25]. This finding could be explained by the higher water content in which NaCl is soluble. Due to inulin and collagen addition, the ash content was significantly higher ($p < 0.05$) in Series B (25.6 ± 0.3 g·kg^{-1}) and Series C (25.0 ± 0.7 g·kg^{-1}) sausages compared to the control group (22.6 ± 1.7 g·kg^{-1}) but these values were also common for cooked sausages [25]. Phosphorus content was uniform in all experimental groups of products (from 5.70 g·kg^{-1} in the control to 5.72 g·kg^{-1} in Series A and C) and was within the limits allowed by regulations [6].

Analysis of the carbohydrate profile showed differences among the quantities and presence of specific sugars in the control and modified sausages. The total carbohydrate content was significantly higher in products from Series A, B and C (99.4 ± 10.6 g·kg^{-1}, 85.6 ± 9.6 g·kg^{-1} and

Tab. 3. Acid value, TBARS value and nitrite content of cooked-emulsified sausages.

Parameter	Storage time [d]	Control	Series A	Series B	Series C
Acid value [g·kg^{-1}]	0	0.80 ± 0.07 [b]	1.74 ± 0.16 [a]	0.47 ± 0.08 [c]	0.36 ± 0.05 [c]
	20	0.75 ± 0.11 [a]	0.33 ± 0.07 [b]	0.76 ± 0.05 [a]	0.28 ± 0.03 [b]
	34	0.95 ± 0.11 [b]	0.88 ± 0.10 [b]	1.16 ± 0.05 [a]	0.57 ± 0.06 [c]
	55	0.38 ± 0.01 [bc]	0.87 ± 0.06 [a]	0.43 ± 0.01 [b]	0.37 ± 0.02 [c]
TBARS value [mg·kg^{-1}]	0	0.08 ± 0.01 [b]	0.08 ± 0.04 [b]	0.09 ± 0.02 [b]	0.14 ± 0.03 [c]
	20	0.03 ± 0.01 [b]	0.03 ± 0.01 [b]	0.02 ± 0.01 [b]	0.06 ± 0.01 [c]
	34	0.04 ± 0.01 [a]	0.05 ± 0.01 [a]	0.04 ± 0.01 [a]	0.04 ± 0.01 [a]
	55	0.05 ± 0.01 [c]	0.05 ± 0.01 [bc]	0.06 ± 0.01 [b]	0.09 ± 0.01 [a]
Nitrite content [mg·kg^{-1}]	0	74.86 ± 1.17 [a]	69.04 ± 4.86 [b]	75.35 ± 2.65 [a]	78.67 ± 3.06 [a]
	20	70.67 ± 0.87 [a]	68.01 ± 1.95 [b]	69.64 ± 1.45 [ab]	70.11 ± 1.12 [ab]
	34	56.07 ± 1.01 [a]	56.08 ± 1.03 [a]	56.31 ± 0.73 [a]	56.44 ± 0.64 [a]
	55	61.24 ± 0.32 [b]	52.56 ± 0.53 [d]	56.53 ± 0.34 [c]	68.4 ± 0.08 [a]

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.
Acid value is expressed as grams of KOH per kilogram.
TBARS – thiobarbituric acid reactive substances (expressed as milligrams of malondialdehyde per kilogram).

74.6 ± 8.4 g·kg^{-1}, respectively) compared to the control group (9.1 ± 4.0 g·kg^{-1}). Glucose in the control group originated from the spice mixture, in which it is present as a carrier. Slightly higher contents of glucose in the modified groups were due to the sum of this sugar from the spice mixture and free glucose from inulin. According to the literature, the content of total free sugars (fructose, glucose and saccharose) in inulin preparations is approximately 100 g·kg^{-1}, calculated on a dry matter basis [29]. Therefore, fructose and saccharose in the modified groups were entirely derived from inulin. This fact was confirmed by the absence of these two sugars in the control product. On the other hand, the low content of free sugars indirectly indicated that inulin did not degrade or undergo hydrolytic changes during the heat treatment of the sausages. According to Kalyani et al. [29], inulin possesses prebiotic properties and is an important ingredient within the concept of functional food and thus, the presence of inulin adds value to the experimental products from this study.

The fatty acids profile of the control and modified sausages was characteristic of pork backfat [30]. Reduced fat products (Series A and B) had almost identical fatty acids profiles characterized by significantly lower polyunsaturated fatty acids (PUFA) and *n*-6 fatty acids content, as well as significantly higher saturated fatty acids content than control products. Compared to the control and reduced fat products, Series C had significantly lower *n*-3 fatty acids, *n*-6 fatty acids and polyunsaturated fatty acids content ($p < 0.05$), significantly higher monounsaturated fatty acids content ($p < 0.05$) as well as similar saturated fatty acids content and a similar *n*-6/*n*-3 ratio ($p > 0.05$). Given that the free fat content of Series C was less than 10 g·kg^{-1}, the difference in the fatty acids content would not have a significant impact on the nutritional value or safety of the product.

The results of lipolysis (acid number) and fat oxidation (TBARS value) tests and the nitrite content in the sausages are shown in Tab. 3. The lowest and most stable acid value was determined in products from Series C (0.36 ± 0.05 g·kg^{-1} to 0.37 ± 0.02 g·kg^{-1}, expressed as grams of KOH), which could be explained by this product having the lowest fat content. In contrast, Series A sausages had the highest acid value both at the beginning (1.74 ± 0.16 g·kg^{-1}) and at the end of storage (0.87 ± 0.06 g·kg^{-1}) compared to other products. A high acid number was also found in Series B sausages (1.16 ± 0.05 g·kg^{-1}) after 34 days of storage. Although Series A and Series B sausages contained less fat than the control sausages, more intensive lipolysis could be related to the higher water content in these products because fats hydrolyse more intensively in the presence of more water [31].

TBARS values ranged from 0.08 ± 0.01 mg·kg^{-1} in the control and Series A to 0.14 ± 0.03 mg·kg^{-1} in Series C sausages at the beginning of storage. During storage, TBARS values initially decreased in all products, then gradually increased to the end of storage and reached values of

0.05 ± 0.01 mg·kg^{-1} in control and Series A sausages or 0.09 ± 0.01 mg·kg^{-1} in Series C. Although significantly higher TBARS values were found in Series C sausages compared to other modified sausages ($p < 0.05$), these values were lower than the maximum acceptable limit of 1 mg·kg^{-1} [32] and the values determined in cooked sausages by other authors, which ranged from 0.49 mg·kg^{-1} to 2.97 mg·kg^{-1} [33]. Despite the fact that Series C sausages contained the least amount of fat, the highest TBARS values in them could be attributed to the more intense oxidation of lipoids from muscle cell membranes probably due to the presence of the highest content of water in these products [31, 34].

The nitrite content in all sausages was within the limits characteristic of this product type and it decreased during the storage time, probably due to its reaction with the stuffing ingredients [25].

Colour parameters

Instrumental colour parameters (Tab. 4) showed that Series C sausages had a significantly lower L^* value than other experimental groups throughout the entire storage period. According to the literature, products with reduced fat content are darker than standard sausages [35]. This could be one of the reasons for the Series C sausages, made without pork backfat, having the lowest L^* values. However, Series A sausages were brighter than the control product, which contained twice as much pork backfat. This finding indicates that the inulin-collagen suspension, even when added in smaller amounts than usual, gives brighter products in combination with fat. Since the same amount of inulin (4 %) was added to all modified sausages, it can be concluded that the higher collagen content in Series B sausages (1.2 % added) and the highest in Series C sausages (1.65 %) contributed to the darker colour of these products compared to the Series A sausages (0.7 %). On the other hand, the smaller share of pork backfat and the greater share of inulin-collagen suspension led to lower red colour intensity, considering that all modified products had lower a^* values than the control sausages. By Day 55, the intensity of the red colour increased in all sausage groups, probably as a consequence of nitrosyl-myoglobin formed by the reaction of residual nitrite with myoglobin [34]. The sausage formulations did not affect the intensity of the yellow colour, considering that b^* values of Series A, Series B and Series C sausages were very close in this parameter to the values of control sausages and common for the product type [25].

Texture parameters

The results of the texture analysis (Tab. 5) showed that despite the variable fat content, there were no significant differences in hardness, adhesiveness, springiness, cohesiveness, gumminess or chewiness of the products. Although Series C sausages were made without pork backfat but with the largest amount of added water and collagen, their hardness, adhesiveness, springiness, cohesiveness, gumminess and chewability observed at the beginning of the storage were similar to those measured in the control sausages. Consistently, no significant differences in the texture parameters displayed the control and Series C sausages at the

Tab. 4. Instrumental colour parameters of cooked-emulsified sausages.

Parameter	Storage time [d]	Control	Series A	Series B	Series C
Lightness L^*	0	78.00 ± 0.43 ^{b}	80.06 ± 0.37 ^{a}	78.27 ± 0.56 ^{b}	75.46 ± 0.29 ^{c}
	20	78.37 ± 0.43 ^{b}	80.49 ± 1.15 ^{a}	79.07 ± 0.33 ^{b}	75.85 ± 0.40 ^{c}
	34	78.07 ± 0.48 ^{c}	81.29 ± 0.43 ^{a}	78.75 ± 0.28 ^{b}	75.89 ± 0.40 ^{d}
	55	78.15 ± 0.25 ^{c}	81.04 ± 0.34 ^{a}	79.08 ± 0.32 ^{b}	76.00 ± 0.40 ^{d}
Redness a^*	0	7.29 ± 0.80 ^{a}	5.78 ± 0.27 ^{b}	5.54 ± 0.38 ^{bc}	4.84 ± 0.36 ^{c}
	20	7.56 ± 0.32 ^{a}	5.53 ± 0.35 ^{b}	5.35 ± 0.46 ^{b}	5.40 ± 0.23 ^{b}
	34	8.68 ± 0.50 ^{a}	6.07 ± 0.48 ^{b}	6.06 ± 0.21 ^{b}	6.00 ± 0.25 ^{b}
	55	8.46 ± 0.13 ^{a}	5.90 ± 0.24 ^{b}	5.97 ± 0.43 ^{b}	6.23 ± 0.31 ^{b}
Yellowness b^*	0	10.28 ± 0.46 ^{a}	9.36 ± 0.27 ^{b}	9.32 ± 0.16 ^{b}	9.87 ± 0.22 ^{a}
	20	10.05 ± 0.15 ^{a}	9.37 ± 1.53 ^{a}	9.66 ± 0.28 ^{a}	9.60 ± 0.20 ^{a}
	34	9.42 ± 0.21 ^{a}	9.04 ± 0.38 ^{a}	9.14 ± 0.14 ^{a}	9.43 ± 0.25 ^{a}
	55	9.20 ± 0.48 ^{a}	8.93 ± 0.43 ^{a}	9.17 ± 0.34 ^{a}	9.22 ± 0.14 ^{a}

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.

Tab. 5. Texture parameters of cooked-emulsified sausages.

Parameter	Storage time [d]	Control	Series A	Series B	Series C
Hardness [g]	0	4458.13 ± 455.63 [a]	4255.83 ± 756.44 [a]	4671.22 ± 370.56 [a]	4502.26 ± 272.92 [a]
	55	4894.36 ± 535.87 [a]	5203.13 ± 750.29 [a]	4922.97 ± 568.65 [a]	4295.45 ± 270.54 [a]
Adhesiveness [$g\cdot s^{-1}$]	0	–85.57 ± 57.92 [a]	–89.37 ± 54.12 [a]	–92.21 ± 52.33 [a]	–97.31 ± 45.02 [a]
	55	–121.94 ± 42.32 [a]	–66.09 ± 48.73 [a]	–89.04 ± 47.26 [a]	–86.47 ± 41.08 [a]
Springiness [mm]	0	0.71 ± 0.05 [a]	0.73 ± 0.04 [a]	0.72 ± 0.04 [a]	0.75 ± 0.04 [a]
	55	0.72 ± 0.03 [ab]	0.70 ± 0.03 [b]	0.73 ± 0.04 [ab]	0.76 ± 0.02 [a]
Cohesiveness	0	0.68 ± 0.02 [b]	0.79 ± 0.08 [a]	0.78 ± 0.01 [a]	0.70 ± 0.01 [b]
	55	0.66 ± 0.01 [b]	0.70 ± 0.02 [a]	0.71 ± 0.01 [a]	0.70 ± 0.01 [a]
Gumminess	0	3027.85 ± 289.37 [a]	3291.42 ± 397.37 [a]	3283.55 ± 235.70 [a]	3165.49 ± 215.76 [a]
	55	3239.47 ± 329.89 [a]	3636.05 ± 499.19 [a]	3481.29 ± 370.01 [a]	3005.51 ± 201.57 [a]
Chewiness [g·mm]	0	2166.67 ± 313.66 [a]	2402.38 ± 424.67 [a]	2390.01 ± 398.07 [a]	2375.70 ± 263.57 [a]
	55	2346.89 ± 331.88 [a]	2565.72 ± 435.00 [a]	2564.10 ± 424.61 [a]	2300.83 ± 193.28 [a]

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.

end of the storage period. This finding confirmed that the inulin-collagen suspension preserved all textural parameters and the values obtained were common for this type of sausage [25]. The beneficial effect of collagen as a substitute for pork backfat in frankfurter-type sausages on texture parameters was also determined by Varga-Visi [3]. Series A and Series B sausages had slightly higher values for cohesiveness, gumminess and chewiness than control and Series C sausages, which can be attributed to the combined action of pork backfat, inulin and collagen on these texture parameters.

Sensory properties

The results of sensory analysis are shown in Tab. 6. At the beginning of storage, all properties of Series A, Series B and Series C sausages were evaluated as better than the control product, except for external appearance, where no differences were observed. Series B and Series C sausages were evaluated with the highest scores for section appearance, colour, texture, odour and taste. At the end of storage, sausages from Series B and Series C were again evaluated as the best, while control sausages were the worst. These results showed that the combination of inulin and collagen as a substitute for pork backfat contributes to the improvement of the sensory properties of cooked-emulsified sausages, giving a stable stuffing and acceptable colours, textures and aromas. At the same time, in the case of Series B and Series C sausages, the scores for the cross-sectional appearance and colour increased during storage, which can be explained by an increase in redness and a decrease in yellowness (Tab. 4) probably as a consequence of the nitrosyl-myoglobin formed by the reaction of residual nitrite with myoglobin [34]. These results suggest that differences in the composition of the sausages did not disrupt normal biochemical processes important for the colour formation of the product. Although Series B and Series C sausages contained significantly more added water and less pork backfat compared to the control and Series A sausages, inulin and collagen contributed to the stuffing stability probably thanks to good water binding capacity [4], which led to improvement in most sensory properties of the products. The odour and taste of all product groups did not change significantly during storage, which could be related to the oxidative stability (Tab. 3) as well as the stuffing stability due to their good water binding capacity.

CONCLUSIONS

The results of this study show that total replacement of pork backfat in cooked-emulsified sausages is possible with a suspension that contains 4 % inulin, 1.65 % collagen powder and 13 % water (ice). Series C sausages made with this suspension and without any pork backfat had free fat content less than 1 %, lower cholesterol content ($p < 0.05$) and higher content of carbohydrates that could serve as prebiotics ($p < 0.05$) than the control sausages. Compared to the control and reduced-fat sausages, Series C sausages had significantly lower n-3 fatty acids, n-6 fatty acids and polyunsaturated fatty acids content ($p < 0.05$),

Tab. 6. Sensory properties of cooked-emulsified sausages

Quality parameter	Storage time [d]	Control	Series A	Series B	Series C
External appearance	0	5.00 ± 0.00[a]	5.0 ± 0.00[a]	5.0 ± 0.00[a]	5.0 ± 0.00[a]
	20	4.83 ± 0.26[a]	4.83 ± 0.26[a]	4.83 ± 0.26[a]	4.83 ± 0.26[a]
	34	4.67 ± 0.26[a]	4.50 ± 0.45[a]	4.67 ± 0.26[a]	4.67 ± 0.26[a]
	55	4.83 ± 0.26[a]	4.83 ± 0.26[a]	4.83 ± 0.26[a]	4.83 ± 0.26[a]
Cross-section	0	2.88 ± 0.26[c]	3.50 ± 0.00[b]	4.00 ± 0.00[a]	3.50 ± 0.45[b]
	20	2.67 ± 0.26[c]	4.25 ± 0.27[a]	4.00 ± 0.00[ab]	3.58 ± 0.58[b]
	34	3.00 ± 0.00[b]	3.17 ± 0.26[b]	4.08 ± 0.38[a]	4.00 ± 0.32[a]
	55	3.33 ± 0.41[b]	3.75 ± 0.27[ab]	4.25 ± 0.42[a]	4.00 ± 0.00[a]
Colour of stuffing	0	2.88 ± 0.26[b]	3.13 ± 0.26[b]	3.88 ± 0.26[a]	3.88 ± 0.26[a]
	20	3.83 ± 0.41[a]	3.17 ± 0.26[a]	3.58 ± 0.20[ab]	3.42 ± 0.20[ab]
	34	3.83 ± 0.26[a]	3.00 ± 0.45[b]	3.92 ± 0.49[a]	3.50 ± 0.45[a]
	55	3.08 ± 0.20[b]	3.08 ± 0.49[b]	4.00 ± 0.00[a]	3.92 ± 0.49[a]
Texture	0	3.13 ± 0.26[c]	3.63 ± 0.26[b]	4.50 ± 0.32[a]	4.13 ± 0.26[a]
	20	2.83 ± 0.26[c]	4.00 ± 0.00[a]	4.00 ± 0.00[a]	3.33 ± 0.26[b]
	34	3.17 ± 0.26[c]	3.83 ± 0.26[b]	4.25 ± 0.27[a]	4.08 ± 0.20[ab]
	55	3.17 ± 0.26[bc]	3.00 ± 0.00[c]	3.83 ± 0.68[ab]	3.92 ± 0.49[ab]
Odour	0	2.88 ± 0.26[b]	3.13 ± 0.26[b]	3.88 ± 0.26[a]	3.63 ± 0.26[a]
	20	2.75 ± 0.27[b]	3.25 ± 0.27[a]	3.00 ± 0.00[ab]	3.00 ± 0.00[ab]
	34	3.17 ± 0.26[b]	3.08 ± 0.20[b]	4.08 ± 0.20[a]	3.92 ± 0.38[a]
	55	3.08 ± 0.20[b]	3.42 ± 0.20[a]	3.50 ± 0.00[a]	3.58 ± 0.20[a]
Taste	0	2.63 ± 0.26[c]	3.13 ± 0.26[b]	4.00 ± 0.32[a]	4.00 ± 0.00[a]
	20	2.58 ± 0.20[c]	3.50 ± 0.00[a]	3.00 ± 0.00[b]	2.83 ± 0.26[bc]
	34	2.92 ± 0.58[b]	3.25 ± 0.27[ab]	3.83 ± 0.26[a]	3.58 ± 0.58[ab]
	55	3.08 ± 0.20[c]	3.42 ± 0.20[bc]	3.58 ± 0.20[ab]	3.83 ± 0.26[a]
Total sensory score	0	3.23 ± 0.88	3.58 ± 0.73	4.21 ± 0.45	4.02 ± 0.53
	20	3.25 ± 0.90	3.83 ± 0.65	3.74 ± 0.70	3.50 ± 0.71
	34	3.46 ± 0.67	3.47 ± 0.58	4.14 ± 0.30	3.96 ± 0.42
	55	3.43 ± 0.69	3.58 ± 0.67	4.00 ± 0.49	4.01 ± 0.43

The results are shown as mean ± standard deviation. Different letters in the same row indicate a significant difference at $p < 0.05$.

significantly higher monounsaturated fatty acids content ($p < 0.05$) as well as similar saturated fatty acids content and n-6/n-3 ratio ($p > 0.05$). The increased water content of the low-fat sausages did not adversely affect the physico-chemical parameters or the fat hydrolysis and oxidation parameters. Total fat replacement led to a decrease in L^* and a^* values but did not influence b^* values or the texture parameters. All sensory quality parameters were evaluated better in reduced-fat and low-fat sausages than in control sausages. In terms of physico-chemical, chemical, colour, textural and sensory parameters, partial replacement of pork backfat with inulin-collagen suspension (Series A and B) did not give significant advantages compared to total fat replacement (Series C). The results of this study indicate the great potential of the inulin-collagen suspension as a substitute for pork backfat in cooked-emulsified sausages and may motivate further research to examine suitability of the suspension for use in other meat products.

Acknowledgements

The authors would like to thank to Miroslav Haška (Haška G i M, Kulpin, Serbia) and Slobodan Tubić (Food BLT, Novi Sad, Serbia) for the support in providing the raw materials and sausage production.

The study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract numbers 451-03-68/2022-14/200143, 451-03-68/2022-14/200134, and 451-03-68/2022-14/200050).

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Received 26 November 2022; 1st revised 23 January 2023; accepted 26 January 2023; published online 7 February 2023.