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INNOVATIVE APPLICATION OF INULIN-GEL SUSPENSION IN POULTRY SAUSAGES: TECHNOLOGICAL IMPACT AND NUTRITIONAL ENHANCEMENT

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Abstract: Consumer demand for healthier foods has led the industry to look for alternatives to reduce high-fat levels. Dietary fibers such as inulin have emerged as promising substitutes for fat, increasing nutritional value and reducing fat absorption. The aim of this research was to formulate chicken cooked sausages in which the fat was replaced by inulin suspension at different levels. Four groups of sausages participated in the experiment: group K without fat replacement and groups 50%IN, 75%IN, and 100%IN with 50%, 75%, and 100% fat replacement, respectively. The results show a significantly higher process and cooking loss in the experimental groups compared to group K ($p<0.05$). Groups K and 50%IN had significantly better emulsion stability ($p<0.05$). Increasing inulin content significantly affected color characteristics, including L* (lightness), a* (redness), and b* (yellowness) ($p<0.05$). The experimental groups of sausages had a lighter color. By reducing fat, the caloric value of sausages decreased significantly and differed between groups ($p<0.01$). Inulin can be used to produce cooked sausages with reduced fat content and optimal physical and chemical properties. In addition to the reduced energy value, this meat product also has good nutritional characteristics.

Key words: inulin, fat, chicken sausages, caloric value, functional food

Introduction

Inulin is considered a functional food ingredient widely used in the food industry as a sugar or fat replacer to improve nutritional profile as it reduces the calorie value of the final product, represents the source of dietary fiber, and has the prebiotic potential. From a technological standpoint, inulin is shown to be an excellent gelling agent, viscosity modifier, and texturizing agent in various foods

(*Melilli et al., 2021; Jayarathna et al., 2022*). The fat-substituting capacity of inulin is tightly related to its ability to form highly stable gels. In order to create inulin-gel, inulin powder has to be suspended in an aqueous solution (at 70°C), appropriately mixed, and cooled down at 40°C overnight. Inulin-gel characteristics are temperature-dependent as inulin forms three-dimensional gels by a network of small crystallites. If diluted at a higher temperature, i.e., above 80°C the inulin gelation is inhibited (*Bot et al., 2004; Glibowski, 2010; Jayarathna et al., 2022*). The properties of these gels resemble that of a network of fat crystals in the oil. Because of this similarity, inulin gels have been identified as an exciting new ingredient for creating unique, functional meat products with a mouthfeel and creaminess similar to the one containing solid fats (*Bot et al., 2004; Yousefi et al., 2018*). Therefore, taking into consideration all of the appealing attributes of inulin gels, numerous studies have been reported with successful implementation in different types of meat products, such as cooked (*Selgas et al., 2005; Berizi et al., 2017; Ferjančič et al., 2021*) and fermented sausages (*Menegas et al., 2013;Vasilev et al., 2011; Glišić, 2019*). Since there is limited information regarding the application of inulin-gels in poultry sausages, this paper aims to develop andpropose a modification of „full-fat, commercially available products with minimum to zero levels of animal fat, as well as to observe its technological properties.

Material and Methods

Experimental design

Poultry meat and pork fatback were used for the production of sausages. Fresh chicken breast meat, held at 4°C, was obtained from the Piljan Komerc chicken farm (Belgrade, Serbia). Pork backfat was resourced from the Meat Processing Unit of the Institute for Animal Husbandry (Belgrade, Serbia), where chicken f sausages were made.

Four treatments were manufactured: control group (K) - commercially made sausage (100% pork backfat), group 1 (50% IN) – 50% pork backfat replacement, group 2 (75% IN) – 75 % pork backfat replacement, and group 3 (100% IN) – with 100% pork backfat replacement with inulin-gel suspension. Inulin was obtained from Cosucra, Belgium (dry matter 95.9%, ash on dry matter 0.01%, carbohydrates on dry matter 100.00%, free fructose, glucose, and sucrose on dry matter 0.1%, inulin on dry matter 99.9%). Inulin-gel suspension was made by the method described by *Petričević et al. (2022)*. Afterward, the suspension was cooled to 4°C, left overnight, and added to the meat batter mixture.

All groups were manufactured on the same day and in an identical manner. Minced chicken breast meat and pork backfat were mixed with ice, condiments (Fenc company, Serbia), additives (NO_2+NaCl salt commercially available, phosphates, and soy isolate), and in experimental groups, previously prepared inulin suspension was added (groups 50% IN, 75% IN, 100% IN). All components were homogenized in a cutter, and stuffed into collagen casings (⌀ 22 mm). The processes of boiling and smoking were performed in the chamber for boiling/smoking with program settings: drying for 10 min at 50°C, smoking at 60°C for 30 min, and heating to 85° until they reached an internal temperature of 72°C. Sausages were then cooled down by spraying with cold water, left to drain for 15 min, and stored at 4°C. After 24 h, sausages were selected from each group for further analysis. The experiment was repeated three times, and from each batch, three sausages were taken for analysis. For further analysis, the rest of the sausages were vacuum-sealed and stored at 4°C for 21 days.

Process loss, purge loss, and cooking loss

Sausage weight was measured after stuffing in the casings, heat treatment, and after three weeks of storage in a cooling chamber at 4°C. The process loss was calculated as a weight difference between sausages before and after heat treatment (%). Chicken sausages were vacuumed and left at 4°C in a cooling chamber to determine purge loss at the storage time. After 21 days, sausages were removed from the vacuum packages, bloated carefully with a paper towel to eliminate any liquid on the surface, and weighed in. Purge loss was calculated as a weight difference between sausages before and after storage time (%). Cooking loss was calculated as a weight difference in the sausages samples before and after cooking in distilled water in a closed glass container (at 80°C for 10 min). It was expressed as a percentage of the weight of the sample before cooking.

Emulsion stability, water-holding capacity (WHC), and pH

Emulsion stability was determined in triplicate for each treatment, as described by *Petričević et al. (2022)*. After undergoing two days of refrigerated storage, cuvettes, each holding approximately 25 ml of the meat batter, underwent a thermal treatment in a water bath set at 98ºC for a duration of 45 minutes. Subsequent to this, a rapid cooling phase ensued in ice water, lasting 10 minutes until the cuvettes reached ambient temperature. Following unsealing, the cuvettes were transferred into measured glass containers, where they remained for an hour to allow the drainage of liquids, encompassing both fat and water released during the heat treatment (HT). The quantity of liquid separated in this process, expressed as a percentage (%) of the initial filling weight before the HT, serves as a metric for quantifying the loss incurred throughout the heat treatment.

The method suggested by *Lin and Huang (2003)* was followed to determine WHC: 5 g (± 0.001 g) of homogenized raw meat batter sample was measured into a 50 ml tube, and 10 ml distilled water was added. The tubes were centrifuged at 2000 g for 10 min, and the final weight was obtained after decanting the supernatant. WHC was calculated using equitation (1). The higher WHC value (expressed by grams of H_2O absorbed/grams of meat) indicates that more water was bound, and therefore higher the water-holding ability of the batter.

WHC=[final sample weight-original sample weight]/original sample weight(g) (1) Sausage samples were used for pH analysis for each treatment using a pH meter equipped with a penetration probe (Hanna HI 83141; Hanna Instruments, USA). The pH meter was precalibrated using standard buffer solutions, pH 4.0 and 7.0 (*SRPS ISO 2917:2004*).

Instrumental color

The CIE L*a*b* color coordinates were determined using a Chroma Meter CR-400 (Minolta, Japan), which was previously calibrated using a standard white surface (illumination D65, observer angle 2° and aperture size 8 mm) as described by *Stajić et al. (2014).* Color attributes as are represented in the CIE L* a* b* system (*CIE, 1976*). The lightness is denoted by factor L*, red proportion is encapsulated by a*, and b* corresponds to the yellowness of color of the samples. Triplicate measurements were conducted for each sample, and the ensuing mean value served as the basis for statistical analysis.

Proximate analysis

The proximate analysis of the sausage samples transpired a day following their preparation. Preceding the chemical analyses, the collagen casings were removed, and the sausages underwent homogenization in a blender. Three sausages were randomly taken from each treatment for proximate composition analysis: moisture *(SRPS ISO 1442, 1998)*; fat content *(SRPS ISO 1444, 1998*); protein content (*SRPS ISO 937, 1992*); ash content (*SRPS ISO 936:1999*); carbohydrates were determined by subtracting the obtained values from 100%; NaCl content was determined by *SRPS ISO 1841-1:1999* method. The caloric value was computed by considering the chemical composition of sausages, with protein, carbohydrates, and fat assigned caloric values of 4 kcal, 1.5 kcal, and 9 kcal per gram of the product, respectively (*Garcia-Santos et al., 2019*).

Statistical analysis

The acquired data were processed by analysis of variance in the one-way ANOVA using the program SPSS Statistics 22. The results are displayed as the mean value ± standard deviation. A t-test determined the statistical significance of the difference between mean values.

Results and Discussion

Table 1 shows the chemical composition of cooked chicken sausages, with a noteworthy trend observed concerning the level of inulin replacement. Our analysis revealed a significant increase ($p < 0.01$) in moisture content in the sausage samples as the inulin replacement level escalated. The increased moisture content in the sausages can be attributed primarily to higher levels of inulin and the incorporation of water in the gel-suspension form within the formulation. Furthermore, the increasing moisture content in the sample groups can also be attributed to the intrinsic properties of inulin. The hydrophilic nature of inulin further enhances moisture retention by facilitating solid interactions with water molecules, emphasizing the critical roles of these components in influencing the product's physical properties.

Table 1. Chemical composition of cooked chicken sausages

Parameter	Groups				Statistical significance
	K	**50% IN**	**75% IN**	**100% IN**	
Moisture(%)	$67.80^{d} \pm 0.10$	$72.49^{c} \pm 0.09$	$74.97^{b} \pm 0.28$	$76.60^{a} \pm 0.53$	**
Total fat(%)	$17.83^{a} \pm 0.16$	$9.06^{b} \pm 0.15$	$4.02^{c} \pm 0.27$	$0.36^{d} \pm 0.05$	**
Protein (%)	$11.17^{d} \pm 0.15$	$11.81^{cb} \pm 0.12$	$12.04^{bc} \pm 0.16$	$13.51^{a} \pm 0.15$	**
Ash (%)	2.68 ± 0.16	2.49 ± 0.08	2.42 ± 0.03	2.28 ± 0.07	ns
Carbohydra tes (%)	$0.54^{d} \pm 0.06$	$4.05^{c} \pm 0.12$	$6.53^{b} \pm 0.34$	$7.23^{a} \pm 0.12$	**
NaCl (%)	1.52 ± 0.04	1.47 ± 0.04	1.52 ± 0.02	1.55 ± 0.06	ns
Caloric value (Kcal/100g)	$216.02^{a} \pm 0.90$	$134.83^{b} \pm 0.16$	$94.18^{c} \pm 0.85$	$60.69^{d} \pm 0.93$	**

ns–not significant; ** – $p<0.01$; $^{a, b, c, d}$: values in the same column with different superscript are significantly different ($p<0.01$)

The results confirm significant differences ($p < 0.01$) in the fat content as well as in the caloric value of the product. A product with a significantly reduced ($p < 0.01$) caloric value is obtained by reducing the fat content or increasing the inulin content. The caloric value in the 100% IN group with 100% fat replacement had about 72% lower caloric value compared to the control group. The results of *Šojić et al. (2011)* were consistent with our results. *Petričević et al. (2022)* state that replacing 50% of the fat in sausages reduces the caloric value by 30%, while the results in this study show a reduction of about 37%. The carbohydrate content also increased significantly ($p < 0.01$); the 100%IN group with the maximum amount of inulin had the highest carbohydrate content. Ash and NaCl content did not differ between groups.

Alaei et al. (2018) stated that the group of chicken sausages with 100% fat replacement with inulin had the best physicochemical, textural, and colorimetric characteristics. The results of the proximal analysis were in line with our results for the same group (100% fat replacement), following 72.63%, 29.90%, and 51.34% for moisture, carbohydrates, and protein content, respectively. They state that fat content was reduced with increased inulin content. The same authors suggest that inulin can be recommended as a fat substitute in making chicken sausages. Contrary to our results, research conducted by *Huang et al. (2011)* showed that the moisture content of sausage samples decreased with an increased level of inulin. This disparity may arise from variations in sausage sample formulations, inulin types, and the specific manner of incorporation into the formulation.

In the present study, substituting fat with inulin suspension is the primary strategy for creating a final product with reduced fat content, leading to decreased energy intake upon consumption. *Menegas et al. (2013)* verified this approach, demonstrating that sausages with 50% fat replacement exhibited significantly lower fat content (28.2%) compared to the control group (45.4%), aligning with findings by *Alaei et al. (2018)*. These results conform with our study, affirming the consistent impact of inulin replacement on fat reduction, as also reported by *Méndez et al. (2015)* and *Huang et al. (2011)*. Notably, *Vasilev et al. (2011)* showcased that cooked sausages containing an 8% inulin suspension had more moisture (63%) and less total fat (22-23%) than conventional counterparts, emphasizing the potential of inulin in altering sausage composition. Additionally, *Selgas et al. (2005)* introduced inulin as dietary fiber in cooked sausages, resulting in a 33-37% reduction in fat content and a 25% decrease in calories.

In our research, increasing the level of inulin suspension in formulationsled to a significant ($p < 0.01$) increase in protein content in chicken sausages, likely due to its calculation in dry matter. While the protein content between the 50% IN and 75% IN groups did not differ, both significantly ($p<0.01$) differed from the other groups. These results were consistent with observations made by *Menegas et al. (2013)* and *Méndez et al. (2015)*, who reported analogous conclusions. *Mendoza et al. (2001)* further supported these findings, demonstrating that protein content increased with higher inulin concentrations up to 12%, beyond which a decline was observed. *Vasilev et al. (2011)* reported protein content ranging from 10.2 to 10.4% in cooked sausages produced with an inulin suspension of about 3.0%, highlighting the intricate relationship between inulin concentration and protein content. In contrast to the conclusions drawn by *Šojić et al. (2011)* and *Mendoza et al. (2001)*, our study produced differing results regarding the ash content of sausages. This variance may be attributed to discrepancies in the methods used for calculating ash content.

The capacity to bind and retain water stands as a crucial determinant in assessing the technological quality of sausages (*Lu et al., 2021)*. In this study, sausages prepared with an inulin-gel exhibited a markedly higher mass loss after heat treatment compared to the control group, as evidenced by the data presented in Table 2 ($p<0.05$). Specifically, the control group exhibited significant variation ($p<0.05$) from the other experimental groups. However, intriguingly, the 75% IN group demonstrated no significant difference from the 50% IN and 100% IN groups, indicating a consistent trend in mass loss across these inulin concentrations.

Additionally, our findings revealed a substantial increase in weight loss after cooking sausages across all experimental groups, with significant differences observed ($p<0.05$). This occurrence can be ascribed to the higher water content in the filling, resulting from the replacement of the fat portion with an aqueous suspension of inulin, as outlined in Table 2. These outcomes emphasize the importance of understanding the impact of inulin-gel incorporation on mass loss during heat treatment and cooking processes, shedding light on potential applications in the food industry.

Table 2. Technological characteristics of cooked chicken sausages

Parameter	Groups				Statistical significance
	K	**50% IN**	**75% IN**	**100% IN**	
Process loss (%)	$19.90^{c} \pm 0.19$	$26.76^{ab} \pm 0.19$	$27.47^{ab} \pm 0.19$	$28.47^{a} \pm 0.19$	*
Purge loss (%)	1.58 ± 0.63	1.50 ± 0.50	1.45 ± 0.28	1.4 ± 0.63	ns
Emulsion stability (%)	$16.20^{b} \pm 0.35$	$18.61^{b} \pm 0.86$	$24.50^{a} \pm 0.99$	$25.80^{a} \pm 0.78$	*
Cooking loss (%)	$12.97^{d} \pm 0.19$	$16.69^{c} \pm 0.19$	$17.54^{b} \pm 0.19$	$24.75^{a} \pm 0.19$	*
pH	6.21 ± 0.12	6.22 ± 0.17	6.21 ± 0.08	6.20 ± 0.09	ns
WHC (%)	1.0927 ± 0.01	1.0998 ± 0.02	1.1069 ± 0.01	1.1260 ± 0.01	ns
Instrumental color					
L	$73.62^{b} \pm 0.82$	$75.56^{ab} \pm 2.01$	$76.01^{ab} \pm 1.62$	$77.96^{a} \pm 0.83$	*
a*	$5.96^{a} \pm 0.19$	$5.06^{b} \pm 0.13$	$4.25^{c} \pm 0.04$	$1.17^{d} \pm 0.06$	*
b*	$10.76^{b} \pm 0.22$	$11.31^{a} \pm 0.11$	$11.80^{a} \pm 0.24$	$11.51^{a} \pm 0.20$	*

WHC – water-holding capacity; L – lightness, a* – redness; b* – yellowness; ns – not significant; * significant at the level of $p<0.05$; $^{a,\ b,\ c,\ d}$: values in the same column with different superscript are significantly different ($p<0.05$).

Color represents a pivotal characteristic of this product type. Introducing fiber into the sausages had a noticeable impact on their coloration. Notably, reducing fat content led to sausages exhibiting a lighter coloration. The color nuances were quantified using the L*, a*, and b* values, as detailed in Table 2, with significant differences observed among the groups ($p<0.05$).

Our analysis revealed a considerable trend in the L* values, which increased proportionally with higher inulin content, reaching its peak in the 100% IN group. This aligns with the findings of *Alaei et al. (2018),* who observed asimilar increase in L* values upon the addition of inulin. In contrast, the study by *Ferjančič et al. (2021)* reported a decrease in L* values when dietary fiber was incorporated. The observed alterations in color could be attributed to the introduction of dietary fiber, especially considering that the inulin-gel mixture itself is predominantly white.

Interestingly, the indicator of redness (a*) exhibited a decrease in our study, contrary to the findings of *Alaei et al. (2018)* and *Ferjančič et al. (2021)*, both of whom reported that the addition of inulin enhanced the natural redness of chicken sausages. This discrepancy underscores the complexity of color modulation in food products and highlights the need for comprehensive investigations into the interplay of various ingredients.

Furthermore, in the present study, the indicator of yellowness (b*) demonstrated an increase with reduced fat content. This contrasts with the research conducted by *Ferjančič et al. (2021)*, where b* values exhibited a decrease, likely influenced by the more pronounced redness of chicken sausages in their study. These variations underscore the intricate relationships between fat content, inulin addition, and color attributes, emphasizing the multifaceted nature of color development in sausages. The research conducted by *Choe et al. (2013)* and *Petričević et al. (2022)* has demonstrated the significant enhancement of emulsion stability in cooked sausages when fibers are introduced, particularly in formulations with reduced fat content. In addition, *Furlan et al. (2014)* conducted astudy exploring the impact of replacing fat with inulin in cooked sausages. Based on inulin incorporation at two distinct levels (1% and 2%), their findings revealed a marked improvement in emulsion stability. This enhancement can be attributed tothe water-binding properties of inulin, coupled with its emulsifying capabilities, making it a valuable additive in sausage formulations.

Furthermore, the outcome of *Petričević et al. (2022)* scientidic article sheds light on the nuanced dynamics of inulin content in sausages. Their research elucidates that higher levels of inulin in sausage formulations lead to elevated process loss and cooking loss. This intriguing observation suggests a delicate balance between emulsion stability and overall product characteristics, highlighting the complex interplay of ingredients in sausage production. These findings and current research findings underscore the importance of careful formulation to achieve desired product attributes.

Conclusion

In conclusion, our study demonstrated the potential of inulin-gel suspension as a promising ingredient in poultry sausages, showcasing its impact on mass loss during heat treatment and cooking processes. The inulin-gel addition significantly influenced the sausages' color attributes, leading to nuanced changes in lightness (L*), redness (a*), and yellowness (b*), highlighting the complexity of color development in inulin-modified sausages. Furthermore, the incorporation of inulin suspension resulted in alterations in the sausages' chemical composition, including reduced fat content and caloric value, and increased protein and carbohydrate content, emphasizing the potential of inulin as a fat replacer and a nutritional enhancer. These findings contribute valuable insights into the utilizationof inulin-gel suspension in poultry sausages, offering opportunities for the development of healthier and more nutritionally balanced meat products. However, further research is warranted to explore the sensory aspects and consumer acceptance of these modified sausages, providing a holistic understanding of their viability in the market.

Inovativna primena inulin-gel suspenzije u pilećim kobasicama: Tehnološki uticaj i poboljšanje nutritivne vrednosti

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Rezime

Potražnja potrošača za zdravijom hranom navela je prehrambenu industriju da traži alternative za smanjenje visokog nivoa masti. Dijetalna vlakna kao što je inulin su se pojavila kao obećavajuća zamena za masti, povećavajući nutritivnu vrednost i smanjujući apsorpciju masti. Cilj ovog istraživanja je bio formulisanje pilećih kuvanih kobasica u kojoj je mast zamenjena suspenzijom inulina u različitimnivoima. U ogledu su učestvovale četiri grupe kobasica: grupa K bez zamene masti i grupe 50% IN, 75% IN i 100% IN sa 50%, 75% i 100% zamene masti respektivno. Rezultati pokazuju značajno veći gubitak process and cooking loss oglednih grupau odnosu na grupu K ($p<0,05$). Grupe K i 50%IN su imale značajno bolju stabilnost emulzije ($p<0,05$). Povećanje sadržaja inulina značajno je uticalo na karakteristike boje uključujući L* (svetloća), a* (udeo crvene boje) i b* (udeo žute boje) ($p<0,05$). Ogledne grupe kobasica su imale svetliju boju. Smanjenjem masti, kalorijska vrednost kobasica se značajno smanjila i razlikovala među grupama ($p<0,01$). Inulin se može koristiti u proizvodnju kuvanih kobasica sa smanjenim sadržajem masti i optimalnih fizičko-hemijskim svojstvima. Ovaj mesni proizvod pored smanjene energetske vrednosti ima i dobre nutritivne karakteristike.

Ključne reči: inulin, mast, pileće viršle, energetska vrednost, funkcionalna hrana

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