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Effect of Casing Diameter on Some Qualitative Properties of Smoked Heat-Treated Sucuk Stored in Cold under Modified Atmosphere Conditions

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Abstract

Heat-treated fermented sausages have a high consumption rate among meat products. In this study, the effects of different casing diameters on some quality characteristics of smoked heat-treated sucuk stored at 4°C under modified atmosphere conditions (70% N_2 and 30% CO_2) were investigated. For this purpose, smoked heat-treated sucuk were produced by filling fibrous casings with three different diameters (45 mm, 50 mm, and 60 mm). Following production, samples packaged in modified atmosphere conditions were examined for microbial, physical-chemical, and sensory properties during 90 days of storage at 4°C. According to the results, casing diameter did not affect ($P > 0,05$) the pH value of the product, while water activity, thiobarbituric acid reactive substances (TBARS) value, residual nitrite content, and L*, a*, and b* values were significantly affected by the casing diameter ($P < 0.05$). Additionally, sensory scores of color, taste, and overall acceptability as well as lactic acid bacteria and micrococci/staphylococci were also significantly affected by the casing diameter factor. ($P < 0.05$). The storage factor had a significant effect on pH, L* value, TBARS value, and residual nitrite content at a $P < 0.05$ level. Moreover, it was found that the storage factor significantly affected the odor and lactic acid bacteria count.

Keywords: Heat-treatment; Casing diameter; Smoking; Sucuk

Kılıf Çapının Modifiye Atmosfer Koşullarda Soğukta Muhafaza Edilen Tütsülenmiş Isıl İşlem Görmüş Sucuğun Bazı Kalitatif Özelliklerine Etkisi

Öz

Isıl işlem görmüş fermente sosisler et ürünleri arasında yüksek tüketim oranına sahiptir. Bu çalışmada, farklı kılıf çaplarının modifiye atmosfer koşullarında (%70 N_2 and %30 CO_2) soğukta (4°C) depolanan tütsülenmiş ısıl işlem görmüş sucuğun bazı kalite özelliklerine etkileri araştırılmıştır. Bu amaçla üç farklı kalibrasyona (45mm, 50mm ve 60 mm) sahip fibröz kılıflara dolum gerçekleştirilmiş ve tütsülenmiş ısıl işlem görmüş sucuk üretimi yapılmıştır. Üretimi müteakiben modifiye atmosfer koşullarında ambalajlanan örnekler soğukta muhafaza süresince (4C'de 90 gün) mikrobiyal, fiziksel-kimyasal ve duyusal özellikler yönünden incelenmiştir. Elde edilen sonuçlara göre kılıf çapı, ürün pH değerini etkilemezken ($P > 0,05$), su aktivitesi, tiyobarbitürik asit reaktif maddeleri (TBARS) değeri, kalıntı nitrit miktarı ile L*, a* ve b* değerleri kılıf çapı faktöründen önemli derecede ($P < 0.05$) etkilenmiştir. Ayrıca renk, tat ve genel kabul edilebilirlik duyusal puanları ile laktik asit bakterileri ve mikrokok/stafilokok sayıları da kılıf çapı faktöründen önemli derecede etkilenmiştir ($P < 0.05$). Depolama faktörü ise pH, L* değeri, TBARS değeri ve kalıntı nitrit içeriği üzerinde $P < 0.05$ seviyesinde önemli etkiye sahiptir. Ayrıca depolama faktörünün koku ve laktik asit bakteri sayısı üzerinde de istatistiksel açıdan önemli etkiye sahip olduğu belirlenmiştir.

Anahtar Kelimeler: Isıl işlem; Kılıf çapı; Tütsüleme; Sucuk

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1. Introduction

Fermented sausages' quality characteristics vary depending on factors such as the source of the meat and fat, the starter culture, additives, type and diameter of the casing, ripening/smoking conditions, and the packaging method (Montanari et al. 2016; Lücke, 2017; Yalınkılıç et al., 2016). These products are generally classified based on criteria such as moisture content, moisture-to-protein ratio, degree of meat/fat processing, weight loss, and water activity (Vignolo et al., 2010). Fermented sausages are generally grouped into two categories according to their drying degree: dry and semi-dry fermented sausages. In dry fermented sausages, the water activity is below 0.90. Another important feature of these products is that they are usually not subjected to the smoking process. In semi-dry fermented sausages, the water activity ranges between 0.90 and 0.95. Additionally, unlike dry fermented sausages, semi-dry fermented sausages are subjected to a cooking (internal temperature: 60-68°C) process (Caplice and Firzgerald, 1999). Products such as Rohwurst, hard salami, Italian-style salami, pepperoni, and sucuk are classified as dry fermented sausages, while products like chorizo, thuringer, heat-treated sucuk, cervelat, and summer sausage fall under the category of semi-dry fermented sausages. Furthermore, soft-textured sausages like Mettwurst and Teewurst are also considered as fermented sausages (Kaya and Kaban, 2019).

In the production of fermented sausages, both natural and artificial casings can be used. These casings not only give shape, size, and integrity to the products but also play a significant role in the volumetric, structural, and chemical changes that occur at various stages of production (Djordjevic et al., 2015). Natural casings are usually derived from the small and large intestines of sheep, goats, and pigs. These casings have a specific permeability to water, water vapor, and gases (Heinz and Hautzinger, 2007). On the other hand, artificial casings are made from cellulose, collagen, or synthetic materials and are more commonly used in industry due to their suitability for standardized product production and automation (Gökalp et al., 2002; Heinz and Hautzinger, 2007).

Smoking, one of the oldest preservation methods used for meat and meat products for thousands of years, is defined as the process of volatile compounds produced by the thermal degradation of wood chips penetrating the product (Djinovic et al., 2008; Hitzel et al., 2013; Kim et al., 2021). In the smoking process, low-tar woods such as beech, oak, linden, apple, maple, and cherry are commonly used (Gökalp et al., 2002). Phenolic compounds derived from smoke are significant substances in terms of the sensory properties of the product. These compounds can also exhibit antimicrobial and antioxidant activities (Djinovic et al., 2008; Hitzel et al., 2013; Kim et al., 2021). The antioxidant activity of smoke is attributed to various compounds, including phenols, phenol aldehydes, and organic acids (Honikel, 2009). Lipid oxidation significantly impacts the shelf life of sausages and analogous meat products. Over time, the accumulation of primary and secondary oxidation products facilitates the development of a rancid taste in processed meats, characterized by undesirable sensory bitterness. Within this framework, antioxidant compounds released during the smoking process serve as crucial natural agents in limiting the lipid oxidation that constrains the shelf life of these products (Morrissey et al., 1998). In the meat industry, three different smoking processes are applied: cold smoking (15-25 °C), warm smoking (25-50 °C), and hot smoking (50-85 °C) (Simko, 2009). Especially in hot smoking, the simultaneous application of smoking and thermal processing provides advantages in terms of both the process and quality parameters such as lipid oxidation, sensory attributes, and microbial safety (Bhuyan et al., 2018).

The type and diameter of the casing used in the production of fermented sausages are important intrinsic factors for both the ripening process and the final product quality (Gökalp et al., 2002; Vignolo et al., 2010). Indeed, research conducted

in this field has concluded that the casing diameter used in fermented sausage production affects the microbiological (De Souza et al., 2018) and sensory (Kos et al., 2019) quality parameters, as well as the biogenic amine content (Huang et al., 2021) and volatile compound profile (Montanari et al., 2016, 2018) of the product.

In Türkiye, mainly two different types of fermented sausages are produced: sucuk and heat-treated sucuk. In the production of both products, the bovine small intestine (dry or brine) is used as a natural casing. In industrial production, in addition to natural casings, collagen, and fibrous casings are also used. Sucuk production relies on a ripening process that includes fermentation and drying, while heat-treated fermented sucuk involves three main steps: fermentation, heat treatment, and drying. The heat treatment process in this product contributes to product safety (Coşkuner et al., 2010). While the cold smoking process is used in the production of many types of fermented sausages, it is not applied in either of the fermented sausage types produced in Türkiye (Gökalp et al., 2002). In the studies conducted on heat-treated sucuk, the physical, chemical, microbiological, and sensory properties of the product were examined (Çalıcıoğlu et al., 2001; Ercoşkun, 2021; Kurt and Zorba, 2011; Yılmaz Oral and Kaban, 2021). There are no studies encountered in the literature on smoked heat-treated sucuk. The aim of this study was to investigate the effects of different casing diameters (45, 50, and 60 mm) on the qualitative properties of smoked heat-treated sucuk.

2. Materials and Methods

2.1. Materials

In the production of heat-treated sucuk, beef, and beef fat were used as raw materials. A commercial starter culture preparation was included in the formulation. Sodium nitrite was used as a curing agent. Three different fibrous casings with diameters of 45 mm, 50 mm, and 60 mm were used for filling.

2.2 Heat-Treated Sucuk Production

The production of heat-treated sucuk was carried out in the Research and Development (R&D) unit of Namet Gıda San. ve Tic. A.Ş. Beef meat and beef fat obtained from veal carcasses were used as raw material. Per kg meat and fat (8:2) were used: 20 g sodium chloride, 7.2 g spice mix (black pepper, white pepper, sweet red pepper, and oregano), and 2 g dextrose. 150 mg/kg sodium nitrite was added to the sucuk batters as a curing agent. A commercial starter culture preparation (*Lactilactobacillus sakei*, *Pediococcus acidilactici* and *Staphylococcus carnosus*) was added to the batters. After the prepared sucuk mixtures were filled into three different fibrous casings (45, 50, and 60mm) with a filling machine (Vemag HP30E, Maschinenbau GMBH), they were subjected to cold smoking (Schröter Technolohle GmbH & Co) at 20°C for 1.5 h. Following this process, each product group was subjected to fermentation at 24°C (Vemag 585, Maschinenbau GMBH). Fermentation was terminated when the pH value dropped below 5.0. After that samples from each calibration group were then subjected to a heat treatment program (including smoking at 60 °C for 50 min) until the internal temperature reached 60°C (HR6, Schröter Technolohle GmbH & Co). Following this process, the samples were subjected to a drying process at 12 °C for 5 days (Vemag 576). After the drying process, the casings were peeled off, and the products were sliced (45 mm: thickness: 1.75 mm; 50 mm: thickness: 1.75 mm; 60 mm: thickness: 1.50 mm) using a slicer machine (Weber CCV100) and packaged under modified atmosphere conditions (70% N_2 and 30% CO_2) (R535, Multivac Sepp Haggenmüller GmbH & Co). The packaged samples were stored at 4°C for 3 months and were subjected to the following analyses on days 0, 30, 60, and 90 of storage.

2.2 Analyses

2.2.1 Microbiological Analyses

For microbiological analyses, 25 g of samples were taken and homogenized in a sterile stomacher bag with 225 mL of sterile physiological saline for 2 minutes (Lab Stomacher Blander 400-BA 7021, Seward, England). The homogenized samples were then analyzed for lactic acid bacteria counts using de Man, Rogosa, and Sharpe Agar (MRS) (30 °C for 48 h under anaerobic conditions), Micrococcus/Staphylococcus counts using Mannitol Salt Agar (MSA) agar (30 °C for 48 h under aerobic conditions), Enterobacteriaceae counts using Violet Red Bile Dextrose Agar (VRBD) (30°C for 48 h under anaerobic conditions) (Baumgart et al., 1993), and yeast-mold counts using Rose Bengal Chloramphenicol Agar (RBC) (25 °C for 5 days under anaerobic conditions) (Gökalp et al., 2010).

2.3.2. Ph and Water Activity (a_w)

Ten grams of samples were weighed and homogenized with 100 mL of distilled water using a homogenizer. The pH value of the homogenized samples was measured using a previously calibrated pH meter (Gökalp et al., 2010). The water activity (aw) of the samples was measured using a water activity device (Novasina, Pfäffikon, Switzerland).

2.3.3. Color Analysis

The color measurements of the heat treated sucuk samples were determined using a colorimeter (Chroma Meter CR-400, Japan). The color values of the samples were measured on the cutting surfaces of the samples (Rödel, 1985).

2.3.4. Residual Nitrite and TBARS Analyses

The residual nitrite level of the samples was determined using the High-Performance Liquid Chromatography (HPLC) method (NMKL 165, 2000) and the results are presented as mg/kg. The analysis of thiobarbituric acid reactive substances (TBARS) was performed using the method described by Lemon (1975), and the results are presented as mg MDA/kg.

2.3.5. Sensory Analyses

The smoked, sliced heat-treated sucuk samples were evaluated by 25 trained panelists in each panel. Before the sensory analysis, participants were informed about the products and given preliminary instructions on tasting the sucuk. The panel was carried out by presenting the samples coded with 3-digit numbers to the panelists along with the sensory panel form. The number of participants in each replication was 25, with a total of 75 participants. Sensory evaluation parameters including color, texture, odor, taste, and overall acceptability were scored on a 1-9 point scale.

2.3.6. Statistical Analyses

The research was designed and conducted based on a completely randomized block design with three replications, focusing on the factors of casing diameter (45, 50, and 60 mm) and cold storage (0, 30, 60, and 90 days). The raw data were examined for normality of distribution and homogeneity of variances between groups and then subjected to analysis of variance (ANOVA) using SPSS version 24 (SPSS Inc., Chicago, IL, USA). For the mean values that showed statistically significant differences ($P < 0.05$) according to the ANOVA, Duncan's multiple range test was also applied.

3. Results and Discussion

3.1 pH

The effects of casing diameter and storage on the pH value of heat-treated sucuk are presented in Table 1. According to the results, casing diameter didn’t have a significant effect on the product's pH value ($P > 0.05$). Similarly, in a study on dry fermented sausages, it was found that the casing diameter did not have a significant effect on the pH value of dry fermented sausages produced with casings of 32

mm, 55 mm, and 80 mm diameter (De Souza et al., 2018). However, the storage process was found to have a statistically significant effect on the product's pH value ($P < 0.05$). There was a partial increase in pH value during the storage period, with the highest average pH value observed on the 90th day of storage. By the end of the storage period, an increase in pH value was observed. The observed increase in pH is likely due to amino acid catabolism and degradation products of proteins (Fernandez-Lopez et al., 2008; Montanari et al., 2018). In line with our findings, a study on heat-treated sucuk also reported a partial increase in pH during the storage period (Bilenler et al., 2017). Conversely, in a study examining the changes in heat-treated sucuk during storage, Coşkuner et al. (2011) found a significant decrease in pH value during the storage period. On the other hand, the interaction between casing diameter and storage process did not have a significant effect on the pH value of heat-treated sucuk ($P > 0.05$).

3.2 Water Activity

The effects of casing diameter and storage process on the water activity value of heat-treated sucuk are presented in Table 1. Among the main sources of variation, the storage process did not have a significant effect on the water activity value of the product ($P > 0.05$). This is likely due to the appropriate packaging material used during the storage period (Coşkuner et al., 2011). Conversely, casing diameter was found to have a statistically significant effect on the water activity value of the product ($P < 0.05$). It was understood that an increase in casing diameter resulted in products with higher water activity values. This was probably due to the difficulty in removing moisture from heat-treated sausages as the casing diameter increases (De Souza et al., 2018). Similarly, Keller et al. (1974) found that it became more difficult to remove moisture as the casing diameter increased from 52 mm to 73 mm in summer sausages. Furthermore, a study on dry fermented sausages also determined that an increase in casing diameter resulted in a higher average water activity in the final product (Heir et al., 2010). The interaction between casing diameter and storage process did not have a significant effect on the water activity value of heat-treated sucuk ($P > 0.05$)

3.3. Color

The effects of casing diameter and storage process on the L*, a*, and b* values of heat-treated sucuk are presented in Table 1. According to the results, casing diameter had a statistically significant effect on the L* and a* values ($P < 0.05$), while the storage process had a statistically significant effect on the L* value ($P < 0.05$). However, neither casing diameter nor storage process had a significant effect on the b* value ($P > 0.05$). A larger casing diameter resulted in an increase in the L* value, whereas the opposite was observed for the a* value. The color, measured instrumentally by the L*, a*, and b* parameters, is one of the most important quality parameters for meat and meat products (Mancini and Hunt, 2005). The process steps applied in sausage production can affect the color parameters of the product either alone or in combination (Supavititpatana and Apichartsrangkoon, 2007). There is a negative correlation between the increase in casing diameter and the a* value (Stegmayer et al., 2023), which supports the findings for the a* parameter in our study. Additionally, a partial decrease in the L* value was observed over time during the storage process ($P < 0.05$). Similar to our findings, a study on sausages packaged in modified atmosphere packaging and stored in cold storage found that the L* value decreased as the storage duration increased (Ameer et al., 2022). The interaction between casing diameter and storage process did not have a significant effect on the L*, a*, and b* values of heat-treated sucuk ($P > 0.05$).

3.4. TBARS

The effects of casing diameter and storage process on the TBARS value of heat-treated sucuk are presented in Table 1. The highest average TBARS value was found in sucuk filled with a 45 mm diameter casing ($P < 0.05$), while

lower TBARS values were detected in the other groups. Additionally, an increase in the TBARS values of the products was observed with the increase in storage duration ($P < 0.05$). This is likely due to the chain reaction caused by radical compounds released once lipid autoxidation begins, resulting in the accumulation of autoxidation products in the product (Feiner, 2006). Furthermore, trace amounts of oxygen passing through the packaging barrier over time may partially influence the increase in TBARS values of heat-treated sucuk during storage (Wang et al., 1995).

Similar to our findings, in a study conducted by Coşkuner et al. (2010), an increase was observed in TBA values during the storage of heat-treated sucuk. Comparable results regarding TBARS values were also obtained in Chinese-style sausages packaged under modified atmosphere during storage (Wang et al., 1995). The interaction between casing diameter and storage process did not have a significant effect on the TBARS value of heat-treated sucuk ($P > 0.05$).

3.5 Residual Nitrite

The effects of casing diameter and storage process on the residual nitrite value of heat-treated sucuk are presented in Table 1. The residual nitrite amounts detected in all casing diameter groups were below 10 mg/kg. This is likely due to the nature of nitrite, which decomposes into other chemical compounds or reacts with compounds present in the sausage environment (Sancak et al., 2008). The highest average residual nitrite level was found in products processed with 60 mm diameter casings, with a statistically significant difference ($P < 0.05$) between this group and the other groups. In contrast to our findings, Uram et al. (1981) found that casing diameter had no significant effect on residual nitrite content during a 3-week storage period in heat-treated salami produced with 90 mm and 64 mm diameter casings. Additionally, a decrease in residual nitrite content was observed over the storage period, with the lowest amount detected on the 90th day. Similar to our findings, a study on heat-treated sucuk reported a decrease in residual nitrite content over a 45-day storage period (Bilenler et al., 2017). This result is also supported by Dong et al. (2007)'s findings. The interaction between casing diameter and storage process did not have a significant effect on the residual nitrite value of heat-treated sucuk ($P > 0.05$).

3.6. Lactic Acid Bacteria, Micrococcus/Staphylococcus, and Enterobacteriaceae

The effects of casing diameter and storage process on the microbiologically significant groups of heat-treated sucuk are presented in Table 2. For both Enterobacteriaceae family and yeast-mold counts, levels were found to be <2 log CFU/g across all casing diameter groups and storage process stages. The fact that Enterobacteriaceae counts were below detectable limits is a positive indication of both the microbial quality of the raw material and the hygiene standards maintained during production (Armutcu et al., 2020). Similarly, a study by Bilenler et al. (2017) on heat-treated sucuk found that coliform bacteria, members of the Enterobacteriaceae family, were below detectable limits, however, yeast-mold counts averaged around 3 log.

Regarding lactic acid bacteria counts, it was observed that increases in both casing diameter and storage duration resulted in higher average counts of lactic acid bacteria ($P < 0.05$). The positive effect of increased casing diameter on the growth of lactic acid bacteria is likely due to the larger calibration providing a more anaerobic environment within the product (Ahn and Min, 2007). There is literature supporting the increase in lactic acid bacteria counts in heat-treated sucuk during the storage process (Bilenler et al., 2017).

Table 1. Overall effect of casing diameter and storage process on the pH, a_w, color, TBARS, and residual nitrite parameters of smoked heat-treated sucuk.

	pH	**a_w**	**L***	**a***	**b***	**TBARS (mg MDA/kg)**	**Residual nitrite (mg/kg)**
Casing Diameter (C)							
45 mm	4,93±0,07a	0,929±0,001a	51,52±1,22a	23,50±1,16b	15,01±1,32a	0,75±0,11b	8,74±2,07a
50 mm	4,96±0,07a	0,934±0,001b	52,28±1,32a	22,57±1,02ab	15,00±0,73a	0,64±0,09a	8,58±2,25a
60 mm	4,95±0,07a	0,944±0,002c	54,27±1,67b	21,82±1,30a	14,83±0,84a	0,65±0,06a	9,88±2,48b
Significance	NS	**	*	*	NS	*	*
Storage time (S)							
Day 0	4,90±0,05a	0,936±0,007a	53,75±1,69b	22,16±1,39a	14,51±0,85a	0,61±0,06a	11,12±1,53c
Day 30	4,92±0,06a	0,935±0,001a	52,66±2,21ab	22,69±1,56a	15,01±0,84a	0,65±0,05ab	9,99±1,79c
Day 60	4,94±0,06a	0,936±0,001a	52,13±1,42a	22,88±0,63a	14,81±0,48a	0,70±0,10bc	8,61±1,73b
Day 90	5,01±0,07b	0,936±0,001a	52,21±1,65a	22,79±1,62a	15,46±1,39a	0,76±0,11c	6,55±1,13a
Significance	*	NS	*	NS	NS	**	**
Interactions							
CxS	NS	NS	NS	NS	NS	NS	NS

a-c: any two means in the same column having the same letters in the same section are not significantly different. *$p < 0.05$, **$p < 0.01$, NS: not significant.

Table 2. Overall effect of casing diameter and storage process on the sensory and microbiological parameters of smoked heat-treated sucuk.

	Color	Texture	Odor	Taste	Overall assessment	Lactic acid bacteria (log CFU/g)	*Micrococcus / Staphylococcus* (log CFU/g)
Casing Diameter (C)							
45 mm	7,12±0,23a	7,32±0,36a	7,20±0,30a	7,00±0,27a	7,03±0,30a	5,03±0,66a	3,23±0,54a
50 mm	7,40±0,29b	7,31±0,60a	7,37±0,34a	7,59±0,20b	7,52±0,15b	5,56±0,32b	3,58±0,26b
60 mm	7,52±0,27b	7,33±0,38a	7,26±0,38a	6,97±0,19a	6,97±0,20a	6,00±0,60c	4,98±0,34c
Significance	*	NS	NS	*	*	**	**
Storage time (S)							
Day 0	7,38±0,28a	7,26±0,45a	7,09±0,25a	7,17±0,28a	7,21±0,32a	4,95±0,64a	4,02±0,66a
Day 30	7,38±0,31a	7,41±0,46a	7,48±0,32b	7,13±0,37a	7,13±0,33a	5,44±0,42b	4,05±0,80a
Day 60	7,39±0,36a	7,23±0,56a	7,23±0,37ab	7,23±0,39a	7,26±0,39a	5,79±0,69c	3,86±1,23a
Day 90	7,24±0,29a	7,39±0,32a	7,31±0,34ab	7,21±0,44a	7,10±0,33a	5,94±0,47c	3,78±0,75a
Significance	NS	NS	*	NS	NS	**	NS
Interactions							
CxS	NS	NS	NS	NS	NS	NS	NS

a-c: any two means in the same column having the same letters in the same section are not significantly different. *$p < 0.05$, **$p < 0.01$, NS: not significant.

For micrococci/staphylococci, as seen with lactic acid bacteria (Table 2), an increase in casing diameter resulted in higher average counts of micrococci/staphylococci ($P < 0.05$). However, a partial decrease in micrococci/staphylococci counts was observed during storage, although this decrease was not statistically significant ($P > 0.05$). The pH value plays a significant role in the growth of micrococci and staphylococci. These microbial groups' growth is negatively affected in fermented sausage environments where the pH is below 5.4 (Kaya and Kaban, 2019). The partial downward trend in *Micrococcus/Staphylococcus* during storage could be attributed to the average pH value of all groups being below 5.4. The interaction between casing diameter and storage process did not have a significant effect on the microbiologically significant groups of heat-treated sucuk ($P > 0.05$).

3.7. Sensory Parameters

The effects of casing diameter and storage process on the sensory parameters of heat-treated sucuk are presented in Table 2. Casing diameter significantly influenced the average values of color, taste, and overall acceptability parameters of heat-treated sucuk ($P < 0.05$). An increase in casing diameter resulted in higher average values for the color parameter, while the highest average taste and overall acceptability values were found in 50 mm diameter sucuk. The only parameter significantly affected by the storage process was odor ($P < 0.05$), with average odor values increasing as storage progressed compared to day 0. In a study examining the effects of different casing calibrations on heat-treated salami, it was found that samples with a 90 mm casing diameter were softer, juicier, and more flavorful than those with a 64 mm casing diameter (Uram et al., 1981). Another study on wild boar sausages filled and ripened in casings with different diameters (35 mm and 50 mm) found that 5 out of 21 sensory parameters were influenced by casing diameter. Among these, taste and odor parameters were significantly affected by casing diameter, while texture and overall acceptability were not influenced by the casing diameter (Kos et al., 2019). The interaction between casing diameter and storage process did not have a significant effect on the sensory quality characteristics of heat-treated sucuk ($P > 0.05$).

4. Conclusion

Considering the results obtained in the study, it was determined that the casing diameter and storage process used in the production of smoked, heat-treated sucuk have significant effects on the product's quality characteristics. However, future studies should investigate the volatile compound and polycyclic aromatic hydrocarbon profile in smoked, heat-treated semi-dry fermented sausages produced with casings of different diameters.

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Author contribution

B.K.: Conceptualization; methodology; data curation; software; writing—original draft; formal analysis; investigation. **B.Y.:** Supervision; conceptualization; methodology, data curation, writing—review and editing; project administration.

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Conflict of interest

The authors have no conflict of interest.

Ethical statement

Ethics Committee approval for this study was obtained from İstanbul Gedik University with the approval number E-56365223-050.04-2024.137548.105.

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