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Replacement of meat by mycoproteins in cooked sausages: Effects on oxidative stability, texture, and color

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PAPER

Abstract

Processed meat is one of the most consumed products worldwide. Naturally, production of proteins with animal origins includes limitations such as costs, energy, time, and environmental problems. Thus, replacement of meats by alternative biomaterials such as mycoproteins can be promising. Mycoproteins with hyphal morphologies, including branches and lengths, have close structures to meat and can be a potential alternative for meat products. Therefore, the major objectives of this study included complete replacement of sausage meats by mycoproteins and comparing characteristics of the novel formula with those of meat. In general, physicochemical, microbial, nutritional, and mechanical characteristics of the formulas were assessed. Results showed that the mycoprotein substitution improved the nutritional and health effects due to the higher valuable protein and lower lipid contents. Besides, it had a high content of essential amino acid and unsaturated fatty acid, compared to meat sausage. Absence of yeasts, molds, *Salmonella* spp., *Eshrichia* (*E.*) *coli*, and *Staphiloccocus* (*S.*) *aureus* verified the effectiveness of the heat treatment and also the effectiveness of the hygienic procedures in both samples. With regard to phycicochemical properties, more contents of moisture and lipids in sausages containing mycoprotein were linked to further water binding capacity (WBC) ($P < 0.05$) and oil binding capacity (OBC) in them, compared to beef samples. Besides, the mycoprotein sample had lower ($P < 0.05$) values of carbohydrates, ash, and pH, compared to the beef sample. In contrast, beef sausages had better textural characteristics, such as hardness, cohesiveness, gumminess, and springiness indexes, compared to mycoprotein sausages. Higher water and OBC values of the mycoproteins led to the filling of the protein interstitial spaces as well as decreasing of the textural attributes. Thus, it resulted in the use of less oil and water in mycoprotein formulations. In conclusion, mycoproteins can be addressed as appropriate replacements for meats in sausages.

Keywords: meat alternatives; mycoproteins; nutritional values; sausages; textural properties

Introduction

In recent decades, the world population has significantly increased from 2.6 to 8 billion individuals (Gabriel *et al.*, 2014). If the global population grows at the recent rate, it may reach 9 billion individuals by 2042, which could pose serious problems in providing food to all (Upadhyaya *et al.*, 2016). Approximately, 1 billion people globally will not be able to properly access food sources with sufficient energy and proteins (Godfray *et al.*, 2010). This can result in serious medical problems such as defective immune system and stunted growth. In contrast, high consumption of meat products can pose serious health problems as well (Qian *et al*., 2020). Research and development of meat replacements majorly focuses on the production of products that imitate the physical characteristics of meat such as appearance, taste, and texture, as well as providing its nutritional values. Muscle products, such as chicken and steaks, minced products, such as burgers and nuggets, and emulsion products, such as Frankfurter and Mortadella sausages, are the major meat replacements (Kyriakopoulou *et al*., 2021). However, excessive meat consumption can significantly affect the global climate change (Hashempour-Baltork *et al*., 2020b). Thus, the quest for novel substitutes for animal proteins requiring less financial resources, energy, and time consumption can be promising. One of the best meat substitutes includes mycoproteins with relatively similar textures to meat (Upadhyaya *et al*., 2016). The common source of mycoproteins is usually *Fusarium* (*F.*) *venenatum*, a filamentous fungus generally recognized as safe (GRAS) (Hashempour-Baltork *et al*., 2020b). Generally, mycoproteins contain 10 g of carbohydrates, 13 g of fats, 25 g of fibers, and 45 g of proteins, as well as various vitamins, carotenes, minerals, and essential amino acids (EAA) in 100 g of dry matter (Finnigan *et al*., 2019). Recent studies on human volunteers have demonstrated that biological values of proteins from mycoproteins are similar to biological values of proteins from milks.

Commonly, sensory characteristics, such as texture, taste, and overall appearance of the final products, are critical for their overall acceptance. Fusarium biomass is virtually odorless and tasteless and is appropriate to imitate the consistency and taste of regular meats. Comparing mycoproteins with textured soya and poultry muscle tissues, recent studies using microscopy techniques have shown that large cable-like fibers (especially in vegetable protein textures) result in rubbery textures, which are unfavorable when chewing. Technically, further fibrous and rubbery eating qualities occur in poultry and mycoprotein products due to their tight packaging laminations, compared to those that occur in products of vegetable protein origins (Hashempour-Baltork *et al*., 2020b). Ideally, mycoproteins can be good replacements for meat since their dry weights include nearly 50% of proteins, similar to grilled steaks. However, the fungi include lower fat quantities (~13%) than those steaks do. Furthermore, this is a vegetable fat with cholesterol alternative (ergosterin) and good fiber content (~25%), which are increasingly accepted by the health-conscious people (Finnigan *et al*., 2017). Based on the literature, mycoproteins can mitigate the problem of food unavailability worldwide. Moreover, even routine production of mycoproteins would need only lower water resources and occupy less land (Hashempour-Baltork *et al*., 2020b). The use of mycoproteins can limit foodborne diseases and lower blood cholesterol. Toxin analysis and allergy assays have shown no general concerns (Hashempour-Baltork *et al*., 2020a). However, a little information is available on various formulations for the replacement of food meats by mycoproteins. Hence, the major objective of the current study was to compare physicochemical, microbial, nutritional, and mechanical characteristics of sausages containing mycoproteins with those containing meat.

Materials and Methods

Preparation of sausages

Sausage samples (40% red meat) were prepared in three replications in a famous meat production factory, Tehran, Iran. Frozen beef samples were defreezed at 4°C for 16 h before use. Then, beef samples were minced twice using laboratory mincer (Model MK-G1800, Panasonic, Japan) equipped with 6–10 mm steel plates. Mycoprotein masses were provided by Ghazabon Paya, Iran. Two sausages of mycoproteins and meats were prepared for 4 kg batters (Table 1) based on the guidelines from meat producers. Formulations of both samples were mostly similar, with differences in meat and mycoprotein contents.

To prepare sausages, minced beef/mycoprotein was transferred into a bowl chopper (Robot Coupe Model R-10, France) and mixed slowly with the dry ingredients, except spices. Ice was continuously added to the mixture in the chopping process to control the temperature. Then, oil and spices were added to the mixture, respectively. The total time of mixing was 10 min while the final temperature of the batters was set below 12°C. Then, the batters were stuffed into impermeable cellulose casings using a hydraulic piston-type stuffer. Then, the sausages were cooked at 76°C for 60 min using a steam chamber and then cooled down to a final temperature of 10°C using ice-water bath and stored at 4°C overnight (Kamani *et al*., 2019). In general, each sausage type was prepared in two batches. Totally, two sausages from each batch were chosen for further analysis.

Table 1. Sausage ingredients.

Ingredient	Content (% w/w)
Meat/mycoprotein	40
Sunflower oil	10
Ice	20
Mixed spices	3.5
Soy protein isolate	5
Gluten	10
Flour	10
Salts	1.5

Physicochemical characteristics

Proximate pH, moisture, protein, lipids, carbohydrate, ash, peroxide value, water holding capacity (WHC), oil binding capacity (OBC), and water binding capacity (WBC) of the two sample types were assessed using official methods (AOCS, 2017).

Microbial characteristics

The count of microorganisms, *Escherichia* (*E.*) *coli*, *Salmonella* spp., *Staphylococcus* (*S.*) *aureus*, *Bacillus* (*B.*) *cereus*, *Clostridium* (*C.*) *perfringens*, yeasts, and molds were enumerated based on the ISO protocols (ISO, 2013).

Nutritional characteristics

Vitamins

Briefly, 10 g of the ground samples were weighed using a 50-mL glass beaker. Then, 20 mL of fresh 5% (w/v) metaphosphoric acid solution were added to the vessel and mixed well. The mixture was then homogenized by stirring at room temperature (RT) for 2 min. The homogenate was centrifuged at 3000 rpm for 5 min; then, the upper solution was filtered using Albet no. 1305 filter papers and re-filtered using 0.45-μm Millipore filters for liquid chromatography (LC) analysis (Valls *et al.*, 2001). Then, stock solutions of 100 μg mL^{-1} vitamin B_5 (pantothenic acid), vitamin B_9 (folic acid), vitamin B_2 (riboflavin), and vitamin B_7 (biotin) (Sigma-Aldrich, St. Louis, MO, USA) were prepared and stored in 4 °C until use. The vitamin content of the sample was assessed using the standard curve, and high-performance liquid chromatography (HPLC) (Waters, USA) was used for the assessment of vitamin B according to Sasaki *et al.* (2020). The method included the use of Capcell Pak C18 SG120 HPLC Column (250 nm × 4.6 mm with 5-μm particle sizes) (Osaka Soda, Japan), gradient elution of phosphate buffer-acetonitrile (pH 3), ion-pairing reagent (mobile phase) with 1.0 mL min^{-1} flow rate and UV detection (210 nm). The vitamin B compound was separated within 60 min. The value of 0.01 μg g^{-1} was set as the detection limit.

Amino acids

Briefly, 10 g of dried sausage sample were hydrolyzed using 1 N hydrochloric acid (50 mL) based on an original protocol by Czauderna *et al.* (2003). Amino acid (AA) standards were purchased as a cell-free AA mixture from Sigma-Aldrich, St. Louis, Missouri, USA. The sample was then centrifuged (10,000 g) to collect the hydrolysate. One-hundred microliters of this hydrolysate were carefully injected into the HPLC instrument (Waters, USA) at 40°C. The HPLC instrument was equipped with Zorbax Eclipse-AAA Column (4.6 mm × 150 mm, 5 μm) (Agilent Technologies, USA) as well as a fluorescence detector. Furthermore, sodium dihydrogen phosphate (NaH_2PO_4) solution (40 mmol l^{-1}) was used in the instrument as Mobile Phase A and acetonitrile:methanol:water solution (45:45:10 v/v/v) as Mobile Phase B.

Fatty acids

Generally, the Folch method (chloroform:methanol 2:1 v/v) was used for the sample lipid extraction (Folch *et al.*, 1957). Fatty acid methyl esters (FAME) were methylated based on the European Official Methods of Analysis (Godfray *et al.*, 2010; Hashempour-Baltork *et al.*, 2018). The FAME were analyzed using gas chromatography (GC) (Agilent 6890, Agilent Technologies, USA) equipped with capillary column (30 m per 0.25 mm ID, 0.25-μm film thickness) and flame ionization detector (FLD) (Thermo TR-5, ThermoFisher Scientific, USA). The instrument used helium (He) as the carrier gas with 0.2 mL min^{-1} flow rate based on a method described by Hashempour-Baltork *et al.* (2017). Fatty acid (FA) was identified by comparing the sample and the reference methyl ester chromatograms (Sigma-Aldrich, USA).

Mechanical characteristics

Texture profile analysis (TPA) was performed using Stable Micro Systems Texture Analyzer Model TA.XT Plus (Stable Micro Systems, UK). The analyzer was equipped with a 50-kg load cell. The sample was cut into pieces of 25 mm and axially fixed on the platform. Two-cycle compression assay was carried out with up to 50% of the strain compression of the original height using steel probes. Return speed, distance, and contact force were 2 mm s^{-1}, 50 mm, and 20 g, respectively. The various attributes of the food, including cohesiveness, hardness (N), adhesiveness (N.S), springiness (%), gumminess, chewiness, and springiness, were assessed (Kamani *et al.*, 2019).

Statistical analysis

Descriptive data of the study were recorded as mean ± SD (standard deviation) using SPSS Software v.17 (IBM Analytics, USA). Duncan's test was used for the comparison of means and different letters represent significant statistical differences ($P < 0.05$). For each sample of each test, three replicates were used.

Results and Discussion

Physicochemical assessments

Proximate analyses of sausages formulated with mycoproteins and beef are shown in Table 2. Results of moisture contents demonstrated that moisture in sausages formulated with mycoproteins significantly was higher ($P < 0.05$) than moisture in sausages formulated with beef. Protein and lipid contents seemed to increase with the substitution of mycoproteins in the formulation of sausages. Higher contents of moisture and lipids were linked to further WBC ($P < 0.05$) and OBC in mycoprotein samples, compared to beef samples. Based on the results, mycoprotein formulation included lower values of carbohydrates, ash, and pH, verified by the previous studies (Hashempour-Baltork *et al*., 2020). The low pH in mycoprotein samples was associated with low pH of mycoproteins (4.7) in comparison to pH of meat (5.6). In another report, use of mycoproteins significantly increased nutritional values of fish sausages (e.g., ash, carbohydrate, fat, and protein) ($P < 0.05$) (Bahmani and Movanes, 2021). In this study, the pH of fish sausages enriched with mycoproteins increased during storage (Bahmani and Movanes, 2021). No significant difference ($P < 0.05$) was generally reported between the two formulations of sausages in WHC and peroxide values ($P > 0.05$). Characterization of these two sausage samples indicated that lesser oil and water should be used in the formulation due to the higher WBC and OBC values in mycoproteins than beef. In addition to higher OBCs, higher proteins and lower carbohydrates could be used in mycoprotein samples as appropriate meals for obese people. These findings verified previous findings, which addressed mycoproteins as healthy nutritious proteins (Finnigan *et al*., 2019).

Microbial assessments

Microbiological analysis was carried out on Day 1 after cooking to understand heat behaviors of mycoproteins and compare microbial patterns of the samples. Absence of yeasts, molds, *Salmonella* spp., and *E. coli* verified the effectiveness of the heat treatment in both samples. Due to the absence of *S. aureus*, the hygienic procedures seemed to be effectively preventive. The number of *B. cereus* and *C. perfringens* were similarly reported to be less than 10 cfu g^{-1} in both samples. Researchers demonstrated that the presence of NaCl and phosphate might inhibit the bacterial growth (Kim *et al*., 2021). Moreover, a similar report has been published on increased load of *Pseudomonas* spp. in fish sausages enriched with mycoproteins during refrigerated storage (Bahmani and Movanes, 2021).

Nutritional assessments

Vitamins

Levels of vitamins B_2, B_5, B_7, and B_9 were assessed in both samples (Table 3). Contents of vitamin B_9 showed no significant difference ($P < 0.05$) between the samples. For other vitamins, mycoprotein sausages significantly achieved higher scores ($P < 0.05$). According to Hashempour-Baltork *et al*. (2020), who comprehensively compared the vitamin B content in meats and mycoproteins, contents of riboflavin, niacin, pyridoxine, and pantothenic acid was 9, 14, 5, and 10 μg g^{-1} in mycproteins and 0.018, 0.5, 0.052, and 0.35 μg g^{-1} in meats. These differences were seen in the formulated products as well.

Table 3. The level of vitamin B group in mycoprotein/beef sausages (μg/g).

Treatment	Vit B2	Vit B5	Vit B7	Vit B9
Mycoprotein sausage	3.31 ± 0.5^{a}*	0.02 ± 0.05^{a}	8.81 ± 1.45^{a}	0.48 ± 0.05^{a}
Beef sausage	1.51 ± 0.5^{b}	0.01 ± 0.04^{b}	2.57 ± 1.5^{b}	0.51 ± 0.03^{a}

*Mean ± SD, Different letters represent significant differences ($P < 0.05$).

Table 2. Proximate analysis and pH of beef sausage.

Treatment	Moisture (%)	Protein (%)	Lipid (%)	Carbohydrate (%)	Ash (%)	pH	Peroxide (mEq/kg)	WHC** (%)	WBC** (mL/g)	OBC** (mL/g)
Mycoprotein-sausage	59 ± 1.9^{a}*	12.5 ± 1.0^{a}	13.9 ± 1.2^{a}	9.8 ± 1.1^{b}	2 ± 0.5^{b}	5.7 ± 0.01^{b}	1.2 ± 0.2^{a}	54 ± 2.5^{a}	0.98 ± 0.09^{a}	0.37 ± 0.08^{a}
Beef sausage	47.5 ± 1.5^{b}	11.6 ± 1.1^{b}	8.9 ± 1.3^{b}	10.9 ± 1.2^{a}	3 ± 0.4^{a}	6.5 ± 0.01^{a}	1.3 ± 0.2^{a}	55 ± 3.3^{a}	0.79 ± 0.1^{b}	0.3 ± 0.08^{b}

*Mean ± SD, Different letters represent significant differences ($P < 0.05$).
**WHC: water holding capacity, WBC: water binding capacity, OBC: oil binding capacity.

Table 4. The amino acid profile in mycoprotein/beef sausages (µg/g).

Amino acid	Content in mycoprotein-sausage (%g per 100 g protein)	Content in beef-sausage (mg per 100 g protein)
L-Alanine	4.84 ± 0.99^{b*}	14.90 ± 0.59^{a*}
L-Arginine	6.74 ± 0.07^{a}	6.0 ± 0.18^{a}
Aspartic acid	5.25 ± 0.03^{b}	15.20 ± 0.10^{a}
L-Cystine	11.21 ± 0.15^{b}	96 ± 0.05^{a}
L-Glutamic	12.92 ± 0.52^{b}	29.02 ± 0.12^{a}
Glycine	4.15 ± 0.23^{b}	9.05 ± 0.35^{a}
L-Histidine	3.20 ± 0.75^{a}	1.10 ± 0.85^{b}
L-Isolucine	5.90 ± 0.63^{a}	3.00 ± 0.53^{b}
L-Leucine	7.80 ± 0.35^{a}	5.01 ± 0.33^{b}
L-Lysine	7.50 ± 0.61^{a}	3.0 ± 0.66^{b}
L-Methionine	1.90 ± 0.80^{a}	1.2 ± 0.11^{b}
L-serine	5.35 ± 0.23^{a}	1.04 ± 0.17^{b}
L-Theronine	13.75 ± 0.77^{a}	11.95 ± 0.95^{b}
L-Tyrosine	4.35 ± 0.97^{a}	4.950 ± 0.907^{a}
L-Valine	5.90 ± 0.70^{a}	4.10 ± 0.07^{b}
Phenyl Alanin	9.78 ± 0.87^{a}	3.15 ± 0.50^{b}
Proline	5.30 ± 0.77^{b}	17.1 ± 0.60^{a}
Tryptophan	6.7 ± 0.60^{a}	1.5 ± 0.70^{b}

*Mean ± SD, Different letters represent significant differences ($P < 0.05$).

Amino acids

Based on the nutritional and physiological roles, AAs can be differentiated as EAAs, including valine, tryptophan, threonine, phenylalanine, methionine, lysine, isoleucine, leucine, histidine (essential for infants), arginine (semi-essential), and nonessential amino acids (NEAA), including tyrosine, serine, proline, glycine, glutamine, glutamic acid, cysteine, asparagine, aspartic acid, and alanine (Damodaran and Parkin, 2017). The AA profiles showed that mycoprotein sausages included almost all EAAs, compared to beef sausages (Table 4). These findings were similar to those of other studies, reporting the presence of EAAs in single-cell proteins (SCP) of *F. venenatum* (Hashempour-Baltork *et al*., 2020). In fact, three food categories totally provide 80.9% of daily protein needs of humans (Górska-Warsewicz *et al*., 2018). The significance of protein nutrition includes EAA content, biological value, digestibility, net protein use, and protein efficiency ratio. Hashempour-Baltork *et al*. (2020) compared the quality of the mycoproteins with that of meat proteins and demonstrated that nutritional indices of these two sources were almost similar. Monteyne *et al*. (2020) reported that mycoproteins were good food sources enriched with EAAs.

Table 5. Fatty acid profile of mycoprotein/beef sausage.

Fatty acid	Content in mycoprotein-sausage (% w/w)	Content in beef-sausage (% w/w)
Palmitic (C16:0)	18.8 ± 0.20^{b}	32.4 ± 0.29^{a*}
Stearic (C18:0)	10.90 ± 0.16^{a}	28.3 ± 0.20^{b}
Oleic (C18:1)	24.95 ± 0.11^{a}	9.13 ± 0.365^{b}
Linoleic (C18:2)	25.35 ± 0.15^{a}	21.31 ± 0.353^{b}
α-Linolenic (C18:3)	15.14 ± 0.18^{a}	5.10 ± 0.748^{b}

*Mean ± SD, Different letters represent significant differences ($P < 0.05$).

Fatty acids

The FA composition of the sausage samples are presented in Table 5. The total SFAs in mycoprotein and beef sausages were 29.7 and 60.7% (w/w), respectively. In fact, unsaturated fatty acid (UFA) levels in mycoprotein sausages (65.44) were significantly ($P < 0.05$) higher than UFA levels in beef sausages (35.54% w/w). These contents as well as previous contents highly verified the results, especially for the ratio of UFA to saturated fatty acids (SFA) of 2:1 (Reihani and Khosravi-Darani, 2018). In 2009, Hosseini *et al*. (2009) reported 3.2–3.5:1 ratio of UFA to SFA. Higher consumption of USFAs provides health benefits to patients with cardiovascular diseases (CVD). Naturally, the ratio of polyunsaturated fatty acid (PUFA) to SFA in beef is typically 0.1. However, the ratio decreases with an increase in meat fats (Vahmani *et al*., 2015). Naturally, the ratio reaches 1.44 in mycoproteins. Chicken fat naturally includes 30% of SFAs, 45% of monounsaturated fatty acids (MUFA), and 21% of PUFAs (Hashempour-Baltork *et al*., 2020; USDA, 2008). These values are close to those of mycoproteins (Table 5).

Mechanical assessments

Table 6 represents mechanical properties of the cooked samples. Hardness of mycoprotein sausages was significantly lower than that of meat sausages ($P < 0.05$). Similar decreases were reported for cohesiveness when meat was totally replaced by mycoproteins. It was reported that beef sausages needed a greater force of chewing, compared to that of nonmeat samples. This was possibly due to the occurrence of stronger networks in myofibril proteins, increasing the product resistance to compression. Mycoprotein sausages showed lower values for gumminess and springiness ($P < 0.05$). Lower springiness values were reported by Youssef and Barbut (2011), when soy protein extracts were used as meat alternatives in emulsified meat batters. Kamani *et al*. (2019) recorded lower levels of food hardness, cohesiveness, gumminess, and springiness by replacement of meats by proteins of

Table 6. The hardness, adhesiveness, springiness, cohesiveness, chewiness and gumminess of mycoprotein/beef sausages.

Treatments	Hardness (N)	Adhesiveness (N.S)	Springiness (%)	Cohesiveness	Gumminess	Chewiness
Mycoprotein-sausage	23 ± 1.1[b*]	1.5 ± 0.19[a]	0.49 ± 0.21[b]	0.19 ± 0.02[b]	20.1 ± 1.2[b]	1.0 ± 0.01[b]
Beef-sausage	37.12 ± 1.5[a]	0.5 ± 0.10[b]	0.75 ± 0.2[a]	0.24 ± 0.01[a]	25.4 ± 1.5[a]	2.1 ± 0.2[a]

*Mean ± SD, Different letters represent significant differences ($P < 0.05$).

plant origin in chicken sausages. Researchers concluded that proteins of nonmeat origin could include further fat and water contents, which might fill the protein interstitial spaces and decrease the product springiness (Kamani *et al*., 2019; Youssef and Barbut, 2011). This is also addressed for mycoprotein replacement regarding WBC and OBC (Table 2). Textural analysis demonstrated association of sample meats with lower values of adhesiveness. It could be interpreted that a decrease in meat quantity might lead to a significant decrease in the consistency of the cooked emulsions.

Conclusion

This study was carried out to investigate the appropriateness of mycoproteins as complete substitutes for meat in beef sausages. The results showed that mycoprotein substitution improved nutritional and health effects due to the high-value proteins with EAAs and less lipid content (mostly UFAs). Also, it has high contents of EAA and UFA, compared to meat sausages. Absence of yeasts, molds, *Salmonella* spp., *Eshrichia* (*E.*) *coli*, and *Staphiloccocus* (*S.*) *aureus* verified the effectiveness of heat treatment and also hygienic procedures in samples. Phycicochemical evaluations show higher contents of moisture and lipids in sausages containing mycoprotein due to WBC and OBC, compared to beef samples. Besides, mycoprotein samples had lower values ($P < 0.05$) of carbohydrates, ash, and pH, compared to beef samples. However, mycoprotein sausages achieved lower scores of hardness, cohesiveness, gumminess, and springiness in mechanical assessments, compared to beef sausages. Mycoproteins could hold excessive water and fat caused by higher WBC and OBC, filling the protein interstitial spaces and decreasing the springiness. This suggested less use of oil and water in mycoprotein formulations. This study has provided valuable information for increasing public awareness on the characteristics of mycoprotein products, including nutritional, textural, and formulation characteristics.

This is the first study that substituted meat with mycoproteins in sausages. However, further studies are necessary to optimize mycoprotein sausages using texture improvement ingredients to enhance their gel-forming and textural characteristics. These are currently the major problems in the manufacturing of meat-free sausages. The production of meat alternatives seems necessary due to the preference of consumers for vegetarian diets, and the increasing nutritional awareness of the populace. Like other functional foods that were unknown in the past, after numerous studies and production of various products, today there is a unique response to these products. In the past 2 years, the COVID-19 pandemic has drawn the public attention to food security and meat supply worldwide with further global demands for meat alternatives with plant origins.

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Conflict of interest

The authors report no conflict of interest.

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